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ASSESSMENT OF ALTERNATIVE MANAGEMENT PRACTICES AND POLICIES AFFECTING SOIL CARBON IN AGROECOSYSTEMS OF THE CENTRAL UNITED STATES

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FOREWORD

Over the past several years, interest in the issue of global warming has increased within the scientific community. Gaining understanding of this complex environmental phenomenon requires the research contributions of specialists in such fields as atmospheric chemistry, ecology, hydrology, forestry, and agriculture. Terrestrial carbon cycle dynamics, agricultural soil carbon management and conservation, and water resources impacts are important areas of research in the global warming issue.

This report is the first major product of the BIOME Agroecosystem Assessment Providing preliminary estimates of carbon sequestration potential for the central United States including the Corn Belt, the Great Lakes, and portions of the Great Plains. This Study Region comprises 44% of the land area and 60%-70% of the agricultural cropland of the conterminous United States. The assessment methodology includes the integration of the RAMS economic model, the CENTURY soil carbon model, meteorologic and soils data bases, and GIS display and analysis capabilities. It assesses the impacts of current agricultural trends and conditions, alternative tillage practices, use of cover crops, and Conservation Reserve Program (CRP) policy on soil carbon.

This report provides evidence of the value of agricultural residue management practices in relation to CO_2 emissions to the atmosphere. By doing so, the report strongly supports current USEPA and USDA policy in this area.

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ABSTRACT

The goal of the U.S. EPA BIOME Agroecosystems Assessment Project is to evaluate the degree to which agroecosystems can be technically managed, on a sustainable basis, to conserve and sequester carbon, reduce the accumulation of CO_2 in the atmosphere, and provide reference datasets and methodologies for agricultural assessment. Agroecosystems play an important role in the global carbon cycle. They contain about 12% of the terrestrial soil carbon, and conservation of this pool is essential to the health of the earth. Application of certain agroecosystem management practices could increase this pool by reducing the build-up of atmospheric carbon. In particular, alternative or sustainable agricultural practices increase soil carbon content. BIOME will assess the potential agroecosystem contribution to global carbon conservation and sequestration.

The carbon sequestration potential of agroecosystems is being estimated through an integration of tasks including application of existing soil carbon mass balance models, analysis of agricultural production cycles, development of data bases for agroecosystem carbon pools and dynamics, development of spatial data bases for assessment of agricultural carbon sequestration potential, and development of cost factors.

This report, the first major product of BIOME, provides preliminary estimates of carbon sequestration potential for the central United States including the Corn Belt, the Great Lakes, and portions of the Great Plains. This Study Region comprises 44% of the land area and 60% to 70% of the agricultural cropland of the conterminous United States. The assessment methodology includes the integration of the RAMS economic model, the CENTURY soil carbon model, meteorologic and soils data bases, and GIS display and analysis capabilities in order to assess the impacts on soil carbon of current agricultural trends and conditions, alternative tillage practices, use of cover crops, and Conservation Reserve Program (CRP) policy.

The study results indicate a 26% to 53% increase in soil carbon for the 40-year projection period from 1990 through 2030 under the methodology assumptions representing a continuation of current (circa 1989-90) agricultural trends and alternative policy scenarios. This represents a potential gain of 1 to 2 GtC in the Study Region by 2030. Conservation tillage alternatives and cover crops appear to have significant potential for increased carbon sequestration. Assessment of soil carbon changes on Conservation Reserve land indicates mixed results across the Study Region with both increases and decreases. However, further study is needed before these conclusions can be fully confirmed. This report provides recommendations to further evaluate and confirm the study results, perform additional model field testing, refine model components, extend the methodology to other regions of the United States, and investigate selected research issues to improve the assessment procedures.

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The Project Team assembled for this study included AQUA TERRA Consultants, EPA-Athens, Computer Sciences Corporation, the Natural Resources Ecology Laboratory (NREL) in Fort Collins, CO, the Center for Agriculture and Rural Development (CARD) at Iowa State University, and selected consultants. The participation by CARD staff was sponsored by EPA OPPE. The report authors are drawn from the first three organizations, but many others contributed to the numerous technical discussions and decisions needed throughout the study.

Staff from the NREL played an advisory role in the development of the study methodology and assisted in the application, refinement, testing, and parameterization of the CENTURY model for use in this study. Numerous colleagues at NREL who were involved in portions of the work included Dr. William Parton, Dr. Ted Elliott, Dr. Alister Metherell, and Ms. Laura Harding. Dr. Parton provided technical guidance in the use of the CENTURY model, including a training workshop, advice on parameter estimation, and technical direction for model refinements. Dr. Elliott participated in project meetings and provided administrative overview. Dr. Metherell, assisted by Ms. Harding, performed model testing on the Sydney, NE site, provided parameter guidance, and implemented model refinements to represent complex crop rotations. Ms. Harding was instrumental in model coding and testing. We are especially grateful for the assistance provided by this group, which was critical to the completion of the study.

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Among the authors at EPA, Mr. Barnwell was the Project Manager providing overall project direction. Mr. Robert Jackson was responsible for the meteorologic and soils data development, directed the model runs for the Study Region, processed the model output, and wrote associated portions of the report.

For Computer Sciences Corporation, Mr. Kevin Weinrich developed and applied the automated calibration procedure for CENTURY and performed the model runs, while Mr. Allen Rowell assisted in data base processing and prepared all the GIS displays and analysis.

Dr. Vern Cole of NREL and USDA-ARS provided critical input to the study methodology and modeling effort; his insight and guidance was instrumental to the study.

For AQUA TERRA Consultants, Mr. Anthony Donigian was the Project Manager responsible for development of the study methodology, overall technical direction of the modeling, analysis of the results, and preparation of the final report. Mr. Avinash Patwardhan was the Project Engineer who directed the CENTURY model application and testing, reviewed model results and operation, and prepared sections of the report. He was assisted by Mr. Radha Chinnaswamy who prepared model input files, executed model runs, and performed model testing on the Lexington site. Ms. Dorothy Inahara performed word processing throughout the study and for the final report.

The contributions from **all** these individuals, both authors and others, was critical to the successful collaborative effort in this study.

SECTION 1

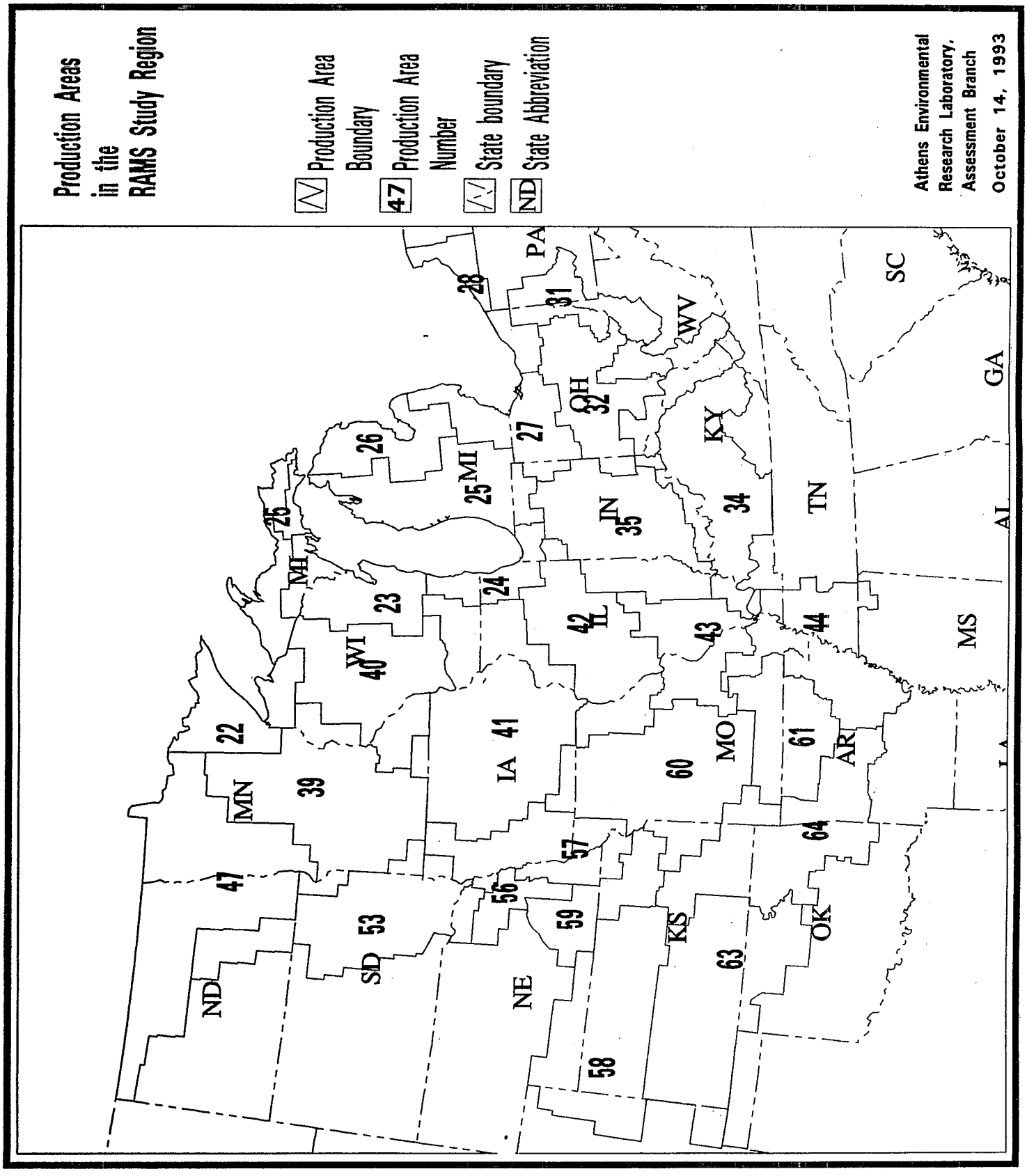
INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

The goal of the U.S. EPA BIOME Agroecosystems Assessment Project is to evaluate the degree to which agroecosystems can be technically managed, on a sustainable basis, to conserve and sequester carbon, thereby reducing the accumulation of CO_2 in the atmosphere, and to provide reference datasets and methodologies for agricultural assessment. Agroecosystems play an important role in the global carbon cycle because they contain 12% of the terrestrial soil carbon. Conservation of this pool is essential to the health of the earth and to the sustainability of agriculture. Application of proper agroecosystem management practices could increase this pool by reducing the build-up of atmospheric carbon. In particular, alternative or sustainable agricultural practices could maintain or perhaps even increase soil carbon content. BIOME attempts to assess the potential agroecosystem contribution to global carbon conservation and sequestration.

This report focuses on the potential impacts of alternative management practices on agricultural soil C in the major agricultural regions of the central United States (Figure 1.1). These impacts are estimated by a soil C mass balance modeling study that incorporates policy considerations and economics in the analysis. A literature review of soil C modeling and impacts of management practices was used to guide the model selection and parameter estimation effort. The models selected for use and/or modification to meet the needs of representing soil C cycles in agroecosystems and impacts of management practices are CENTURY and DNDC (see Section 2.4 for model descriptions). These models share a common ability to examine the impacts of alternative management practices on soil organic C, and are readily accessible to potential users. The model results reported herein are derived from CENTURY model simulations; the DNDC model was used for comparison and evaluation purposes for only selected test regions and its results have been reported in a separate document (Li and Cialella, 1993).

An important aspect of this effort is the development of the assessment framework and methodology that defines: (1) the agricultural production systems and scenarios (i.e., crop-soil-climate combinations) to be assessed as impacted by national policy, (2) the integration of the model needs with available databases, and (3) the operational mechanics of evaluating C sequestration potential with the integrated model/database system. We worked closely with EPA's Office of Policy and Program Evaluation to define a reasonable set of policy alternatives for this assessment, focusing on policy that might be effected through a revised Farm Bill, such as incentives to selectively promote conservation tillage, crop rotations, cover crops, and/or good



F'gure 1.1 Study region with production areas and state boundaries

stewardship of the conservation reserve. Policy alternatives are translated into basic data for use in soil C models through economic models. These data, including such elements as agricultural practices, fertilization rates, and production levels are used in the soil C models to produce net carbon changes on a per unit area basis. The unit-area emissions are combined with areal-extent data using data base programming and GIS capabilities to produce an estimate of total carbon and nitrogen changes, and thus estimate changes in greenhouse emissions and associated impacts.

While data from long-term field studies have provided much information about the possible rates and directions of change in soil C under various management regimes, our current knowledge base is very fragmented. Most of what we know concerning soil organic matter (SOM) dynamics has been obtained by studying SOM losses; we understand less about SOM accumulation and how it varies across soil types, climatic regions and management regimes. A network of field sites in the Corn and Wheat Belts has been organized through a cooperative agreement with Colorado State University (CSU) and Michigan State University (MSU). Emphasis is on collection, preparation, and evaluation of soil C data. Sites where comparisons of management practices are possible have been given highest priority. Outputs of the studies will be useful in future validation of the results of this modeling study as well as providing a better understanding of the response of SOM to management.

1.2 ASSESSMENT FRAMEWORK

As noted above, a key element in this effort was the development of the assessment framework and modeling methodology to integrate the economic analysis, the soil carbon modeling, and the available data bases into an operational mechanism for accomplishing the goals of the study. Figure 1.2 represents our operational assessment strategy and framework. We needed to define agricultural production systems and scenarios (i.e., crop-soil-climate-practice combinations) to be assessed in terms that would be sensitive to national and international policy considerations. The integration of the model needs with available databases was a critical feature to insure reasonable temporal and spatial representation of agricultural practices, and the feasibility of the operational mechanics for evaluating C sequestration potential with the integrated model and data base system.

The objective of the assessment is to estimate the greenhouse gas emissions from agriculture and to estimate the relative impact of various policy alternatives on these emissions. We have worked closely with the U.S. EPA's Office of Policy and Program Evaluation (OPPE) and Iowa State University's Center for Agricultural and Rural Development (CARD) to define a reasonable set of policy alternatives for this assessment. An example set of policy alternatives is shown in the box labeled "OPPE" in Figure 1.2. Included are several national policy alternatives and their possible effect on agricultural production levels, especially agriculture policy alternatives that might be effected through a revised Farm Bill, such as incentives to selectively promote conservation tillage, sustainable agriculture, or good stewardship of the conservation reserve.

Assessment of Agricultural Carbon Sequestration Potential

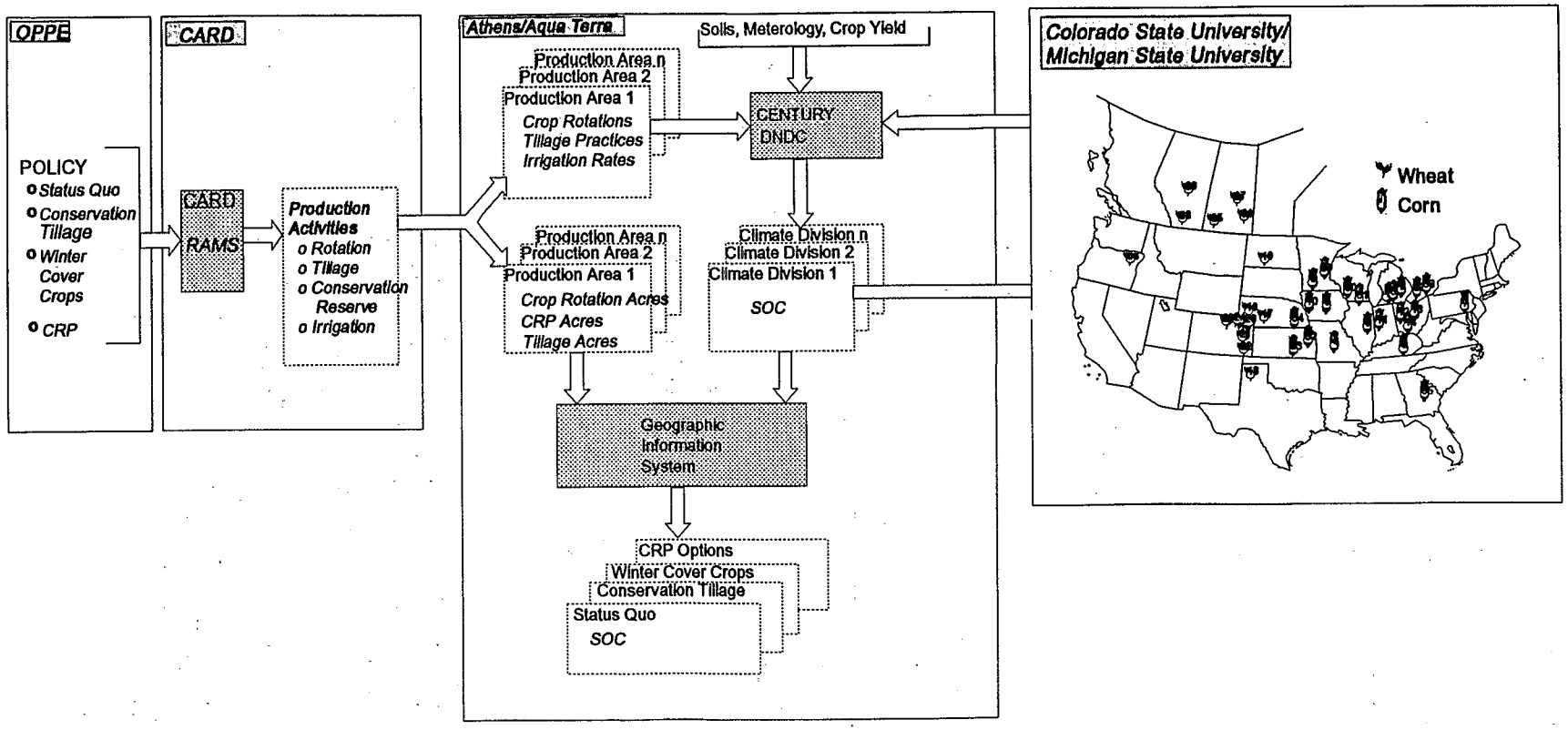


Figure 1.2 Assessment of agricultural carbon sequestration potential

As shown in the box labeled "CARD", these policies are used to drive economic models that predict national production levels using models such as the Basic Linked System (BLS), a set of national and regional models linked by policy and a world price determination process. CARD's Resource Adjustment Modeling System (RAMS) is being used to translate policy alternatives into basic data for use in soil C models. The CSU/MSU box in Figure 1.2 shows the data collection sites and the input of this component to the agricultural soil carbon modeling effort.

The 'center' box in Figure 1.2 includes the primary steps in the modeling methodology to produce the estimates of soil C sequestration, which is the central focus of this report. The data produced by the RAMS analysis, including such elements as crop rotation acreages, tillage practices, irrigation areas, and cover crops are used in the soil C models to produce net soil C changes and greenhouse gas emissions on a per unit area basis. Data are produced for a range of "Production Areas" (PAs), which are hydrologic areas defined by the Water Resources Council that are used for aggregated economic reporting. The economic models also provide statistics on crop acres, acreage in the conservation reserve, and other agricultural land usage. These data, along with soils, climate, and crop yield data, are used by the CENTURY and DNDC soil C models (described in Section 2.4) to simulate the impacts of various agricultural production systems on soil C and N levels as a basis for calculating greenhouse gas emissions.

Model simulations are performed for Climate Divisions (CDs), which are subsets of the PAs developed to allow a finer spatial representation of both climate and soils characteristics. The unit-area emissions produced by the CENTURY and DNDC models are combined with areal-extent data using GIS and data base programming techniques to produce estimates of total changes in soil carbon over time for each alternative policy scenario. As noted above, the results reported herein are based on the CENTURY model simulations; the DNDC model simulations were limited to seven selected CDs for testing and evaluation purposes, and its results have been reported by Li and Cialella (1993). Section 7.1.2 includes a brief discussion of the DNDC model results.

1.3 STUDY CONCLUSIONS AND RECOMMENDATIONS

During the course of the study, thousands of simulation runs were performed as part of the model testing, calibration, and evaluation of alternative policy scenarios. Considering model runs for each of 80 Climate Divisions, with 4 to 6 crop rotations and multiple crops, up to 6 soil types, 4 alternative tillage practices, and multiple policy alternatives, no simple summary can adequately describe the range of conditions and impacts identified. Section 6.0, along with Appendices C and D, presents and discusses details of the study conclusions and recommendations. Figure 1.3 attempts to aggregate a portion of the study results into a timeline of agricultural soil carbon (SOC), predicted by the CENTURY model, for the Study Region for the 120-year simulation period, beginning with conversion of native vegetation to agricultural production in about 1907, through **current conditions** (i.e., 1988-89); three alternative projections through the year 2030 are included for different levels of annual crop yield increases. These results were obtained by summing the products of the unit area changes in SOC under

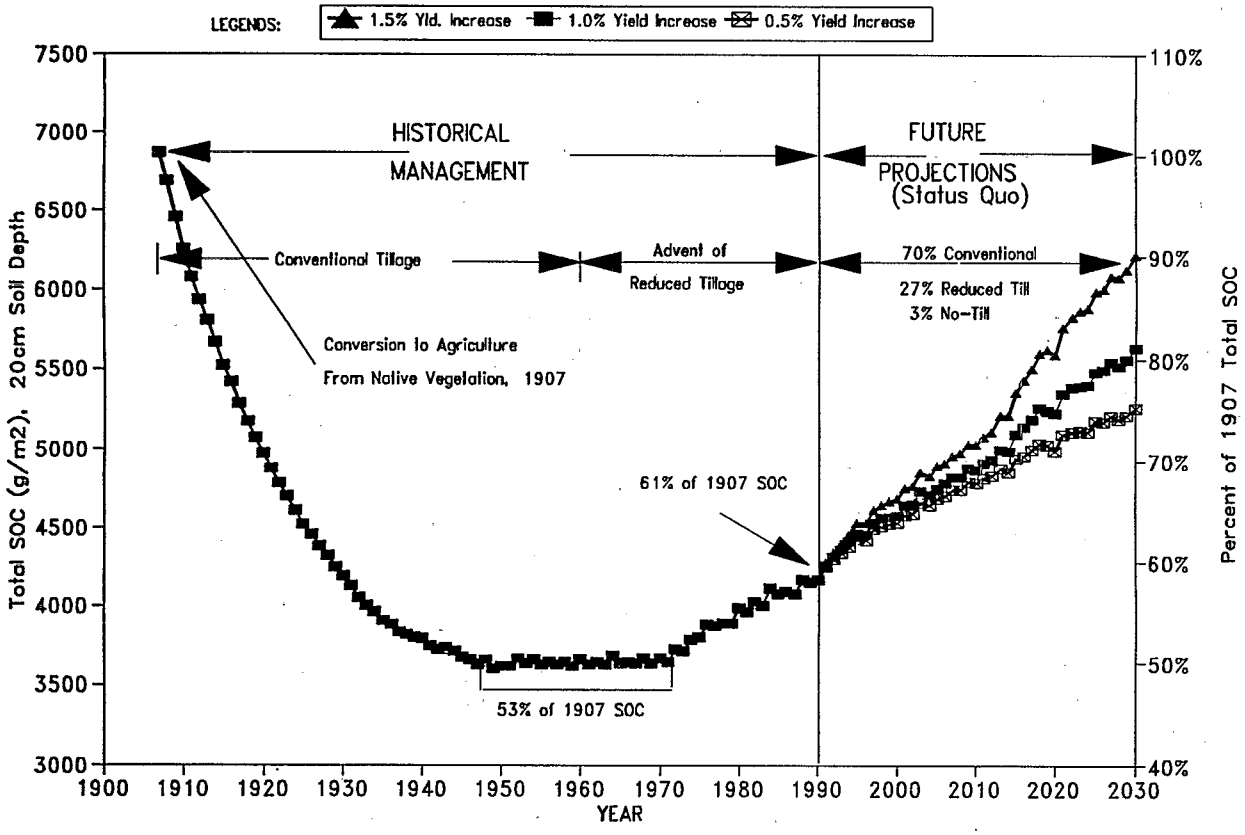


Figure 1.3 Simulated Total Soil Carbon Levels for the Study Region under the Status Quo Scenario For Three Alternative Levels of Future Crop Yield Increases.

each crop/rotation/tillage combination and the area associated with each combination within each CD, then summing the values for all CDs in the Study Region, and dividing by the entire Study Region area; thus the values are in units of **grams C per square meter (gC/m^2)** for a 20-cm soil layer.

The Total SOC values for the projection period of 1990 to 2030 in Figure 1.3 are for the 'Status Quo' condition, which represents a continuation of current 1989-90 cropping, rotation, and tillage practices through 2030, along with the impacts of the three alternative levels of annual increases in crop yields -- 1.5%, 1.0%, 0.5%. The historical portion of the curve shows the characteristic, and well-documented, decrease in SOC following land conversion to agriculture in about 1907, a continuing drop in SOC until about 1950, a period of stable and slightly increasing SOC through 1970, and then significant SOC increases throughout the remainder of the period through 2030. Allison (1973), identifies a period with stable or slightly increasing

SOC which is consistent with the 1950-70 simulations, but subsequent increases of the magnitude shown in Figure 1.3 from 1972 through 1990 have yet to be confirmed. These results reflect the impacts of increasing crop yields during this period, modeling assumptions that represent an associated increase in residues remaining and returning to the soil, and a decrease in the level and intensity of tillage beginning in 1972.

For the 1990-2030 projection period, the continuing increase in SOC is based on the mix of cropping and tillage practices identified by the RAMS analysis for the current 1989-90 timeframe, along with the assumed levels of crop yield increases. The curves show **steady, almost linear increases in SOC from 1970 through 2030.** For the historical period of 1970 to 1990 the increase occurs at an annual rate of about 0.6% per year, which is also about the same rate as for the 1990-2030 increase under the 0.5% crop yield increase assumption. For the 1.5% and 1.0% assumed yield increase levels during the 1990-2030 projection period, the Total SOC increases at 1.2% and 0.9% per year, respectively. If this general pattern is accurate, agricultural SOC within the Study Region made a comeback from a low of about 50% of original (i.e., native vegetation) levels in 1950-70, to about 60% of these levels by 1990. Continuing the increase would lead to 2030 Total SOC levels that approach 75% to 90% of the original SOC prior to the onset of agricultural production (circa 1900).

Below are **capsule** conclusions and recommendations derived from the study results, which are further expanded and discussed in Sections 6.0 and 7.0:

1. Reasonable extrapolation of current agricultural practices and trends will lead to an increase (sequestration) of **about 1 to 2 Gt C** within the Study Region by the year 2030, or about **25 to 50 Mt C per year**. This represents about a **25% to 50% increase** over current 1990 levels. Nationwide the increase could be 50% greater since our Study Region includes only 60-70% of total U.S. cropland.

2. The key assumption underlying these predictions is the projection of **annual crop yield increase from 1990 to 2030;** the lower range reflects an increase of **0.5% per year,** while the upper limit of 50% increase reflects a **1.5% per year crop yield increase.** The validity of this assumption needs to be re-assessed or confirmed, and if valid, policies and research should be promoted to support the chances of agriculture attaining these levels of yield increase.

3. **Conservation tillage practices** can significantly increase soil carbon, but the impacts are highly variable across the Study Region. The degree of impact is due to complex interactions of combinations of crops and rotations, soils, and climate. For many combinations, SOC increased 10% to 15% for Reduced Till and up to 50% for No Till, while much lower changes occurred in other C/R/Ts and CDs.

4. The overall impact of increased Reduced Till (RT) and No Till (RT) practices in terms of **Total SOC change for the Study Region,** ranged from 2% to 3% higher than Status Quo under the Medium Conservation Policy, and 6% to 11%

higher under the High Conservation Policy. These conclusions should be considered preliminary given the capabilities of current models and our limited knowledge of the quantitative impacts of tillage practices. Moreover, current (i.e. 1992) nation-wide levels of No Till and Conservation Tillage (i.e. combined NT and RT) **exceed** the levels included under the Medium Conservation scenario; within the Cornbelt both NT and RT currently approach the levels included in the High Conservation scenario. Thus, the conservation scenarios assume relatively modest changes in practices as compared to more current CTIC data. Further evaluation of the study procedures, conservation tillage usage, model parameter sensitivity, and more research is needed in this area of tillage impacts before these **preliminary** conclusions can be confirmed.

5. **Cover Crops** can lead to significant increases in soil carbon in crop, soil and climate regimes where they are feasible and appropriate. Although only 12% of the Study Region cropland included cover crops (under the Cover Crop scenario), this increased soil carbon by **140 Mt** through 2030. Since southern and eastern portions of our Study Region were most appropriate for cover crops, this may be an attractive alternative for promoting carbon gains in the South and Southeastern U.S.

6. The results of the CRP simulations are mixed. In many cases, 20 years of CRP leads to SOC values higher than the dominant rotation by the year 2030, and usually higher than under continuous CRP. In other CDs, the dominant rotation maintains the highest SOC throughout the projection period. The key factor is likely the relative carbon inputs of the dominant rotation as compared to the CRP conditions. When the dominant rotation is a corn-based rotation, its 2030 SOC is usually the highest. However, this is not always true, especially if only one year of corn is in the rotation. The percent difference for the CRP simulations can range from a few percentage points to up to 20% or higher.

The following modeling and methodology recommendations are derived from the study results, and are further discussed in Section 7.0:

1. The model predictions, especially related to historical trends, impacts of tillage practices and effects of crop yield increases need to be further evaluated and assessed in coordination with the soil carbon database efforts at CSU and MSU.

2. Extension of the methodology to other portions of the United States, and possibly other agricultural regions of the world, should be considered. Application to selected portions of an entire region may be sufficient to estimate region-wide impacts of alternative agricultural practices and production systems.

3. We need to review and establish expected increases in crop yields, plus crop biomass and residues, for major crops and regions of the country in order to determine how best to include this aspect of predicting future SOC conditions, and associated carbon sequestration, under alternative policy scenarios. The importance of these issues is evident in the study results.

4. We need to consider projections of the impacts of future climate scenarios on the assessment of carbon sequestration under alternative policy scenarios. The current study results are based on future climatic conditions that are the same as historic conditions. An assessment of how the study results would change if climate changes, and associated feedbacks to agricultural production systems are considered is needed.

5. Development of appropriate data bases and modeling procedures for representation of the C and N balances in agricultural systems impacted by animal waste application is needed. Accurate databases on animal waste production, including sources, quantities, composition, treatment, storage, and application to croplands are not readily available.

6. We need to develop and/or aggregate databases for improved historical crop yield, cropping and crop rotations, agronomic practices, and economic (production) data, especially as related to soil and climate conditions, in order to evaluate and improve the historical simulations of SOC changes.

7. Continuing investigations are needed into the impacts of cropping and tillage practices on SOC, and development of appropriate modeling procedures to accurately represent these effects. In particular, the impacts of No Till on the entire range of soil physical, chemical and biological processes demand further study.

8. We need to study further the potential impacts of CRP with particular focus on the land characteristics (e.g. soils, topography, cropping and crop rotations) of the areas taken out of production. To more accurately assess CRP changes, including increases or decreases in CRP land, more detailed cropping information is needed to define the production systems from which, and to which, CRP land is transferred.

9. We need to provide a more detailed representation of the N cycle in agricultural soils in close integration with the soil carbon cycle, including calculation of N_2O emissions, as impacted by various agricultural production systems. Possible integration of CENTURY and DNDC capabilities in this area should be considered.

10. We need to investigate the ultimate fate and disposition of erosional SOC losses in terms of both field and landscape level impacts with regard to greenhouse gas emissions from agricultural systems. Estimates of historical erosion losses and associated agricultural practices are needed to better represent the historical pattern of SOC changes and current condition, as a basis for projecting future changes, directions, and alternative policy impacts.

To establish the current state of knowledge on many of these research issues, and to help direct future assessments and needed research, we recommend convening a workshop of both regional and national experts on agronomy, plant physiology, soil carbon processes, tillage practices, agricultural policy, and SOC/SOM modeling. The focus of the workshop would be on the issues identified above to: (1) identify improvements to the assessment methodology; (2) assist in determining parameter adjustments to best represent regional and crop differences in tillage practices and impacts; (3) identify both available and needed databases on tillage practices, crop rotations, animal waste production and disposition, soils characteristics, climate, etc.; (4) establish regional historical agricultural practices and erosional impacts on SOC; and (5) identify associated ongoing research efforts and priorities for future research activities.

1.4 REVISIONS TO THE DRAFT REPORT INCLUDED IN THIS FINAL REPORT

In May 1993, the draft report on this study was prepared and distributed to the Project Team members, and a limited number of outside reviewers, in order to obtain comprehensive review comments on both the entire methodology and the preliminary study results. A Project Review meeting was then held in July 1993, in Fort Collins, CO, to discuss the initial results and the review comments, and address any technical issues related to the study methodology, the operational modeling procedures, and the parameter values associated with alternative tillage practices and policy scenarios. From this review meeting, a number of methodology and operational changes were implemented prior to performing the final model simulations, and subsequent analyses, included in this final report. Although the changes resulted in significantly different model results, the general nature of the conclusions are essentially the same as in the May 1993 Draft Report; those draft results were also reported by Donigian et al., (1993) at the International Symposium on Greenhouse Gas Emissions and Carbon Sequestration, held in Columbus, Ohio, April 5-9, 1993.

The primary differences from the Draft Report implemented in the modeling procedures for the final study results presented herein, are as follows:

a. The CENTURY model output variable used to assess soil carbon storages and changes was revised to include both plant root and surface residues. All analyses in this report are based on this quantity, referred to as **Total Soil Carbon** (with the same acronym, Total SOC), unless otherwise specified. Total SOC is a better indicator of the carbon sequestration potential of alternative agricultural practices and policies because root and

residue amounts will differ as a function of the practices and alternatives. Figure 1.4 shows the typical timeline of how Total Carbon, Total SOC, and the various pools vary

during the year. In order to avoid the complication of the dynamic variation in plant carbon during the year, **the annual value of Total SOC used in our analyses is the minimum during the year of the sum of soil carbon, plant root carbon, and the surface residue carbon pools;** this also allowed a more consistent means of assessing SOC changes for a wide range of crop rotations (e.g. wheat-fallow) and policy scenarios (e.g. cover crops).

b. The yield calibration procedure for the projection time period of 1989 to 2030 was adjusted to maintain the HIMAX parameter as a constant based on values calibrated for the recent historical period of 1971 to 1988. HIMAX controls the amount of plant C that is included in the grain, and subsequently harvested for cash crops. As HIMAX increases, more plant C is included in the grain and likely lost from the soil system through harvest. The preliminary results in the Draft Report were based on HIMAX being calibrated for the projection period and for alternative tillage practices; this lead to lower C content of residues, lower C inputs to the soil, especially for reduced tillage and no-till practices, resulting in lower SOC for these practices.

c. Investigations of the No Tillage simulations from the Draft Report indicated an over-estimation of the affect of crop residues on soil temperature, leading to lower soil temperatures and a retarding impact on crop growth and associated residues. For the CENTURY model results in this report, this adjustment to soil temperature was **not included** in the simulations in order to eliminate any bias in the comparisons of tillage alternatives.

d. A key issue in the Draft Report was the uncertainty associated with the assumption of a 1.5% annual yield increase for all crops during the projection period. Because of the critical impact of this assumption, and the automated simulation capabilities of the Athens-EPA GIS group, we also evaluated the impacts of alternative annual yield increases of 1.0% and 0.5%. Although the detailed results for crops, rotations, and tillage practices are presented only for the 1.5% increase assumption, Section 6.4 discusses the Study Region impacts of the alternative yield increase assumptions and Section 1.3 summarized the key conclusions.

e. The following selected changes were made to CENTURY model parameters and/or capabilities as a result of further discussions and investigation of the Draft Report results:

   1. The factor that indicates the impact of chisel plowing on soil decomposition was decreased from 1.6, the value used for moldboard plowing, to 1.4 to represent less disruption and lower decomposition for the Reduced Tillage options that include chisel plowing.

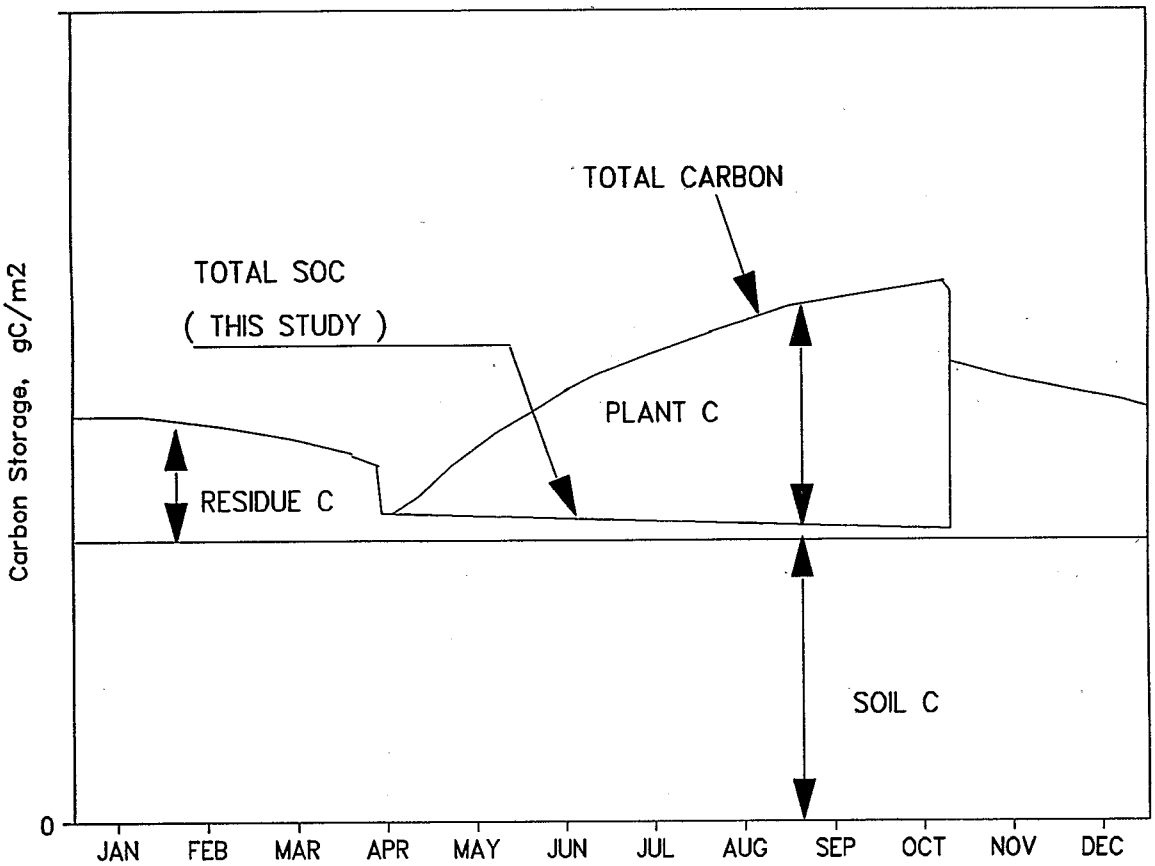


Figure 1.4. Typical Timeline of Soil, Residue, and Plant Carbon Changes During the Year

2. The crop model in CENTURY includes an option to calculate fertilizer nitrogen needs based on a user-defined nitrogen level in the crop. This level was changed from the minimum nitrogen concentration to the maximum nitrogen concentration so that the resulting nitrogen concentration of the crop residues would not be so low as to inhibit residue decomposition.

3. The irrigation calculation was modified to initiate supplemental irrigation when the **root zone soil moisture** fell below a user-specified level, as opposed to the moisture in the entire soil profile as used in Draft Report results.

d. Due to EPA printing regulations, the color maps of the model results shown in the Draft Report have been replaced with multiple gray-scale tones in this report. Appendix D includes a complete set of the GIS-mapped CENTURY model results.

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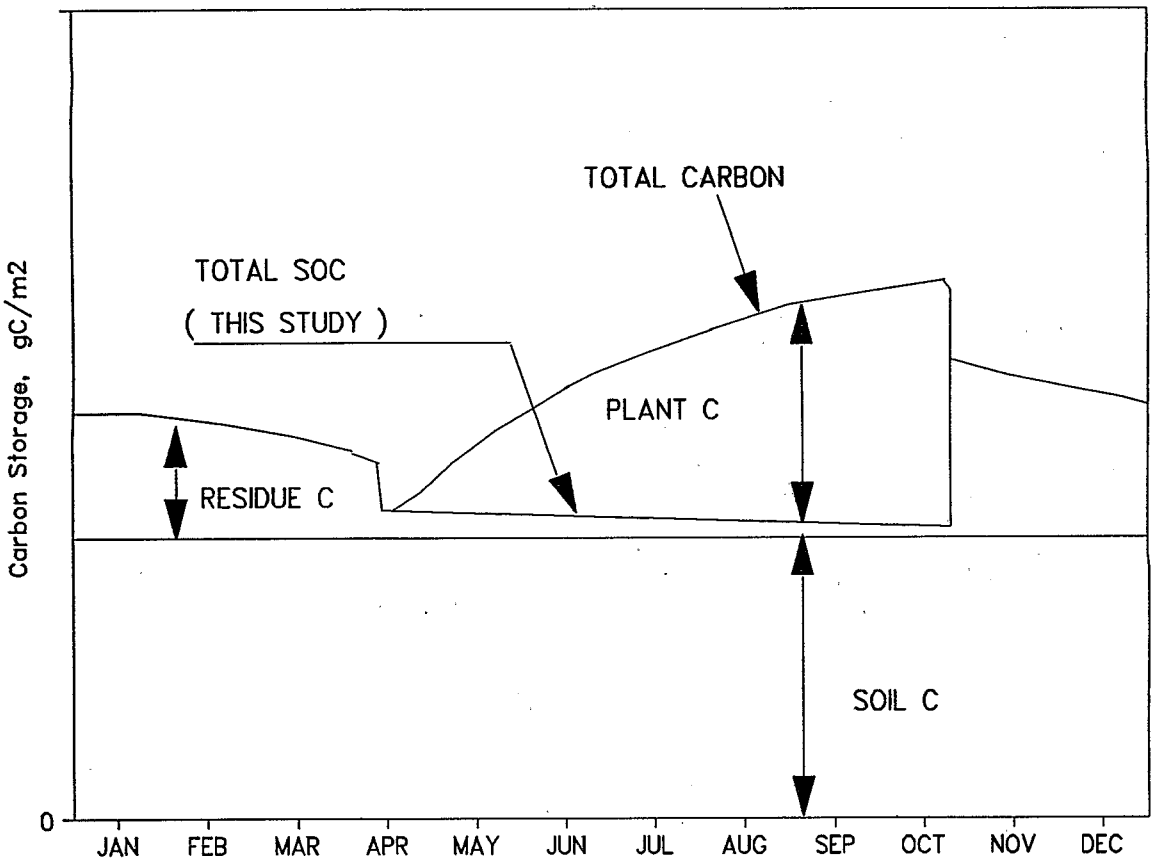

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1.5 FORMAT OF REPORT

Section 2.0 describes the separate, supporting soil carbon data aggregation effort by CSU and MSU in terms of the carbon pools, dynamics, and modeling technology on which the data effort is focused. Section 3.0 describes the overall project methodology that was developed to integrate the SOC modeling, the RAMS output, and soils/climate data bases to provide an operational pathway for assessing agricultural SOC sequestration potential. Section 4.0 describes the data bases and data manipulation for preparing the model input, while Section 5.0 discusses in detail the procedures and parameter values used to represent baseline agricultural production systems and alternative scenarios. The simulation results are presented and discussed in Section 6.0, with references to Appendices C and D, which contain tabulated model results and a complete compilation of the GIS displays of the Study Region for all policy alternatives and selected characteristics. Section 7.0 reviews the key methodology and modeling assumptions to set the stage for recommendations for directing future model development and testing, methodology development, and research efforts.

SECTION 2.0

AGROECOSYSTEM CARBON POOLS, DYNAMICS, AND MODELING

The objectives of this portion of the BIOME study were to (1) conduct field and laboratory investigations to develop defensible data for evaluating carbon pools and dynamics for agroecosystems, (2) identify critical soil and climatic parameters that might affect those dynamics, and (3) review available soil carbon models for their ability to assess the impact of alternative agricultural management practices on carbon storage and fluxes in agroecosystems. The data base being developed in support of this effort will be used to test and validate the models under a range of soil, climatic, and agronomic conditions. The first two objectives are being accomplished through a joint study of agroecosystems in the Great Plains and the Corn Belt of the United States by Colorado State University (CSU) and Michigan State University (MSU). The model review was conducted as part of this effort in order to select an appropriate tool for assessing carbon sequestration potential for the Study Region. This section describes both of these efforts and is abstracted from the study Interim Report by Barnwell et al. (1991); Sections 2.1 through 2.3 discuss the data base development effort currently being conducted jointly by CSU and MSU; these sections are abstracted from the proposal for that project, and were authored by the investigators at those institutions. Section 2.4 describes the results of the soil carbon model review.

The CSU/MSU studies focus on corn, soybeans, wheat and rangelands. Priority is being given to sites with historical data concerning the effects of management practices on SOM and supporting data pertaining to climatic conditions. The data will be used to parameterize and evaluate carbon budget models. Emphasis is on collection, preparation, and evaluation of carbon budget data. Sites where comparisons of management practices are possible have been given highest priority. Because of its spatial and temporal variability, CO_2 and other greenhouse gas flux measurements have been inferred from soil storages rather than being measured. Outputs of the studies will be data useful in the quantification of soil and plant organic carbon pools and dynamics for the dominant agricultural crops, including rangeland, in the two regions.

2.1 RATIONALE

2.1.1 Project Objectives

The objective of the CSU/MSU research project is to develop credible data sets concerning the potential for agroecosystems of the Great Plains and Corn Belt to sequester carbon. To accomplish this, CSU and MSU are: (1) reviewing the national and international literature on the impact of driving variables, including management, on SOM and producing a document

summarizing the results; (2) holding workshops where the scientific cooperators of this project present summarized data from their sites, which will be further integrated into a form that can be used to parameterize and validate SOM models; and (3) reviewing the experiments presented by the cooperators to obtain a uniform characterization of soil organic matter and organic matter input relating to specific pools useful for parameterizing and validating SOM models. The results of this data effort are planned for publication in book and diskette form in late 1993 (Paul and Eliott, In Preparation).

2.1.2 Project Perspective

The plan for data collection allows CSU and MSU to evaluate the potential impact of different management practices on the sequestration of C in soil organic matter of the Central United States. They believe that it is also necessary to have spatially explicit information about the regional distribution of ecosystem driving variables, including management, to make quantitative estimates of C sequestration. It is essential to know the size of the different SOM pools and the total amount of SOM because almost all existing SOM models use two to three different SOM pools. Until recently, it has not been possible to separate these SOM pools analytically. With recent breakthroughs, it is possible to characterize two conceptually important pools: the slow pool (Elliott and Cambardella, 1993) and the active pool (Boyle and Paul, 1989) across geographic zones and soil types within different management treatments that have potential for increased SOM levels.

2.1.3 An Approach to the Study of Regional Ecosystem Properties

Several levels of resolution of time and space must be considered in order to integrate information on SOM at the regional level (Figure 2.1). Generalized agroecosystem models are used to integrate information on processes and properties (e.g., Parton et al., 1987). Where information gaps are observed, appropriate new experiments can be designed and data bases collected or collated.

Agroecosystem models must be parameterized and validated over a wide range of management practices, climates, soils and time scales. Fortunately, appropriate data are available from field plot experiments that have been ongoing for many years. These experiments are located on the research sites of the USDA-ARS, State Experiment Stations, Agriculture Canada and corresponding studies in other countries (Figure 2.2). As a result, much of the information needed to validate agroecosystem level models already exists. However, this information generally is not available as extant data bases and not all necessary kinds of information have been collected at each site. It will take a concerted effort to collate this information and collect pertinent new data from existing sites in a form that is useful for agroecosystem model validation. This is the main focus of the data base development effort of the CSU/MSU study.

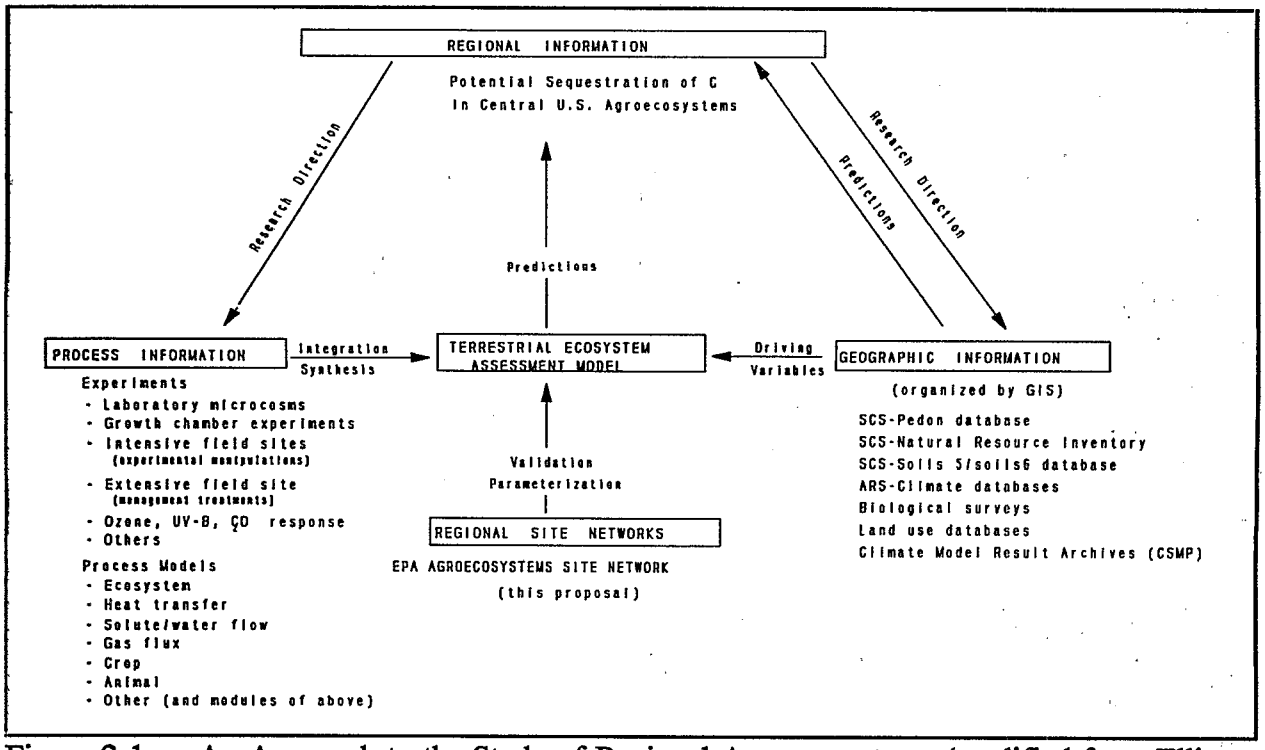


Figure 2.1 An Approach to the Study of Regional Agroecosystems (modified from Elliot and Cole, 1989)

2.2 LOSS AND SEQUESTRATION OF CARBON FROM CENTRAL U.S. ECOSYSTEMS

The conversion of native ecosystems to agricultural lands in the Great Plains and Corn Belt regions of the Central United States was perhaps the most extensive ecological disturbance known in North America during the past 150 years (Wilson, 1978). A major consequence of this land conversion has been the substantial loss of organic matter from soils across the regions (Haas et al., 1957; Campbell 1978). These soil C losses have been a primary anthropogenic source of carbon dioxide, second only to fossil fuel combustion in contributing to historical increases of global CO_2 concentrations (Post et al., 1990).

Since soil carbon levels in most Great Plains and Corn Belt agricultural soils have been reduced to levels well below those existing prior to the establishment of agriculture, the potential should exist to increase present soil C levels, thereby providing a sink for atmospheric CO_2. At present there is considerable debate whether increases in atmospheric CO_2 concentrations and global warming will result, independently, in significant changes in soil C storage (e.g., Prentice and Fung, 1990; Schlesinger, 1990). While not discounting the importance of these factors, increasing agricultural soil C levels may be more dependent on agricultural management practices and land use changes.

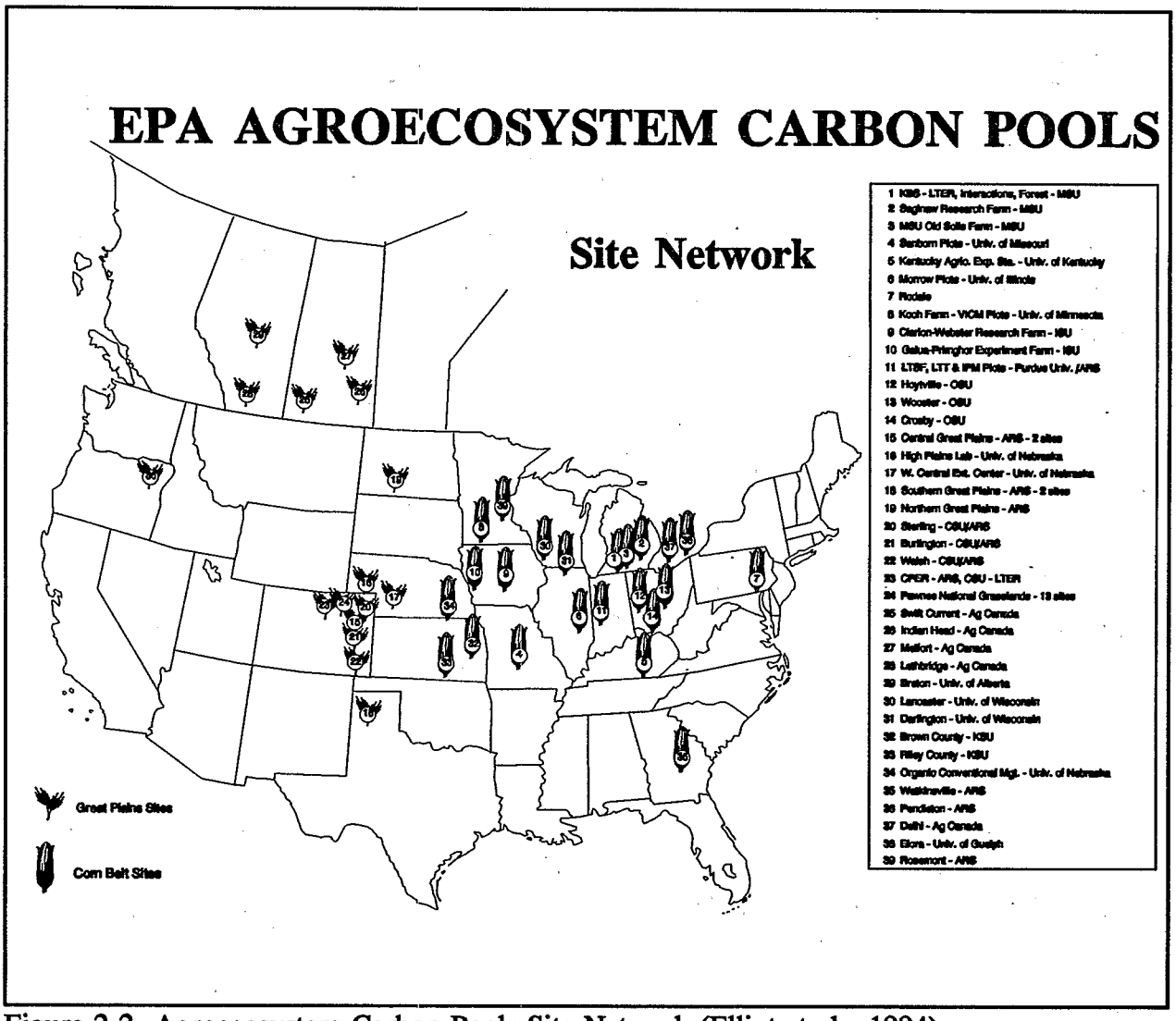


Figure 2.2 Agroecosystem Carbon Pools Site Network (Elliot et al., 1994)

Many of the agricultural practices that have been traditionally applied in the Great Plains and Corn Belt [e.g., moldboard plowing, fallow with no plant cover, removal or burning of crop residues and monoculture cropping (Cole et al., 1989)], represent a "worst-case" for soil C maintenance, by minimizing organic matter inputs and promoting a high degree of soil organic matter decomposition. Currently, agricultural management in the United States is undergoing rapid change in response to a variety of pressures, including high costs of energy and chemical inputs, environmental concerns about nutrient and pesticide pollution and soil erosion, and product quality demands by consumers (National Research Council, 1989). It is encouraging to note that many of the techniques designed to address these issues have also demonstrated a potential for increasing soil C levels above those maintained under conventional management. Such practices include reduced or no-till management (Blevins et al., 1983; Dick, 1983; Lamb et al., 1985); reduction in the proportion of fallow relative to crop in semiarid regions (Wood et al., 1991); and use of cover crops, green manure and animal manure (Paustian et al., 1992; Vitosh et al., 1973). However, the extent to which soil C levels can be regulated through the application of various combinations of these practices for different cropping systems, soil types, and climatic regions is not yet clear.

In addition to changing management trends on production land, land use changes may have a considerable impact on region-wide C storage potential. Over the past 50 years, significant acreage in cropland has been abandoned or converted back into perennial grassland and forest. For example, more than 100,000 ha of farmland in northeastern Colorado alone were abandoned during the 1930's, and in more recent years, large areas of Great Plains cropland have been converted to grassland under the Conservation Reserve Program (Joyce and Skold, 1988). Similar changes have occurred in regions of the Corn Belt, in particular in the Great Lakes region and in eastern areas bordering on the Appalachians. For example, from 1950 to 1990, the agricultural land base of Michigan declined by 7 million acres, much of which was previously in corn, soybean and wheat production (Michigan Dept. Agric., 1990). To date, there has been little systematic evaluation of how these shifts in land use have affected regional soil C balances or of what effect future changes may have.

While data from long-term field studies have provided much information about the possible rates and directions of change in soil C under various management regimes, our current knowledge base is very fragmented. Most of what is known concerning SOM dynamics has been obtained by studying SOM losses. We understand little about controls on SOM accumulation and how they vary across soil types, climatic regions and management regimes. Such information is crucial for estimating the potential for carbon sequestration in agricultural soils of the Great Plains and Corn Belt regions.

2.2.1 Driving Variables, Processes and Properties

The proposed approach in the CSU/MSU study to assembling an appropriate database for assessing the potential for C sequestration in agroecosystems is based on the general concept of relating key driving variables to ecosystem processes and properties. Jenny (1941, 1980) popularized the concept of driving variable control to explain soil properties and their geographic

distribution. Originally, he proposed five driving variables, i.e., climate, parent material, relief, organisms and time, as determinants of soil processes. His framework acknowledged that soils are one of many interrelated ecosystem components.

Observations have been made that describe the empirical relationships between independent driving variables and dependent ecosystem properties. For example, the distribution of soils and vegetation have often been related to patterns of temperature and precipitation. Ultimately, the origin of ecosystem properties, such as soil C content, is the outcome of the multifarious interactions of a suite of independent driving variables. Since the response variables (properties) of such descriptions are autocorrelated, it becomes impossible to unambiguously relate ecosystem properties to each other, even though these properties are usually the ecosystem components we measure in our studies. External variables drive the system but the components of the system interact in complicated ways and are also subject to feedback effects that further complicate interpretation of relationships among components. While statistical analyses may be able to account for some of the complexity, higher order interactions are notoriously difficult to understand even though we accept that they have important influences on system properties. Thus, the statistical approach cannot appropriately account for feedbacks among components. However, these feedbacks can be accounted for through the use of simulation models.

2.2.2 Regional Patterns and Controls on Soil Organic Matter

SOM content is determined by the balance of inputs (primary production in most cases) and outputs (decomposition and erosion). The primary factors controlling production and decomposition in agroecosystems are related to Jenny's (1941) state factors, i.e., temperature and precipitation and their timing (climate), parent material (often represented by texture), relief (landscape position), organisms (particularly the plant community) and management (Elliott et al., 1993). These factors seldom act alone, but rather they interact in complex ways. In addition, these factors may influence production and decomposition differentially across gradients of these factors.

Regression analysis of 500 rangeland and 300 cultivated soils across the semi-arid Central United States indicated that organic C increased with precipitation and clay content and decreased with temperature (Burke et al., 1989). Losses of soil C due to cultivation increased as precipitation increased, with relative losses being lower in clay soils. Soil C estimates made with these regression models agreed well with estimates made using the CENTURY model for this region (Burke et al., 1989). It remains to be determined whether these relationships hold for the more mesic Corn Belt region. Steady-state simulations were made for 24 grassland sites in the U.S. Great Plains and compared with data from each site (Parton et al., 1987). Regional trends in SOM were adequately predicted using four site-specific variables -- temperature, moisture, soil texture, and plant lignin content. Grazing intensity during soil development also had a significant impact on soil C levels. Sites within close proximity, thus having similar climate, have been shown to be strongly influenced by soil texture (resulting from different parent material) (Tiessen et al., 1982; Schimel et al., 1985; Aguilar and Heil, 1988). Relief also determines levels of SOM (Honeycutt, 1990a, 1990b; Schimel, et al. 1986; Yonker et al., 1988)

but is often confounded with the influence of texture. Similarly, the influence of the vegetation on SOM is difficult to isolate because it can also be a response variable to other state factors such as climate. However, there are instances, such as the grassland-tree transition zone in the Central United States, where trees and grass exist under the same set of driving variables and impart different influences on SOM (Jenny, 1941; Anderson, 1987).

2.2.3 Agricultural Management and Soil Organic Matter

In agricultural systems, many factors influencing SOM levels are subject to management control -- through tillage, crop selection, addition of fertilizer and organic amendments, irrigation and residue treatment (i.e., removal, burning). For example, cropping practices and residue management directly affect both the amount and quality of C inputs to soil. Soil C levels in several long-term experiments were highly correlated with residue input rates (Larson et al., 1972; Rasmussen et al., 1980; Paustian et al., 1992) and there is clear evidence that differences in the quality of organic inputs in combination with N fertilizer levels influence SOM levels (Parton et al., 1983; Paustian et al., 1992).

Other management practices can have a more indirect influence on C inputs, C losses or both. Tillage affects water and heat fluxes in soil; e.g., no-till soils tend to be cooler and wetter than under conventional tillage. Crop growth, which is of course the target of most management efforts, can interact strongly with soil water dynamics and thereby influence decomposition processes. In semiarid ecosystems, such as the Great Plains, high plant water-use efficiency and subsequent moisture limitation of decomposition may tend to favor production over decomposition. This may explain the high levels of SOM that occur in semiarid grasslands (Elliott and Cole, in press). With increased moisture, as one moves to the corn growing regions, declines in SOM are observed even while production increases, perhaps because water residence time in soil is longer and decomposition remains high. In the wetter regions, factors that enhance production, such as fertilization, may stimulate increases in SOM because water controls on decomposition become less important. Of course, in poorly drained soils SOM may again increase.

Change in management, whether conversion from native ecosystems or shifts to more productive or environmentally sound practices, influences SOM by affecting either decomposition, production or more likely, both. Reduced soil tillage intensity, as with no-till management, has been shown to decrease the rate of SOM loss when plowed out of native sod compared with more intensive tillage management (Lamb et al., 1985) and to increase the rate of SOM mineralization (Rice et al., 1986). We have found greater losses of total C and N with increased tillage intensity (Cambardella and Elliott, 1992) with the greatest proportion of loss from the particulate fraction. On land previously under conventional tillage, introduction of no-till invariably results in a more surficial organic matter distribution (Doran, 1987) and in many cases higher overall soil C levels (Blevins et al., 1983; Dick et al., 1990). Lower C losses (or greater C gains) under no-till could be the result of decreased decomposition because of reduced soil disturbance, less contact of litter with soil, cooler soils, less erosion or (in drier environments) it could be the result of increased production due to greater water availability to plants.

In semiarid systems, where a bare fallow period is inserted into the rotation to store enough soil water to obtain a crop every other year, SOM losses after plowing can be great and continue for more than 50 years (Haas et al., 1957). The soil in the fallow part of the rotation is warmer and wetter and there are no organic matter inputs from plants. With the use of no-till, crops can be grown more frequently than the conventional once-every-two-years for the wheat-fallow rotation. With increases in cropping frequency SOM levels can show significant increases in periods as short as 4 years (Wood et al., 1991) with concomitant increases in potentially mineralizable C and N (Wood et al., 1993). Rates of SOM loss are reduced with increased frequency of cropping (Janzen, 1987). In the more mesic sites in the Corn Belt region, replacing winter fallow practices with cover crops or including perennial legumes or grass in the rotation promotes higher levels of SOM (Power, 1987; Dick et al., 1990).

2.2.4 Representation of Regional Data

One of the chief difficulties in representing information on regional ecosystems is determining what constitutes representative data. Information obtained from a single site, even though carefully replicated at that site, is essentially pseudoreplicated (Hurlbert 1984) if that site is intended to represent an entire region. Yet, if one moves too far from the original site for a replicate site, state factors such as soil texture, temperature or precipitation may change resulting in lack of good representation. In some sense, it is not possible to have replicated ecosystems. It is arbitrary as to what class of variables are similar enough to represent a region. If enough samples are taken within a region to adequately represent it, we have a good representation of that region but we do not know whether that region is representative of all potential regions developing under that specific set of driving variables. At the very least, we should be reluctant to extrapolate our predictions to regions developing under different sets of driving variable.

It is best to have a high sampling density spanning gradients of driving variables to obtain representation of a region if we are to make predictions pertaining to that region. That is why CSU and MSU have chosen to use an extensive network of sites. There are, of course, tradeoffs between the number of sites and the number of properties obtainable from each site. If indeed there are only a few pertinent state factors (driving variables) (Parton et al., 1987), it should be possible to represent those sites with these state variables and characterizations of initial conditions. They favor an extensive site network with measurement of important and reliably determined variables rather than detailed and hard-to-interpret analyses run on samples from a few sites. It is equally important to have samples taken in as similar a fashion as possible at all sites (preferably by one or a few field researchers) to ensure comparability of data. The study is limited by the availability of long-term sites that have adequate ongoing experiments and data sets but CSU and MSU have brought together an extensive set of sites they believe are representative of the grassland, wheat and corn growing regions of the Central United States.

2.3 PROJECT PLAN

2.3.1 Site Network Overview

The CSU/MSU study is simple in concept but has been a challenge to organize. As the main component of the data collection project, they have brought together a group of cooperating scientists that collectively have access to a network of sites (Figure 2.2) covering the Corn Belt and Great Plains of the Central United States. The establishment of this network of 39 long-term sites provides the background necessary for understanding carbon storage relative to past and possible future management practices. The sites represent north-south and east-west gradients, an approximate five-fold range in soil carbon, and an excellent range in native vegetation and soil texture. A number of the sites have stored samples and or access to present day native sites. Tables 2.1, 2.2, and 2.3 contain summaries of sites, their locations, the period of data available at each, and the treatments at each.

2.4 MODELING SOIL ORGANIC MATTER

Simulation modeling provides a means of integrating the numerous factors affecting SOM and of predicting changes in soil C as a consequence of altered management practices and/or changes in climatic conditions. Although various SOM models have been developed and refined over the past 15 years (e.g., Jenkinson and Rayner, 1977; van Veen and Paul, 1981; Parton et al., 1983; Jenkinson et al., 1987; Parton et al., 1987; 1988, 1989; Paustian et al., 1992), several key features are common to all. These include multiple SOM fractions that differ in decomposition rate, temperature and moisture as the primary climatic driving variables, effects of soil physical properties on organic matter stabilization, and the influence of the quantity and quality of crop residues on the formation of new soil organic matter. Thus, based on past experience in modeling SOM, the suite of existing data and new measurements has been designed to be well-suited for the planned modeling efforts.

To explain the rationale for data acquisition in relation to modeling requirements, we will briefly describe the assumptions and data requirements of the CENTURY model (Parton et al., 1987), probably the most widely applied SOM model currently in use. The model was developed at CSU and members of the MSU group have been active collaborators in the application and further development of the model. The model has been used to simulate SOM dynamics in both grassland and agricultural ecosystems (Parton et al., 1983; Parton et al. 1987, 1988; Cole et al., 1989; Paustian et al., 1992) and has also formed the basis for larger-scale regional analyses of SOM patterns in Great Plains grasslands (Burke et al., 1989, 1990; Parton et al., 1987, 1989).

The CENTURY model characterizes SOM in terms of three fractions each having characteristic decomposition rates or turnover times ranging from 1.5 years (active) to 50 years (slow) to 1000 years (passive), which are modified by climatic variables (temperature and moisture), soil texture, and tillage disturbance. Fresh organic matter (crop residues, manure, plant litter)enters the soil where its decomposition rate is influenced by chemical composition, expressed through lignin and N content, as well as climatic conditions and location (surface or incorporated in soil).

TABLE 2.1 Corn Belt sites and cooperators

Name	Location	Period	Treatments	Contact Person and Affiliation
KBS/LTER	Hickory Corners, MI	1989-	Randomized block design (6 reps) w/ 8 cropping systems;	G. Robertson MSU
KBS/Interactions	Hickory Corners, MI	1986-	Previously cultivated soil: Continuous corn - 2 tillages, 2 fertilizer rates On virgin soil (never-tilled) No-till continuous corn with 0 N fertilizer vs. Native grass vegetation 6 treatments	G. Robertson MSU
KBS/Forest	Hickory Corners, MI	1942-	11 permanent points were randomly established in 1942, to serve as loci around which soil would be sampled over the next 50 years at 10 year intervals.	K. Pregitzer MSU
Saginaw Research Farm	Thomas Township, Saginaw County, Michigan	1972-	Crop rotation trials consisting of 4 systems X 3 rotation lengths, including corn, sugar beets, navy bean, oats, alfalfa	D. Christenson MSU
MSU Old Soils Farm	East Lansing, MI	1963-1982	Split-block design with 3 replicates. Whole plots with 5 nutrient addition treatments (continuous corn) Never-tilled woodlot is located within 300 m	M. Vitosh MSU
Sanborn Plots	Columbia, MO	1888-	Treatment combinations consist of various crop rotation and fertility amendments. (treatments on 9 of the original 39 plots have been unchanged since 1888)	J. Brown G. Wagner G. Buyanovsky Univ. of Missouri
Kentucky Agricultural Experiment Station Farm	Lexington, KY	1970-	Split block design (4 reps per treatment) Continous corn 2 tillage treatments X 4 N fertilizer levels Control plots w/ bluegrass sod	W. Frye Univ. of Kentucky
Morrow Plots	Urbana, IL	1876-	3 rotations as main plots. Nutrient-additions in subplots of main plots; various combinations of manure, liming and NPK to subplots within each rotation.	R.Darmody T.Peck Univ. of Illinois
Rodale	Kutztown, PA	1981-	Randomized block with split-plots (rotation entry points as split-plot), 3 cropping systems	R. Janke S. Peters Rodale

Koch Farm - VICM Plots	Lamberton, MN	1989-	Randomized block with split-plot design, 2 rotations X 4 management levels The experiment is repeated on another area of the farm with a history of high fertilizer and pesticide inputs.	R. Crookston W. Nelson Univ. of Minnesota
Clarion-Webster Research Farm	Kanawha, IA	1954-	Randomized block with split-plot design 5 crop rotations (2 reps within year, all years in rotation as main plots) X 4 N fertilizer levels (split-plot)	J. Pesek ISU
Galua-Primghor Experiment Farm	Sutherland, IA	1957-	Randomized block with split-plot design 6 crop rotations (2 reps within year, all years in rotation as main plots) X 5 N fertilizer levels (split-plot)	J. Pesek ISU
Purdue LTSF Plots	West Lafayette, IN	1952-	Split-block design 21 combinations of P-K fertilization, applied to Corn-Soybean-Wheat-Corn (2 reps per treatment) 3 Residue levels 2 N levels (0 and 200 kg N per ha)	D. Stott D. Mengel R. Turco Purdue University
Purdue LTT Plots	West Lafayette, IN	1975-	Split block design (4 reps per treatment) Corn-Soybean rotation with 4 tillage treatments	D. Stott D. Mengel R. Turco Purdue University
Purdue IPM Plots	West Lafayette, IN	1981-	Split-plot design; whole plot=tillage & rotation, split-plot=weed mgmt. 3 rotations (each crop in each year for a total of 7 sequences)	D. Stott D. Mengel R. Turco Purdue University
Hoytville Plots	Wood County, OH	1963	Randomized block design 3 Tillage treatments X 3 rotations	W. Dick OSU
Wooster Plots	Wooster, OH	1962-	Randomized block design 3 Tillage treatments X 3 rotations	W. Dick OSU
Crosby Plots	South Charleston	1962-	Randomized block design Continuous corn X 3 Tillage treatments	W. Dick OSU

Darlington	Darlington, WI	1958-	Continuous corn with three N rates (plowed)	L. Bundy Univ. of Wisconsin
Lancaster	Lancaster, WI	1967-	Crop rotations by N rates (plowed)	L. Bundy Univ. of Wisconsin
NTRM Plots	Rosemont, MN	1980-	Three cultivation types and three N levels under continuous corn.	E. Klapp ARS
Organic Conventional Management	Mead, NE	1975-	Four crop rotations by fertilizer levels (including manure)	G. Lesoing J. Doran Univ. of Nebraska

TABLE 2.2 Great Plains sites and cooperators

Name	Location	Period	Treatments	Contact Person and Affiliation
Long-Term Tillage Experiment	USDA-ARS Central Great Plains Research Station Akron, CO	1967-	4 tillage with 5 crop rotations	A. Halvorson ARS
Rotation x N Experiment	USDA-ARS Central Great Plains Research Station Akron, CO	1985-	No-tillage with 2 rotations and 5 N levels	A. Halvorson ARS
Long-Term Tillage Studies C&D	High Plains Agricultural Lab Sidney, NE	1970-	4 tillages with wheat/fallow rotation	D. Lyon Univ. of Nebraska
North Platte Cropping Systems	University of Nebraska West Central Research & Extension Center No. Platte, NE	1981-	Minimum tillage (irrigation) with 4 crop rotations	G. Hergert Univ. of Nebraska
Graded Terraces	USDA-ARS, Conservation & Production Research Lab, Bushland, TX	1958-	2 tillages with 3 crop rotations	B. Stewart O. Jones ARS
Mini-Bench Site	USDA-ARS, Southern Great Plains Bushland, TX	1982-	2 tillages with 4 crop rotations	B. Stewart O. Jones ARS
Tillage-Rotation Experiment	USDA-ARS, Northern Great Plains Research Laboratory Mandan, ND	1984-	3 tillage with 2 rotations and 3 fertilizer levels	A. Black D. Tanaka ARS
Dryland Agroecosystems in Eastern Colorado	Sterling, Stratton, & Walsh, CO	1985-	No-till with 3 sites and 5 rotation treatments (2 reps)	G. Peterson D. Westfall CSU
Central Plains Experimental Range - (USDA-ARS) Long-Term Ecological Research - (NSF)	Nunn, CO	1930- (ARS) 1981 - (LTER)	Several grazing intensities	J. Welsh W. Lauenroth ARS/CSU

Earthwatch Sites	Pawnee National Grasslands, Weld County, CO	1990	Secondary succession or no disturbance (13 paired native vs go-back sites). More to be established.	D. Coffin CSU
Swift Current	Swift Current, Canada	1966-	Twelve crop rotations in all phases	C. Campbell R. Zentner Ag Canada
Indian Head	Indian Head, Canada	1958-	Eleven crop rotations from 1958 with three additional from 1968. All phases present.	G. Lafond Ag Canada
Melfort	Melfort, Canada	1957-	Eight crop rotations with all phases present	A. Moulin L. Townley-Smith Ag Canada
Elora	Guelph, Canada	1965-	Three tillages under continuous corn	P. Voroney R. Beyaert Univ. of Guelph
Delhi	Guelph, Canada	1989	Three rotations and two tillages. constructed for long-term use with stable isotope labelled plots.	P. Voroney R. Beyaert Univ. of Guelph
Dryland Rotations	Lethbridge, Canada	1951-	Three crop rotations with fertilizer treatments	H. Janzen Ag Canada
Restorative dryland rotations	Lethbridge, Canada	1951-	Thirteen treatments (rotations) including native grass	H. Janzen Ag Canada
Long-term no-till	Lethbridge, Canada	1967-	Two tillage and two crop rotations	H. Janzen Ag Canada
Breton Plot	Edmonton, Canada	1939- 1981-	Two long-term rotation treatments (64 years) and three rotation treatments on two soil types (11 yrs)	N. Juma Univ. of Alberta
Brown County	Brown County, Kansas	1974-	Three crop rotations and two tillages	J. Havlin KSU
Riley County	Riley County, Kansas	1975-	Three crop rotations and two tillage treatments	J. Havlin KSU

TABLE 2.3 Sites outside of the Great Plains and Corn Belt

Name	Location	Period	Treatments	Contact Person and Affiliation
Watkinsville	Watkinsville, GA	1974 1982 -	Soybeans with conventional and no-till on similar soils	R. Bruce ARS
Pendleton	Pendleton, OR	1930, 1950, 1960-	Several crop rotations, tillage and ammendment treatments.	P. Rasmussen ARS

In addition to the driving variables, the amount and composition of the existing SOM (i.e., size of each of the three SOM fractions) are necessary initial conditions for the model and will influence the trajectories of soil C changes under a given set of driving variables.

Standard climatic data are available for all the sites in the proposed network, including additional information such as pan evaporation and soil moisture in some cases. Crop yield data can be used as the basis for estimating productivity and thereby residue input rates; in many instances, direct measurements of aboveground residues are available although data on below-ground inputs are scanty. Uncertainty about below-ground organic matter inputs is admittedly an area of concern; however, standard productivity data together with information from the literature on how yield indices and root production vary as a function of crop type and growing conditions can be used to obtain reasonable estimates of input rates. Similarly, data on crop N content, crop type and stage of maturity (to estimate lignin content) enables one to characterize residue input quality. One of the tasks of the existing data synthesis and literature review effort is to provide such additional information. The major component missing from the existing data that is an ecologically meaningful fractionation of SOM across all the sites. Therefore, the sampling and soil analyses planned for future study address this lack of information.

2.4.1 Review of Available Soil Carbon Models

As part of the work effort, a literature review was conducted with the key focus on the dynamics and modeling of SOM and soil carbon, soil carbon budgets, and impacts of soil and agricultural management practices. Barnwell et al. (1991) provides a summary of major carbon modeling codes identified in the literature survey. Table 2.4 illustrates the information contained in the model reviews; Table 2.5 presents the models and references reviewed and summarized in Barnwell et al. (1991). A list of evaluation criteria and capabilities for comparison of soil carbon models was developed and is presented in Table 2.6. These criteria were used in the selection of an appropriate model for use in this investigation for evaluation of agricultural soil carbon sequestration.

Below we have provided capsule summaries of the six major models reviewed, followed by an intercomparison of the key capabilities used in the evaluation.

CENTURY Model -

As noted earlier, Parton et al. (1988) developed the CENTURY model to simulate the dynamics of C, N, P, and S in cultivated and uncultivated grassland soils. Recent model refinements have resulted in the Agroecosystem Version 4.0 of CENTURY to better represent complex cropping patterns, rotations, and management practices (Metherell et al., 1993). The model uses monthly time steps for simulation, and model runs can be performed for longer time periods ranging from 100 to 10,000 years. The model simulates three soil organic matter fractions: 1) active fraction (turnover time of 1-5 yr); 2) a protected fraction that is resistant to decomposition (turnover time 20-40 yr); and 3) a physically protected and chemically resistant fraction (turnover time of 200-1500 yr). SOM dynamics, nutrient mineralization, and plant production

1. Name of the Model -

2. Type of Model
   ___ Surface and Vadose zone model: Simple Approach
   ___ Surface and Vadose zone model: Detailed Approach
   ___ Vadose zone model: Simple Approach
   ___ Vadose zone model: Detailed Approach
   ___ Vadose and Groundwater model: Simple Approach
   ___ Vadose and Groundwater model: Detailed Approach
   ___ Multi-media model: Simple Approach
   ___ Multi-media model: Detailed Approach

3. Processes Simulated
   ___ Simulate soil hydrologic balance
   ___ Simulate soil moisture
   ___ Simulate soil temperature
   ___ Simulate crop/plant seasonal vegetation changes
   ___ Simulate carbon cycle in soils
   ___ Simulate carbon and nitrogen cycles in soils
   ___ Simulate carbon, nitrogen and phosphorus cycles in soils
   ___ Simulate other nutrients in soils

4. Purpose/Scope of model
   Purpose: BRIEF DESCRIPTION OF PURPOSE OF MODEL
   Predict emission of greenhouse gases
   ___ CO_2
   ___ N_2O
   ___ CH_4
   Unique Features:
   ___ Simulates effects of changing climate
   ___ Simulates effects of soil temperature
   ___ Simulates effects of residue management
   ___ Simulates effects of soil physical properties
   ___ Simulates soil organic matter dynamics
   ___ Simulates crop growth as a function of moisture, temperature, nutrients, etc
   ___ Simulates changing cropping/tillage practices
   ___ Integral Database/Database manager
   ___ Integral Input/Execution Manager
   ___ Integral graphic capabilities

5. Description of method/techniques

6. Compartments of soil processes simulated
   ___ Single soil layer
   ___ Multiple soil layers

7. Data requirements/Availability

8. Output options available

9. Limitations

10. Ease of application
    System setup: ___ mandays ___ manweeks ___ manmonths ___ manyear
    Assessments: ___ mandays ___ manweeks ___ manmonths ___ manyear
11. Assumptions

12. Hardware/Software requirements

13. Experience

14. Validation/Review

15. Model code maintenance and update
16. Contact
17. References

Table 2.4 - Soil carbon model review form.

Model Name	Reference
CENTURY Model	Parton et al., 1988
DNDC Model	Li et al., 1991
NCSOIL Model	Molina et al., 1983
OBM Model	Esser, 1990
PHOENIX Model	McGill et al., 1981
SIB Model	Sellers et al., 1986
TEM Model	Raich et al., 1991
Box Model	Box, 1988
Frissel and van Veen Model	Frissel and van Veen, 1981; van Veen and Paul, 1981; van Veen et al., 1984
Gildea et al. Model	Gildea et al., 1986
Jenkinson and Raymer Model	Jenkinson and Raymer, 1977; Jenkinson 1990, Jenkinson et al., 1991
Moore et al. Model	Moore et al., 1981
Oeschger et al. Model	Oeschger et al., 1975
Smith Model	Smith, 1979

Table 2.5 List of soil carbon models reviewed

as impacted by cultivation practices were simulated for a 10,000 year run. The results indicate that weathering of mineral P and S from the parent material is the primary source of soil P and S, in contrast to soil N where greater than 95% is found in the organic form. The primary source for soil N is atmospheric deposition and biological fixation. The C:N ratio for SOM was reported to be fairly constant and "varying C:P and C:S ratios as a function of the available soil P and S levels is an important aspect of the model and allows it to simulate the impact of different levels of available P and S on the cycling of P and S in the soil".

Schimel et al. (1990) studied grassland biogeochemistry and its link to atmospheric processes. Model simulations obtained using the CENTURY model adequately represented the observed geography of C and N. It was stated that "increases in temperature and associated changes in precipitation caused increases in decomposing and long-term emission of CO_2 from grassland soils". The release of nutrients through the loss of organic matter resulted in increased net primary production. This conclusion demonstrates the fact that nutrient interactions play a major role over vegetation response to climate change.

Attribute
Sponsoring Agency
Simulation Time Step
Rainfall/Runoff Analysis
Erosion
Soil Hydrologic Balance
Soil Moisture
Soil Temperature Capability
Soil Processes (Carbon, Nitrogen, Phosphorus, Sulphur)
Fertilizer Input Capability
Tillage/Residue Management Capability
Cropping Practices Capability
Crop Type Capability
Crop Growth Simulation
Available on Microcomputer
Data and Staff Requirements
Output Options (CO_2, N_2O, CH_4)
Overall Model Complexity

Table 2.6 Evaluation criteria and capabilities for comparison of soil carbon models.

Paustian et al. (1992) performed model analyses using the CENTURY model for studying the influence of organic amendments and N-fertilization on SOM in long-term plots. Changes in soil C and N after 30 years were predicted within $\pm$ 30% of observed values. External organic matter input either increased or maintained the SOM levels; however, a decrease in SOM was observed when crop roots were the only source of fresh organic matter. The N losses simulated were 7 to 20% of total N inputs and the N balances calculated by the model were in close agreement with observed data.

A GIS system along with the CENTURY model was used for regional modeling of grassland geochemistry (Burke et al. 1990). The driving variables for the model consisted of soil texture, monthly precipitation, and monthly minimum and maximum temperatures which were included in the GIS system. Net primary production was affected primarily by climatic factors and it closely followed spatial variation in precipitation. However, it was reported that SOM is controlled by soil texture.

DNDC Model -

Li et al. (1992a) developed a physical based model called DNDC (Denitrification Decomposition Model) for estimating nitrous oxide (N_2O) and dinitrogen (N_2) evolution from soils. The submodels included in the model are thermal-hydraulic flow, decomposition and denitrification. The model calculates dynamic soil temperature and moisture profiles, and estimates shift of

aerobic-anaerobic conditions in soils using climatic data of rainfall events and air temperature. The dominant processes between rainfall events are the decomposition of organic matter and the oxidation reactions. These processes affect levels of total organic carbon, soluble carbon and nitrate in soils between rainfall event. However, during rainfall the dominant process is that of denitrification resulting in production of nitrogenous gases of N_2O and N_2. The major input data requirements for the denitrification-decomposition (DNDC) consist of climatic scenario, soil texture and its properties, and initial organic matter and nitrate in soil. The DNDC model can aid in estimating the following (Li, 1992a):

1) Effects of changing organic C in soil on emissions of CO_2 and N_2O from soils.

2) Rate of carbon accumulation in soils, based of current residue inputs, and both physical and chemical soil properties.

3) Soil management changes affecting accumulation rates of carbon, and emissions of CO_2 and N_2O from soils.

4) Effects of climate change (monthly average air temperature and precipitation) on carbon accumulation rates, and CO_2 and N_2O emissions from soils.

Li et al. (1992b) conducted sensitivity and simulation analyses using the DNDC model, which provided the following conclusions:

1) Increasing denitrifier biomass from 0.0001 to 1 kg C/ha results in slight increases in N_2O emission; also, there is a gradual increase in N_2 emission.

2) During rainfall events, the soluble carbon increases and the change in denitrification rate depends on NO_3^- content in soils.

3) If soil NO_3^- is low (1 mg N/kg) then even with a 5000-fold increase in soluble carbon (simulated condition), there is a little increase in denitrification. However, if soil NO_3^- is high (100 mg N/kg), then denitrification increases significantly with increasing soluble carbon.

4) Decreasing soil pH gradually decreases denitrification value to 0 kg N/ha at pH of 3.75.

5) Denitrification rate increases when soil temperature increases from 0 to 30°C and decreases sharply between 30 and 40°C.

6) N_2O emissions increase as in soil profile thickens and then stabilize at a constant value after which there is no effect of soil thickness. This "effective" soil thickness depends on the duration of rainfall and is reported to be less than 20 cm if rainfall duration is not longer than 20 hours.

7) A linear increase in N_2O emission occurs with increasing rainfall duration.

8) Soluble carbon concentration is highly depend on initial organic carbon and residue content in soil.

9) The trends and magnitude of simulated N_2O emissions are consistent with the results obtained in field experiments.

Li et al. (1992c) applied the DNDC model for estimating N_2O emissions from fallow, grass and sugarcane fields at Belle Glade, FL. Good agreement was reported between simulated and observed results of N_2O emissions, nitrogen mineralization rates, and changes in nitrate and ammonium at soil surface. High emissions of N_2O were observed following rainfall events; however, rainfall was not only the factor controlling N_2O emissions. Emissions also depended on nitrate concentration distribution in the soil profile. Soil surface NO_3 concentrations were inversely related to rainfall as they decreased with rainfall and gradually increased after rains ceased. The following conclusions were noted in regards to vegetation and the way it affects N_2O emissions:

1) Higher canopy interception will decrease denitrification.

2) A decrease of nitrate content due to plant uptake and an increase in soluble carbon resulting from root secretion will change the ratio of N_2O to N_2 emitted in soil.

Jenkinson and Rayner Model -

Jenkinson and Rayner (1977) developed a model to simulate the behavior of SOM that was divided into five fractions. These fractions consisted of decomposable plant material (DPM), resistant plant material (RPM), biomass (BIO), humified organic matter (HUM) and inert organic matter (IOM). The model assumes that each fraction contains a single species that undergoes biological decomposition by the first-order process. On a monthly basis, the addition of plant carbon from crop residues is represented by the DPM and RPM fractions. In the model, the organic carbon inputs are assumed to enter the DPM or the RPM pools, which decompose forming CO_2, microbial biomass, and humified organic matter. It is assumed that, for all soils, the ratio of microbial biomass to humified organic matter remains the same during biological activity. In the model, decomposition of humified organic matter by biological activity results in CO_2, microbial biomass, and residual humified matter. The inert component does not undergo any transformation during biological activity.

The model has been validated on Rothamsted soils for organic carbon content and total N content in the top 23 cm of soil. Good correlation between observed data and simulated results is reported. The current model (Jenkinson, 1990) was also validated for both organic carbon and microbial biomass contents, and simulated and observed results were in good agreement.

Frissel and van Veen Model -

Frissel and van Veen (1981) developed an N transformation model based on four stages of organic matter transformation. The stages used in the model are:

1) C/N ratio controls mineralization and immobilization.

2) Consideration was made for differences in decomposition rates of organic compounds in plant residues for amino acids, cellulose, lignin fractions and microbial mass (in this stage the authors assumed that the organic matter decomposition is controlled by C uptake by the biomass rather than the C/N ratio).

3) N transformations were incorporated into a multi-layer soil model.

4) SOM fractions were incorporated into the C and N pool.

The model was based on the assumption that SOM can be represented by several carbon and nitrogen pools. The biomass growth rate was controlled by the carbon availability from the added soil pool, and it was assumed that there was no change in the microbial population if no carbon was added to the soil. Nitrogen immobilization was proportional to biomass growth and it was assumed that mineralization occurred simultaneously and independently of immobilization. The authors used the C/N ratio to characterize mineralization and immobilization. They assumed that if the C/N ratio was less than 20 to 30, then net mineralization occurs; otherwise, net immobilization occurs.

OBM Model -

Esser (1990) developed the Osnabruck Biosphere Model (OBM) to simulate global terrestrial sources and sinks of CO_2 with special reference to soil organic matter. The model is grid-based and estimates the influences of "(i) the rising atmospheric CO_2 level, (ii) the temperature change due to greenhouse effect, and (iii) the clearing of forests and other natural vegetation, on the development of the biospheric pools, the SOC, and the atmospheric CO_2" (Esser, 1990). Model simulations for the period of 1860-1980 and for 1980 only were performed. Five conclusions were drawn from the study:

1) The effect of CO_2 fertilization is very important.

2) The landuse database should be improved to reflect changing landuse practices.

3) SOC pool can be predicted using the simple assumption that the lignin fraction of litter contributes to SOC.

4) SOC losses after clearing are sufficiently predictable considering the reduced net primary productivity of field crops.

5) The effects of landuse changes and clearings on SOC and litter are, on a global scale, compensated by the CO_2 fertilization effect.

The model results have not been validated with independent data.

NCSWAP Model -

Clay et al. (1985) developed the NCSWAP (Nitrogen Carbon Soil Water and Plant) model for estimating nitrogen and carbon transformations in soils. NCSWAP calculates dynamics of carbon and nitrogen organics, ammonium, and nitrate that result from the processes of residue decomposition, mineralization, immobilization, nitrification and denitrification. The model divides the active soil organic phase in two dynamic pools, one labile and one resistant. These pools are defined by their kinetic rate constants and are handled separately in the model, each decomposing exponentially. A variable is introduced in the model that determines whether residue decomposition results in N mineralization or immobilization.

The soil moisture is modeled using the Green-Ampt infiltration equation, and the model also accounts for redistribution of water in the soil profile. Subroutines to calculate soil temperature and plant growth are also included in the model. The model results are in good agreement with observed data.

TEM Model -

Raich et al. (1991) developed the grid-based Terrestrial Ecosystem Model (TEM) to simulate the C and N pool sizes and fluxes at continental to global scale using soils, vegetation, and climate data to predict net primary productivity. The dimensions of each grid are 0.5^0 latitude by 0.5^0 longitude. The model assumes that vegetation and detritus is distributed homogeneously within grid cells. Each grid cell is classified by vegetation type and soil texture. The model simulates interactions among terrestrial ecosystems and environmental variables at continental or global scales using a monthly time step. Nutrient pools are divided into five state variables: carbon in living vegetation, nitrogen in living vegetation, organic carbon in detritus and soils, organic nitrogen in detritus and soils, and available inorganic nitrogen. The model includes all dead plant material in the soil pool and all living plant material (roots, shoots, and leaves) in the vegetation pool.

2.4.2 Other Models and Inter-Model Comparisons

McCracken (1991) also provides a review of computer models that aid in determining carbon dioxide release into the atmosphere. The models reviewed were those by Aber et al. (1982), Jenny (1980), Pastor and Post (1986). The author concluded from modeling results and

observations that "soil N levels are correlated with soil organic C, statements made for C tend to apply also to soil N". This conclusion is in agreement with Stevenson's (1986) findings.

Models developed by Box (1988), Gildea et al. (1986), Moore et al. (1981), and Smith (1979) were also reviewed, details of which are provided in Barnwell et al (1991). The Box model (Box, 1988) is a spreadsheet type model that estimates global CO_2 fluxes under varying climatic and soil conditions. Gildea et al. (1986) developed a model to estimate terrestrial nitrogen loadings that can be used with an aquatic nutrient cycling model. The purpose of the Moore et al. model (1981) is to estimate annual net exchange of carbon between terrestrial ecosystems and the atmosphere. Smith (1979) developed a general model to simulate the C, N, P, and K dynamics in soils.

A comparison of the models reviewed is presented in Table 2.7. All the models reviewed simulate the simultaneous C and N cycles in soils except OBM, Box, and Moore et al. which only simulate the C cycle, and the Gildea et al. model which only simulates the N cycle. All of the models reviewed were developed for the purpose of research and, except for CENTURY, no application of the models other than by the developers was found. This raises a question as to whether the models can be used effectively by others. From the group of the models reviewed, the CENTURY and Jenkinson and Rayner models have undergone the most field testing and validation to date.

To study the carbon sequestration potential of various agricultural production systems it is important that the models allow simulations of various crops and cropping practices under various soil and climatic conditions. All of the models account for the type of crop grown; however, only CENTURY, DNDC, NCSWAP, and Gildea et al. models allow simulation of varying cropping practices. Soil moisture and temperature play an important role in transformation reactions that affect C and N storages in soils. All the models include the effects of varying soil moisture on C and N cycles; however, the same is not true for soil temperature effect, which is ignored in the Jenkinson and Rayner, Box, and the Gildea et al. models. As crop growth consumes nitrogen and respires CO_2 during growth, it is important that the models account for crop growth with relation to changing C and N storages in soils.

Information regarding model availability to general users, data requirements, and model complexity is incomplete for many models, and is often difficult to obtain due to limited documentation. However, from the models reviewed, the CENTURY, DNDC, Jenkinson and Rayner, Frissel and van Veen, and the NCSWAP models standout as candidate models that can aid in evaluating the carbon sequestration potential as they account for changing soil-crop-climate systems. Potential model users need to obtain more detailed information regarding data requirements and availability, model code availability, and system requirements in order to assess their ultimate utility for evaluating alternative agricultural production systems.

Table 2.7 Comparison of Soil Carbon Model Features

Attribute/Model	CENTURY	DNDC	Jenkinson & Rayner	Frissel & van Veen
Model Developer	Colorado State Uni.	Bruce Company	Rothamsted Experiment Station	Research Institute Wageningen
Simulation Time Step	Monthly	Daily	Monthly	?
Rainfall/Runoff Analysis	Yes	Yes	Yes	Yes
Irrigation Application	Yes	Yes	?	?
Erosion	Yes	No	No	No
Soil Hydrologic Balance	Yes	Yes	Yes	Yes
Soil Moisture	Yes	Yes	Yes	Yes
Soil Temperature	Yes	Yes	No	Yes
Soil Processes				
Carbon	Yes	Yes	Yes	Yes
Nitrogen	Yes	Yes	Yes	Yes
Phosphorus	Yes	No	No	No
Sulphur	Yes	No	No	No
Fertilizer	Yes	Yes	Yes	?
Tillage/Residue Management	Yes	Yes	Yes	Yes
Cropping Practices	Yes	Yes	No	No
Crop Type	Yes	Yes	Yes	Yes
Crop Growth Simulation	Yes	Yes	No	No
Available on Microcomputer	Yes	Yes	Yes	?
Data and Staff Requirements	Low	Medium	?	?
Output Options				
CO_2	Yes	Yes	Yes	?
N_2O	Yes	Yes	?	?
CH_4	No	No	No	No
Validation Status	Medium	Low	Medium	Low
Overall Model Complexity	Medium	Medium	?	?

Table 2.7 (cont'd.)

Attribute/Model	OBM	NCSWAP	TEM	BOX
Model Developer	General Ecol. Group, F.R.G. Osnabruck	Uni. of Minnesota St. Paul, MN	Ecosystem Center Marine Bio. Lab. Woods Hole, MA	Uni. of Georgia Athens, GA
Simulation Time Step	?	Daily	Monthly	Monthly
Rainfall/Runoff Analysis	Yes	Yes	Yes	Yes
Irrigation Application	?	Yes	?	?
Erosion	No	?	Yes	No
Soil Hydrologic Balance	Yes	Yes	Yes	Yes
Soil Moisture	?	Yes	Yes	Yes
Soil Temperature	?	Yes	?	No
Soil Processes				
Carbon	Yes	Yes	Yes	Yes
Nitrogen	No	Yes	Yes	No
Phosphorus	No	No	No	No
Sulphur	No	No	No	No
Fertilizer	?	Yes	?	?
Tillage/Residue Management	Yes	Yes	?	No
Cropping Practices	No	Yes	?	No
Crop Type	Yes	Yes	Yes	Yes
Crop Growth Simulation	No	Yes	Yes	No
Available on Microcomputer	?	?	?	?
Data and Staff Requirements	?	?	?	?
Output Options				
CO_2	?	Yes	?	Yes
N_2O	No	No	?	?
CH_4	No	No	No	No
Validation Status	Low	Low	Low	Low
Overall Model Complexity	?	?	?	?

Table 2.7 (cont'd.)

Attribute/Model	Gildea et al.	Moore et al.	Smith
Model Developer	Univ. of New Hampshire	Univ. of New Hampshire	ORNL Oak Ridge Tennesse
Simulation Time Step	?	?	?
Rainfall/Runoff Analysis	Yes	?	Yes
Irrigation Application	?	No	?
Erosion	No	No	No
Soil Hydrologic Balance	Yes	?	Yes
Soil Moisture	?	?	Yes
Soil Temperature	No	?	Yes
Soil Processes			
Carbon	No	Yes	Yes
Nitrogen	Yes	No	Yes
Phosphorus	No	No	No
Sulphur	No	No	Yes
Potassium	No	No	Yes
Fertilizer	Yes	No	Yes
Tillage/Residue Management	Yes	No	Yes
Cropping Practices	Yes	No	?
Crop Type	Yes	Yes	Yes
Crop Growth Simulation	No	No	Yes
Available on Microcomputer	?	?	?
Data and Staff Requirements	?	?	?
Output Options			
CO_2	No	Yes	Yes
N_2O	?	No	?
CH_4	No	No	No
Validation Status	Low	Low	Low
Overall Model Complexity	?	?	?

2.4.3 Closure

The focus of the literature search and model review was the identification and documentation of available soil carbon models, and their abilities to investigate soil carbon budgets, transformation, and pathways in agroecosystems, and impacts of tillage and cropping practices on the soil carbon cycle. The initial evaluation reduced the number of 'candidate models' to four or five primary models that were further investigated. Unfortunately, essentially all existing models are primarily 'research models' in that few have undergone more than limited field testing and validation. One of the key issues in the selection of a model for this study was to provide a level of model complexity (and associated data requirements) that was consistent with the project needs **and** was compatible with the national level databases available (discussed in the next section) for providing the model input. As a result of this assessment, the CENTURY model was selected as the primary tool for use and/or modification to meet the needs of representing soil carbon cycles in agroecosystems and impacts of management practices. The DNDC model was selected for application to limited portions of the Study Region as a consistency check of the soil process representation. Section 5.0 describes the development of the modeling framework and methodology to define the agricultural production systems and scenarios (i.e., crop-soil-climate combinations) to be assessed, the integration of the model needs with available databases, and the operational mechanics of evaluating carbon sequestration potential with the integrated model/database system.

SECTION 3.0

MODELING METHODOLOGY FOR SOIL CARBON SEQUESTRATION

In order to effectively use one or more models to assess the soil carbon sequestration potential of agricultural regions of the United States, a **framework or methodology** was needed to address issues of model integration, data needs and availability, temporal and spatial scales of analysis, detail of representation of agricultural practices, and associated technical model application questions. This section provides the integration of these concerns in the form of the overall **project methodology** that was followed to assess both current conditions of soil carbon, and SOC, in agricultural systems, and projected changes. Changes were evaluated under a continuation of current conditions (i.e., status quo) and selected alternative futures derived from policy changes. Individual components of the methodology are discussed in subsequent sections. Section 4.0 describes the component databases and data analyses performed in support of the methodology. Section 5.0 discusses our approach to modeling agricultural production systems and the various scenarios we analyzed to project future changes in SOC. Section 6.0 describes the preliminary results and conclusions from application of this methodology.

3.1 INTRODUCTION

In Section 1.0 the overall operational strategy for the study was discussed in terms of the high-level integration of models, databases, and their linkage for assessment of policy impacts on agriculture and resulting soil carbon levels. Figure 3.1 shows the expanded 'modeling box' of the high-level assessment strategy flowchart (Figure 1.2). As noted earlier, the objective of the study was to estimate the greenhouse gas emissions and C sequestration potential of agricultural production systems, and the impact of various policy alternatives designed to reduce emissions by increasing soil C levels.

The modeling system shown in Figure 3.1 includes four primary components:

- Resource Adjustment Modeling System (RAMS) to provide baseline cropping practices and changes in practices as impacted by policy alternatives,
- CENTURY and DNDC soil models to provide unit-area (i.e., per hectare) changes in soil carbon and greenhouse gas emissions for each designated agricultural production system,
- EPA Agroecosystem Carbon Pools database developed by CSU and MSU to provide field site data for model testing and validation, and

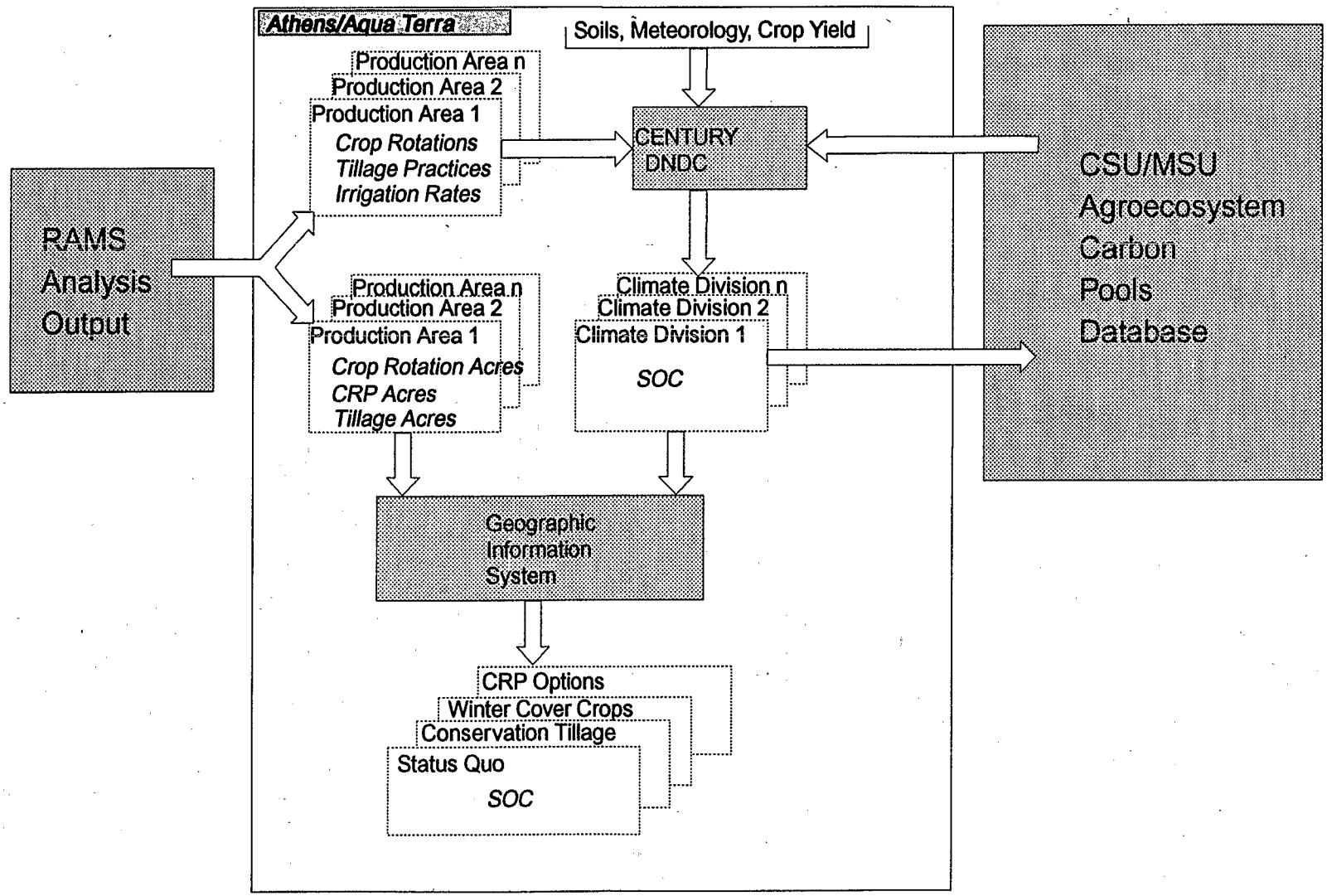


Figure 3.1 Modeling system for assessment of agricultural carbon sequestration

- GIS capabilities to integrate the unit-area soil C and emission values with cropping acreages for display and analysis of impacts of baseline and policy alternatives.

The results of the soil carbon model review described in Section 2 led to the selection of the CENTURY and DNDC models for use in the modeling component of the study. Although soil carbon/soil organic matter models are still largely 'research-type' tools, these two models have been applied and tested on a variety of sites throughout the world, and have shown an acceptable degree of success in reflecting observed soil data. However, both models needed further refinement in this project to represent the range of crops, cropping/tillage practices, and crop rotations common to U.S. agriculture. Furthermore, the CENTURY model was the primary soil model used in the methodology because of its greater execution efficiency, validation experience, and flexibility in representing complex production systems; the DNDC model provided a more mechanistic simulation of the nitrogen cycle to allow consistency checks with the CENTURY model results for selected scenarios in selected sections of the Study Region.

A number of critical issues needed to be resolved in order to develop an effective and reasonable methodology for assessing SOC levels -- past, current, and future -- as impacted by all aspects of agricultural production systems and the variability of soils and climate characteristics. Agricultural production systems needed to be defined in terms of crops, rotations, tillage, chemical inputs, etc., in a manner consistent with the CENTURY model. Soil and climate data needed to be transformed to a level of spatial and temporal detail consistent with the spatial detail of the assessment. Since the RAMS and CENTURY models were both part of the integrated methodology, differences in spatial scales needed to be considered in establishing the appropriate scale for the assessment. In order to estimate **future changes** to soil carbon in agroecosystems, we needed to know the **current status** as impacted by past cropping practices, tillage, historical yields, etc., as a baseline condition.

Following discussions of the component models in the next two sub-sections, the remaining portions of Section 3 discuss the specific details of the 'Project Methodology' including the critical issues identified above.

3.2 CENTURY AND DNDC MODELS - OVERVIEW AND TESTING

3.2.1 CENTURY Model Overview

As noted in Section 2.0, Parton et al. (1988) developed the CENTURY model to simulate the dynamics of C, N, P, and S in cultivated and uncultivated grassland soils. Recent model refinements have resulted in the Agroecosystem Version 4.0 of CENTURY to better represent complex cropping patterns, rotations, and management practices (Metherell et al., 1993). The model uses monthly time steps for simulation, and model runs can be performed for time periods ranging from 10 to 10,000 years. The model is composed of five organic matter pools, two represent litter or crop residues and three represent SOM. The fresh organic matter, which includes plant material and animal manure, is divided into metabolic and structural litter

fractions, depending on its lignin:nitrogen ratio. The SOM is divided into three fractions: 1) an "active" fraction that has a rapid turnover rate (1-5 years) and consists of microbial biomass and metabolites; 2) a "slow" fraction with an intermediate turnover time (20-40 years) that represents stabilized decomposition products; and 3) a "passive" fraction that represents the highly stabilized, recalcitrant organic matter (200-1500 years turnover).

In the model, soil moisture is calculated as a function of the ratio of monthly precipitation (plus irrigation) to monthly evapotranspiration, and soil water movement is calculated using a simple piston flow formulation. The soil temperature term is calculated as a function of average monthly soil temperature for the 20-cm soil layer surface. First-order rate constants depending on soil temperature and moisture are used to represent the decomposition rates. The other factors that affect the organic matter transformation include soil texture and the lignin content of the litter. This lignin content of the litter pool influences the relative amount of the structural material that is assimilated by microorganisms (transferred to active pool) or gets incorporated into the slow pool. The soil texture influences the relative amount of decomposing organic matter that is either mineralized to CO_2 or enters the slow pool as decomposition products.

The carbon cycle, as represented in CENTURY, is depicted in Figure 3.2, and Figure 3.3 shows the associated nitrogen cycle. The carbon that is released due to decomposition gets partly mineralized and the remaining gets added as a decomposition product to one or more organic matter pools. The carbon flow dictates the release of nitrogen, as nitrogen is considered to be mainly in C-bonded forms. The C:N ratios of materials entering the soil organic pools are used to calculate the mineralization and immobilization of N. The model allows the representation of C:N ratios of the material entering the organic pool to be constant or to vary at specified time intervals. If the N content of decomposition products entering a given pool is less than the minimum required for the recipient pool, then mineral N is immobilized, and conversely if organic N content is in excess, then that amount is mineralized. The model uses simple equations to represent N inputs by atmospheric deposition and through plant and soil fixation. The losses of N forms represented include leaching, gaseous losses, crop removal, and erosion. The CENTURY model has submodels for estimating plant growth and soil water balance. These submodels provide information on plant litter inputs and climatic variables for SOM computations. Plant growth is expressed as a function of a potential growth rate moisture, temperature, shading and seedling modifiers. The potential plant growth rate is used to calculate the crop nutrient demand. If nutrient availability is insufficient to satisfy nutrient demand, then the crop production is reduced accordingly. The soil water content is calculated as a function of the ratio of monthly precipitation (plus irrigation and stored water) to monthly potential evapotranspiration. Options in the model allow the user to either specifically define fertilizer and irrigation applications, or direct the model to calculate (and satisfy) the plant nutrient and moisture needs based on user-defined criteria, e.g., fraction of optimum production or moisture deficits at which irrigation is initiated. These options are discussed in more detail in Section 5.0.

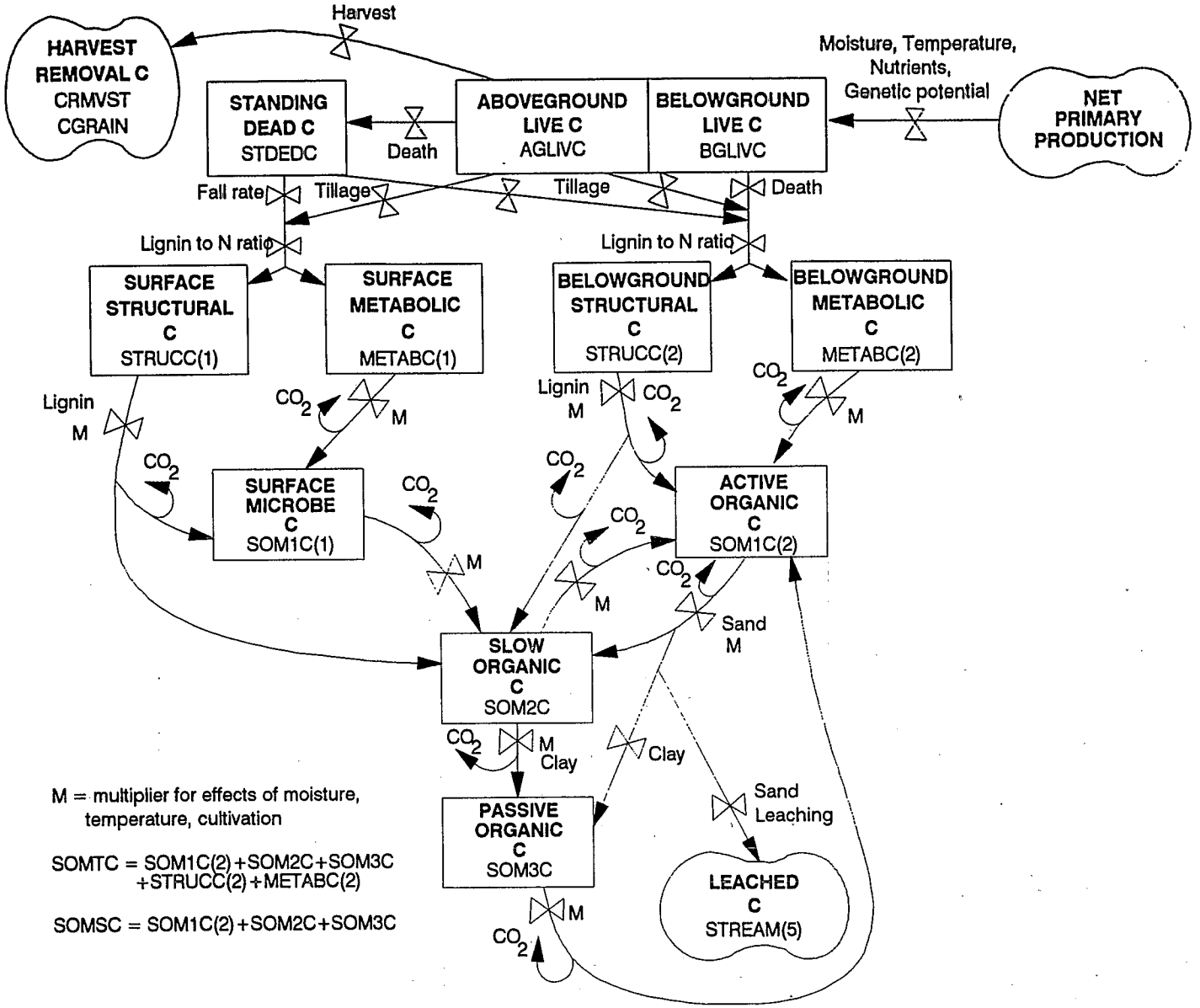


Figure 3.2 Flow diagram for the CENTURY soil organic C submodel (Agroecosystem Verson 4.0, from Metherell et al., 1993)

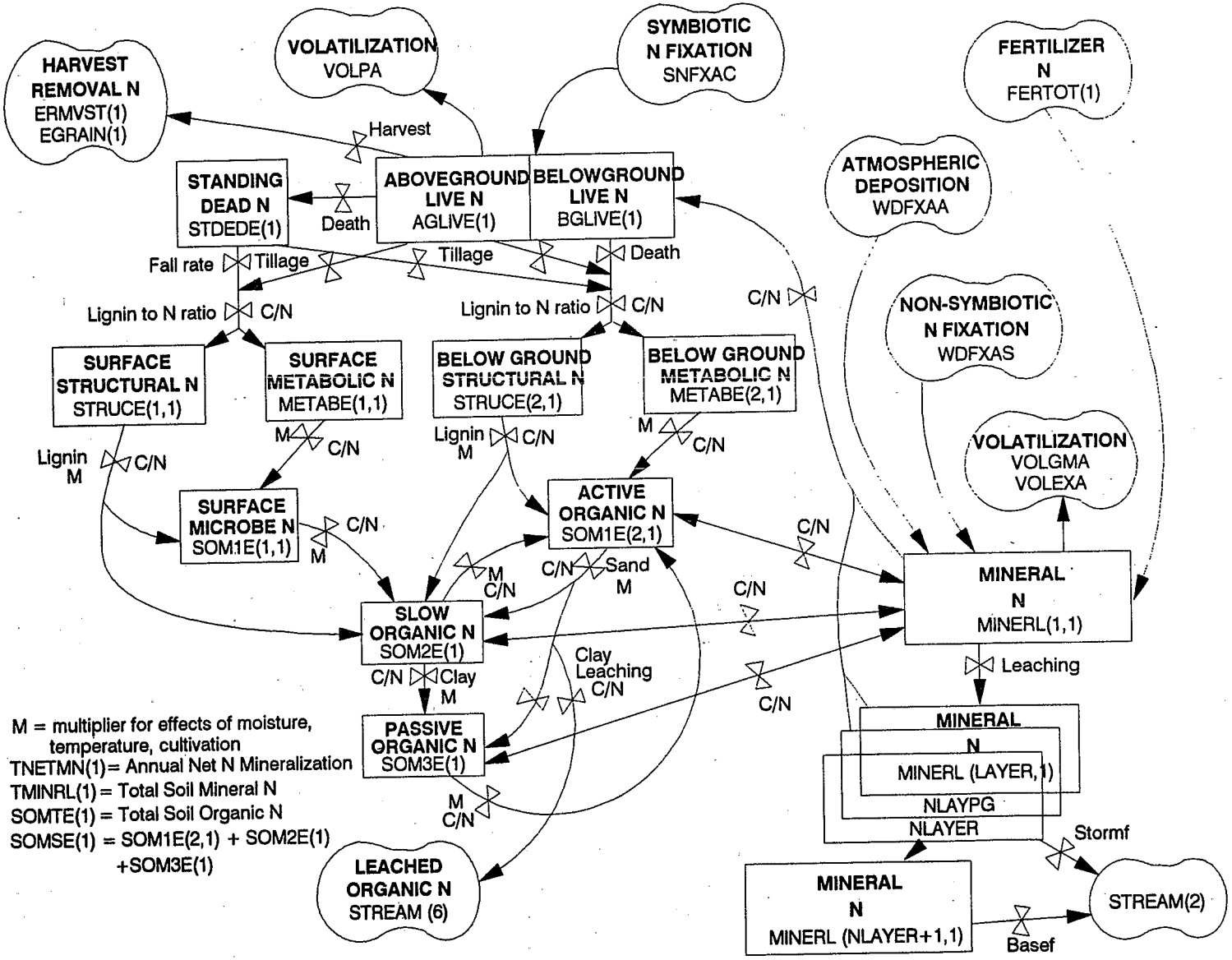


Figure 3.3 Structure and state variables for the CENTURY N submodel (Agroecosystem Version 4.0, from Metherell et al., 1993

3.2.2 CENTURY Model Testing and Application

Much of the model testing to date has been done on grassland and wheat systems. The CENTURY model has been validated by Parton et al. (1987) by simulating steady state C and N levels and aboveground plant production for 24 sites in the Great Plains. The simulation results were compared with mapped plant production and soil C and N levels for fine, medium, and sandy textured soils. The authors found that the model overestimated the C and N soil levels for fine textured soils, underestimated for sandy soils, and did an excellent job for medium textured soils. The effect of soil texture and climate on the soil C and N levels in the Great Plains was adequately represented by the model. The model results of aboveground plant production were in excellent agreement with the observed values.

Schimel et al. (1990) studied grassland biogeochemistry and its link to atmospheric processes. Model simulations obtained using the CENTURY model adequately represented the observed geography of C and N. It was stated that "increases in temperature and associated changes in precipitation caused increases in decomposing and long-term emission of CO_2 from grassland soils". The release of nutrients through the loss of organic matter resulted in increased net primary production. This conclusion demonstrates the fact that nutrient interactions play a major role over vegetation response to climate change.

Paustian et al. (1991) have used the model to study the influence of organic amendments and N-fertilization on SOM. Schimel et al. (1990) used the CENTURY model to study grassland biogeochemistry and its link to the atmospheric processes. Burke et al. (1990) used CENTURY coupled with a geographic information system to study the spatial variability in storage and fluxes of C and N within grassland ecosystems. The model has also been used by Cole et al. (1989) to study the effects of SOM dynamics in the North American Great Plains. Parton et al. (1989) used the CENTURY model to simulate the regional patterns of soil C, N, and P dynamics in the U.S. central grasslands.

In the current study, CENTURY model capabilities in the Agroecosystem Version 4.0 for representing additional crops (e.g., legume hay and soybeans), complex cropping patterns and multi-year crop rotations were added (Metherell et al., 1993), and additional model testing was performed. Appendices A and B, respectively, describe CENTURY testing efforts on a wheat-fallow rotation field site in Sydney, NE, and a continuous corn (with winter cover crop) site in Lexington, KY. An additional test site for a corn-soybean rotation in Kanawha, IA was also selected but data availability precluded completion of the testing for this study.

The additional model testing has shown that CENTURY can adequately represent soil carbon levels as impacted by tillage practices, nitrogen fertilization levels, and cover cropping practices, all of which are significant needs for the current study. Further model testing and development is needed to improve the soil nitrogen cycle representation and its impacts on crop yields; see Appendices A and B for further details on the CENTURY model testing.

3.2.3 DNDC Model Overview

Li et al. (1992a) developed the physically based Denitrification Decomposition (DNDC) model for estimating nitrous oxide (N_2O) and nitrogen (N_2) evolution from soils. The submodels included in the model represent thermal-hydraulic flow, decomposition and denitrification. The model calculates dynamic soil temperature and moisture profiles, and estimates shift of aerobic-anaerobic conditions in soils using climatic data of rainfall events and air temperature. The dominant processes between rainfall events are the decomposition of organic matter and the oxidation reactions. These processes affect levels of total organic carbon, soluble carbon and nitrate in soils between rainfall events. However, during rainfall the dominant process is that of denitrification resulting in production of nitrogenous gases of N_2O and N_2. The major input data requirements for the denitrification-decomposition (DNDC) consist of the climatic scenario, soil texture and its properties, and initial organic matter and nitrate in soil. The DNDC model can aid in estimating the following (Li, 1991a):

1) Effects of changing organic C in soil on emissions of CO_2 and N_2O from soils.

2) Rate of carbon accumulation in soils, based on current residue inputs, and both physical and chemical soil properties.

3) Soil management changes affecting accumulation rates of carbon, and emissions of CO_2 and N_2O from soils.

4) Effects of climate change (monthly average air temperature and precipitation) on carbon accumulation rates, and CO_2 and N_2O emissions from soils.

Li et al. (1992b) applied the DNDC model for estimating N_2O emissions from fallow, grass and sugarcane fields at Belle Glade, FL. Good agreement was reported between simulated and observed results of N_2O emissions, nitrogen mineralization rates, and changes in nitrate and ammonium at the soil surface. High emissions of N_2O were observed following rainfall events; however, rainfall was not the only factor controlling N_2O emissions. Emissions also depended on the nitrate concentration distribution in the soil profile. Soil surface NO_3 concentrations were inversely related to rainfall as they decreased with rainfall and gradually increased after rains ceased.

As evident by its name, DNDC was designed primarily to represent the nitrogen cycle and simulate N emissions. Thus, much of the model testing to date has focused on N emissions, although sites in Germany (uncultivated grass) and Missouri (fertilized winter wheat) for CO_2 emissions were included in the initial model testing (Li et al., 1992b). As part of this study, testing was performed on additional field sites world-wide, including the 150-year records of the well-known Rothamsted Experimental Station in England, and the model results were generally consistent with the observed data (Li, C., personal communication, 1992).

3.3 RAMS MODEL OVERVIEW

The Resource Adjustment Modeling System (RAMS) was developed in 1990 by the Center for Agricultural and Rural Development (CARD) at Iowa State University. RAMS is a regional, short-term, static, profit maximizing, linear programming model of agricultural production defined at the producing area (PA) level. The function of RAMS is to provide quantitative estimates of optimal levels of production activities. It is assumed that those performing the production activities are trying to maximize profits while being constrained by technology, government policy, and the resource base (e.g. land). Considerable detail of the technology and policy environments of crop production at the regional level makes RAMS a useful instrument for the analysis of policy changes at a disaggregated level. PA's are hydrological areas, adjusted to county boundaries, representing aggregated subareas defined by the U.S. Water Resources Council (1970). The areas are small enough so that the assumption of homogenous production across the area can be reasonably made. RAMS has been previously used to evaluate restrictions on the use of atrazine and other triazines in corn and sorghum production (Bouzaher et al., 1992). For this earlier use, RAMS was constructed to interface with plant and geophysical process models. For the present analysis RAMS is interfaced with the CENTURY and DNDC models. Information about production patterns and cropping systems is passed to these models. Such linking of environmental and economic realms generates a more comprehensive evaluation of policies designed to sequester carbon in agricultural soils.

RAMS is composed of 27 crop producing areas. Each region is assumed to be a separate decision-making entity with the model solved in each region independent of the outcomes in the others. The outline of the production regions forms the boundary for the Study Region (See Figure 3.4 and Section 3.4).

Cropping systems are characterized in the model by activities that specify crop rotation, tillage, contour management, and irrigation. Each activity is defined by a combination of the four dimensions. Table 3.1 lists the possibilities for each. Winter cover crops are a new addition to RAMS, and were added as part of this study to investigate carbon sequestration alternatives. Cover crops are included only for a subset of all crop sequences within each rotation. Furthermore, the subset depends on the geographic location of the PA. In general, the choice of crop sequences amenable to cover crops in any PA depends upon the time period in which cover crops can grow and the scarcity of moisture. The growing period for winter cover crops is greater following crops with earlier harvest dates and/or succeeding crops with early planting dates. Southern PA's typically have longer, and warmer, growing seasons allowing substantial growth of a winter cover crop. Some western PA's simply do not have enough water to support both a commodity and a winter cover crop (Cruse, 1992, personal communication).

RAMS also has a detailed weed control sub-sector. More than 400 chemical and mechanical weed control alternatives are specified. Each alternative consists of a tank-mix of chemicals, and details about how and when they are applied. A government commodity program sub-sector incorporates the major rules and provisions of commodity programs and conservation compliance from the Food, Agriculture and Trade Act of 1990 (FACTA)(House of Representatives, 1990).

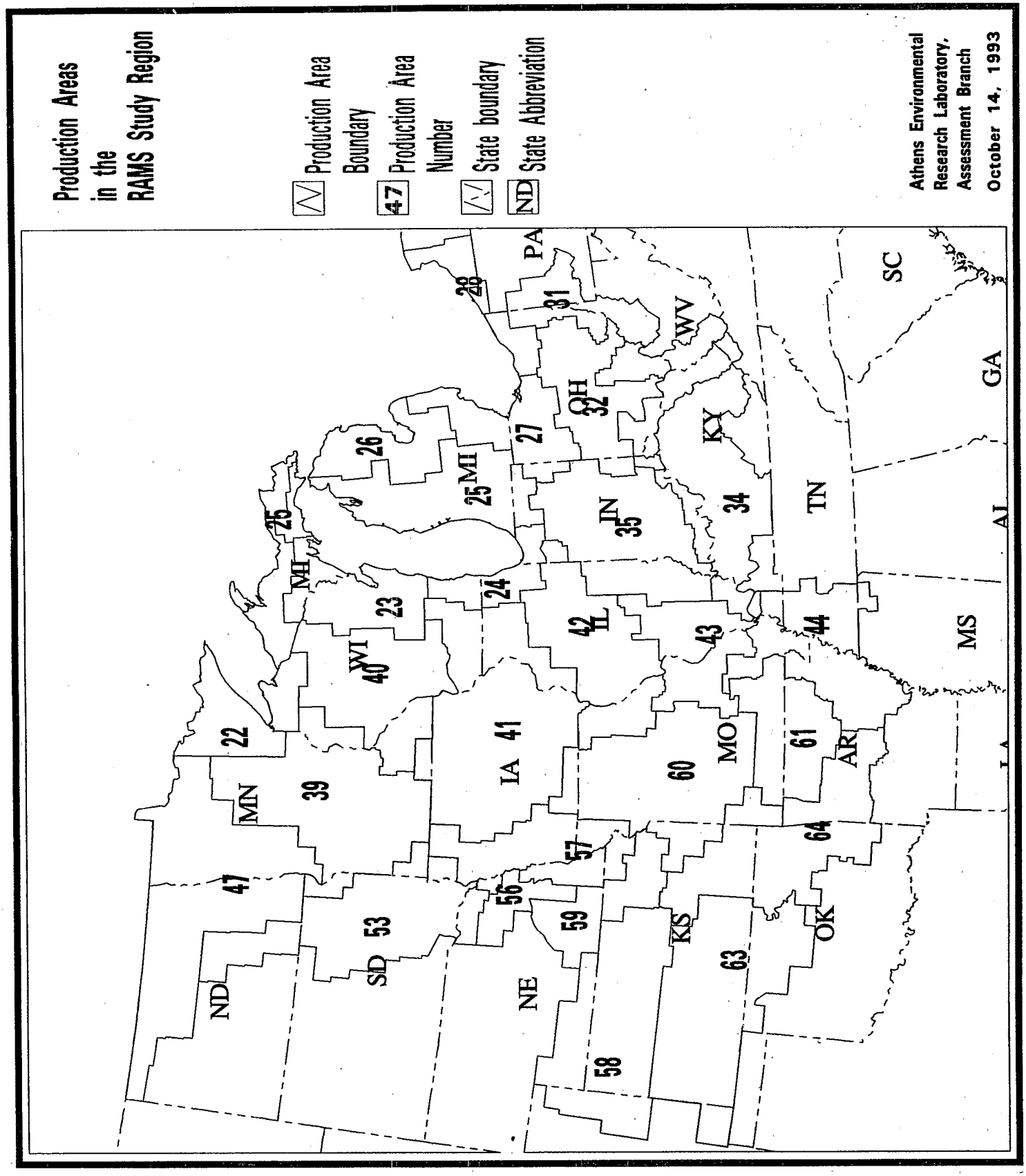


Figure 3.4 RAMS study region, production areas, and state boundaries

Table 3.1 Activities and Constraints in RAMS

Crop Production Activities

Defined by:

Rotation Management - ten to twenty-five rotations per PA

- up to 6 year rotation of following crops
  barley, corn, corn silage, cotton, non-legume hay, legume hay oats, peanuts, sorghum, sorghum silage, soybeans, sunflower, spring wheat, winter wheat
- rye or hairy vetch winter cover crops for designated crop sequences in some PA's

Tillage Management

- conventional till - fall plow
- conventional till - spring plow
- conservation (or reduced) till
- no-till

Contour Management

- straight row
- contouring
- strip cropping
- terracing

Irrigation Management

- dryland
- irrigated - surface water source
- irrigated - groundwater source

Other Activities

Weed Control Activities- one activity for each strategy (317 for corn, 98 for sorghum)

Strategies include one or more of following chemicals (generic names)

- atrazine, alachlor, metolachlor, propachlor, pendimethalin, EPTC, Butylate, cyanazine, simazine, dicamba, bromoxynil, 2,4-D, bentazon, glyphosate, nicosulfuron, primisulfuron

Commodity Program Activities

Single activity for Conservation Reserve Program

Deficiency payments and set-aside requirements for following program crops

- barley, corn, cotton, oats, sorghum, spring wheat and winter wheat

Crop Marketing Activities - for each crop grown

Resource and Institutional Constraints

- Single class of land available for production or idling under commodity programs
- Government commodity program participation base for each program crop
- Conservation Reserve Program enrollment base
- Seven levels of highly erodible land reflecting degrees of erodibility
- Calibration bounds on tillage, crop acres, and chemical use

The government commodity program activities simulate deficiency payments, along with set-aside and conservation compliance restriction, and land retirement from crop production under the Conservation Reserve Program. Commodity marketing activities are included, and resource and institutional constraints bound the profit maximizing solution in each PA.

The outcomes of the model include the indicators used to evaluate the economic costs and benefits as well as the production patterns, and choice of cropping systems, which are fed to the CENTURY and DNDC models. Primary economic indicators include net returns to production, acreage planted, tillage practices, rotations, erosion, and fertilizer and herbicide use. A more detailed description of RAMS can be found in Bouzaher et al. (1992).

3.4 INITIAL STUDY REGION AND PRODUCTION AREAS

Although the intent of the overall agroecosystem component of the EPA Climate Change study is to include **all** U.S. agriculture, the need to integrate both economic and policy implications with soil carbon modeling led to restrictions in the spatial scope of this initial effort. Consequently, this assessment was restricted to the RAMS Study Region shown in Figure 3.4; this region encompasses the traditional agricultural regions of the Corn Belt, the Lakes States, and portions of the Northern Plains. Approximately 216 million acres of cropland are included in the RAMS region, representing 60% to 70% of the total U.S. cropland, depending on specific definitions of harvested versus total cropland acres (USDA, 1992). In addition, the RAMS region is **25% of the continental United States**, and the **216 million cropland acres represents 44% of the entire Study Region.**

Also shown in Figure 3.4 are the RAMS 'Production Areas' (PAs) representing the basic spatial unit of analysis for the economic and policy analysis; typically the RAMS results are aggregated to state or some other political unit for analysis, or the results are summarized for the entire Study Region. These PAs are defined as hydrologic areas delineated by the U.S. Water Resources Council (1970), except that the boundaries are adjusted to conform to county boundaries, for aggregated economic reporting of various economic and agricultural statistics. The PA boundaries do not coincide with state boundaries, and there may be multiple PAs within a state. As noted earlier, the RAMS model performs its analysis on each PA producing aggregated crop yields, rotations, agronomic practices, and economic variables for the entire PA. The modeling of soil carbon and agricultural practices in this study required a finer spatial resolution based on climate and soils data; this is discussed in the sections below on the Project Methodology and in Section 4.0.

3.5 PROJECT METHODOLOGY

This section describes the modeling methodology developed to integrate the issues of spatial detail of the required data, modeling of agricultural practices, estimation of current or initial soil carbon conditions, and procedures for assessing alternative future conditions resulting from policy scenarios. An overriding concern throughout the work was to strike a balance between the number of combinations of soils, climate, crop rotations, tillage practices, and associated

model runs needed to adequately represent the heterogeneities of the study region, within the time and resource constraints of the assessment.

Figure 3.5 shows the basic steps in applying the methodology to the RAMS Study Region; these steps are discussed in more detail below:

1. Divide the Study Region into 'Climate Divisions' (CD) that can be represented with individual climate timeseries of the monthly precipitation and max/min air temperature needed by the models. The CD boundaries were defined to coincide with both Production Area (PA) and county boundaries to facilitate the transformations (i.e., aggregation/disaggregation) of cropping practice and soils data. Figure 3.6 shows the climate divisions along with PA and state boundaries. **The 'Climate Division' is the basic spatial unit of analysis for this study.** Section 4.0 describes the component climate and soils data bases, and the procedures and assumptions used to delineate the CD boundaries.

2. For each CD, identify the distribution of soil textures on the agricultural cropland. Section 4.2 describes how we used the NRI/SOILS5 database (Goebel, 1987) and the EPA DBAPE system (Imhoff et al., 1991) to determine the surface soil textural distributions for all counties in each CD for **six major textural groups**: sand/loamy sand, sandy loam/sandy clay loam, loam, silty loam, silty clay loam/silty clay, clay/clay loam.

3. For each CD, identify the primary crops/rotation/tillage (C/R/T) scenarios as defined by the RAMS output for the 'status quo' condition. The RAMS output identified 80 different rotations used in the Study Region; these were grouped into 35 rotations for modeling purposes, based on similarity of crops, cropping sequence, and modeling capabilities. Of the 35 rotations simulated, 13 represent almost 85% of the cropland in the Study Region; thus the primary rotation sequences are represented in the reduced list.

   The RAMS output for each PA (and each policy alternative) is transformed to a CD based on the ratio of 'county cropland' to 'PA cropland' and then aggregated for the specific counties in each CD (see discussion in Section 4.3).

4. Establish Initial Conditions (Current, i.e., 1988-90) for SOC (and other needed model variables) to be used for each C/R/T for each soil texture within each CD. Section 5.2 describes the procedure for this based on calibrating model results to historical crop yields from 1907 through 1988 for the major rotations and practices in each CD. Since SOC is a direct function of soil texture and historical practices (primarily crop yields and residue management) within a defined climate regime, it was necessary to evaluate these controlling factors in our estimation of initial SOC value for each CD.

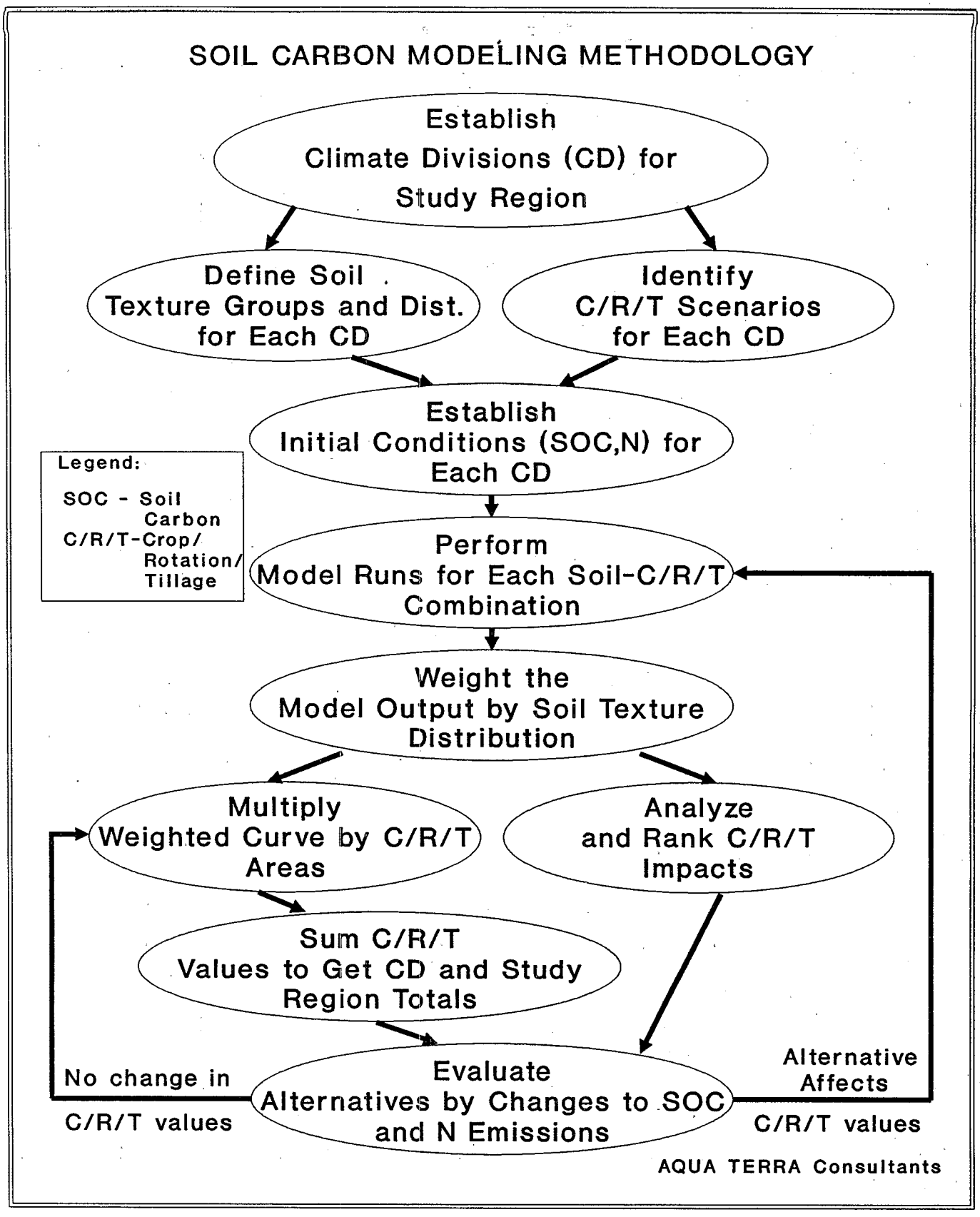


Figure 3.5 Soil carbon modeling methodology

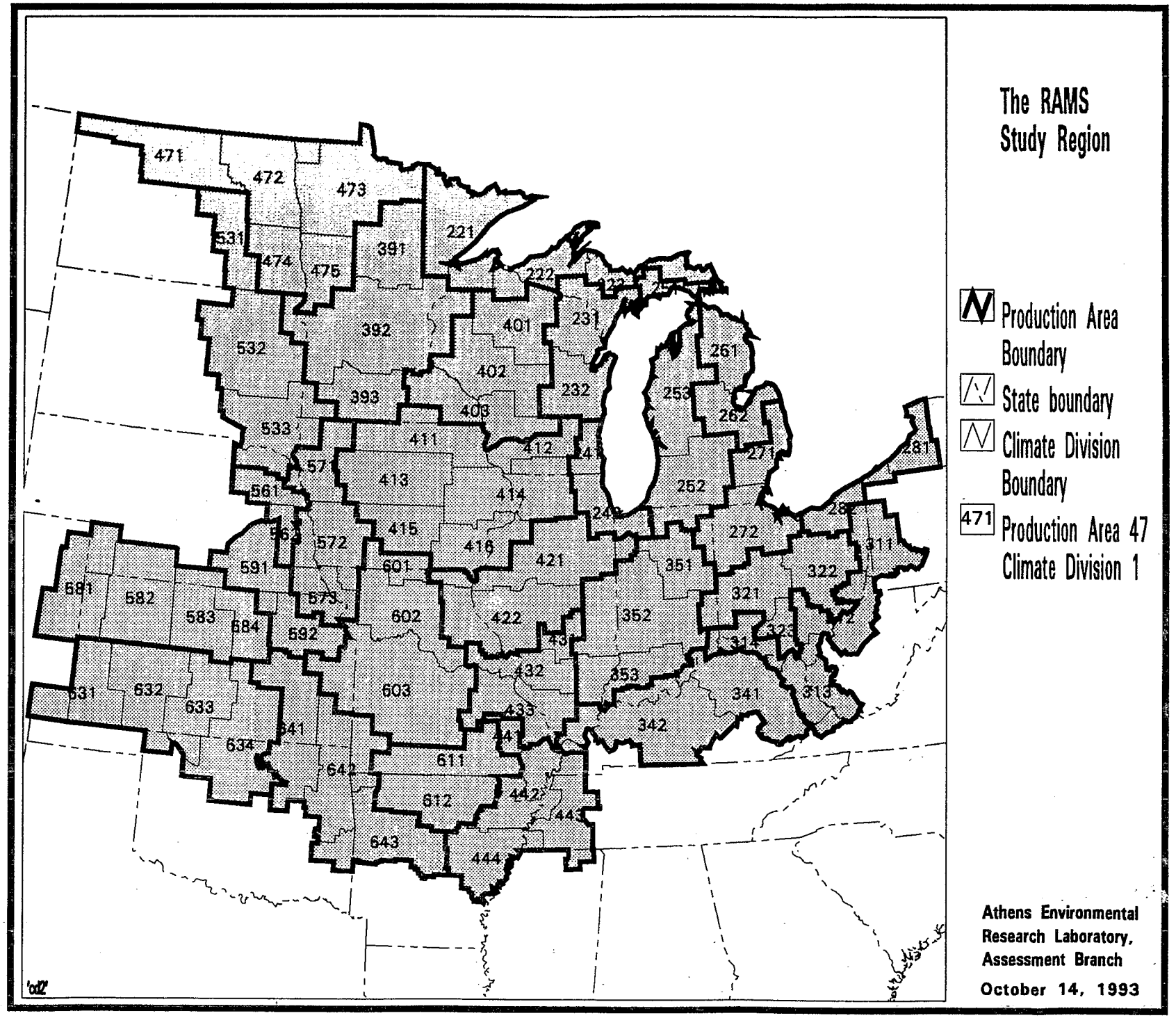


Figure 3.6 Production areas and climate divisions in the RAMS study area

5. For each CD, extend the historical CENTURY model runs (from Step 4, above) through the 40-year projection period of 1990-2030 for **each C/R/T and each soil texture group**, and output SOC (year-end values, gC/m^2) and N Emissions (annual total, $gN/m^2/yr$) for analysis. We also outputted and analyzed other model variables (e.g., yields, primary productivity, carbon inputs) to check the validity of the simulations in each CD.

   A key factor in the modeling of SOC during the projection period of 1990 to 2030 is the assumption of changes, primarily increases, in crop yields. Based on U.S.D.A. estimates derived from the deliberations of a group of agronomic and agricultural research experts, **an annual increase of 1.5% in yields was assumed** for each crop throughout the 40-year period (U.S.D.A., 1990). In addition, the impacts of alternative yield increase levels (i.e., 1.0%/year and 0.5%/year) were evaluated for region-wide impacts. The yield increase assumption has a critical impact on projected changes in SOC due to its impact on carbon inputs to the soil; higher yields will provide increased carbon inputs and increased SOC. This issue is discussed further in Section 5.0 where the assumptions for both baseline and alternative scenarios are presented.

6. Weight the output from each soil-C/R/T (CENTURY) run by the soil texture distribution for that CD to get one timeseries of SOC (and each other output variable) for each C/R/T within each CD. Figure 3.7 is an example for a CD in Iowa where a corn-soybean rotation was run for three soil textures and a weighted curve was developed.

7. For each CD, we then multiply the weighted curve (e.g., for SOC, gC/m^2; N emission, $gN/m^2/yr$) by the area for each C/R/T combination; these areas are provided by the RAMS output for each PA, which is transformed to a CD basis. The resulting values of SOC or N emissions for each C/R/T are then analyzed to determine the total SOC changes and N emissions for each CD. Since the projections are available for each year of the projection period, the analysis can be done on an annual basis, in 10-year increments (i.e., 1990-2000, 2000-2010, 2010-2020, 2020-2030), or for the entire 40-year period (i.e., 1990-2030).

   The totals for each CD are then summed to provide totals for the entire Study Region for the entire projection period or any subset thereof.

8. The evaluation of 'Status Quo' or baseline conditions, and comparison with each alternative scenario, is based on the relative impacts on SOC changes and N emissions. However, not all alternative scenarios require execution of new or additional model runs. Alternatives that simply change the acreages of the rotations (i.e., each C/R/T combination) do not require additional model runs; Step 7 would be repeated for each new set of rotation acreages, in a simple spreadsheet-type calculation. Alternatives that lead to changes in the individual

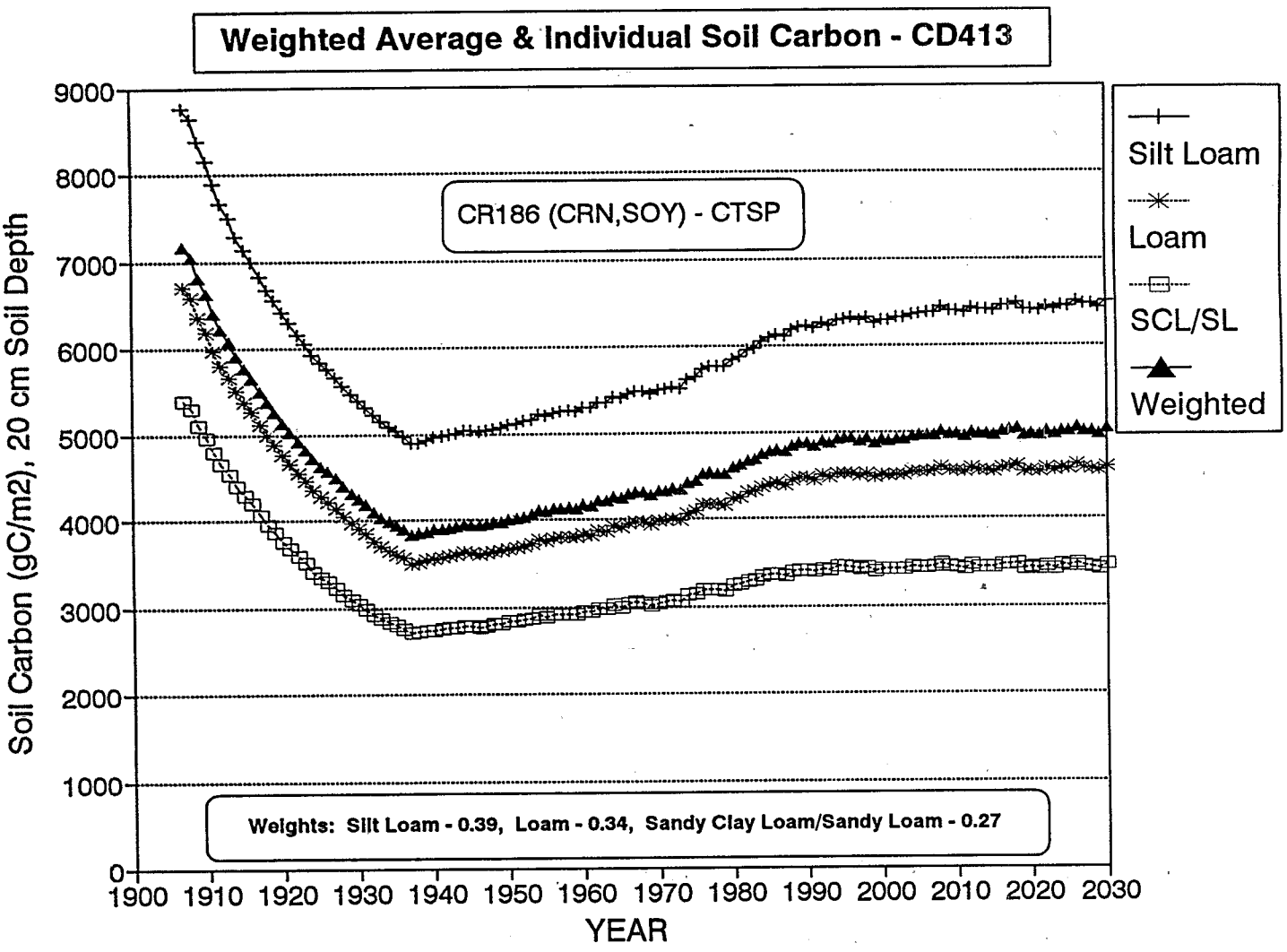


Figure 3.7 Weighted average and individual soil carbon

C/R/T curves (e.g., changes in tillage practices, new rotations, addition of cover crops) require new model runs, so Steps 5 through 7 are all repeated, along with calculation of the total SOC changes and N emissions.

Application of the methodology to the entire Study Region required an extensive effort in the development of the input data for soils, meteorology, and agricultural practices. Also, we needed to define the important components of agricultural production systems for both current baseline, or status quo, conditions, and for alternative future conditions resulting from selected policy mechanisms. The data base and model input development is described in Section 4.0, followed by the description of, and assumptions in, modeling agricultural systems with the CENTURY model, in Section 5.0, for the baseline and alternative scenarios.

SECTION 4.0

DATA BASES AND MODEL INPUT DEVELOPMENT

As part of the EPA BIOME Agroecosystems Assessment project, an extensive array of data bases and GIS coverages were identified, collected, and reviewed by the EPA-Athens staff, and implemented on their computer system for potential use in this study. The Interim Project Report (Barnwell et al., 1991) provides details of the climate, soils, land use/land cover, fossil fuels, energy, ecoregion, life zones, topography, vegetation, CO_2 emissions, and other data bases available at the EPA Athens Laboratory (Barnwell et al., 1991). This section focuses on the specific data bases used to develop input data needed by the soil carbon models, and manipulation of these data to derive selected model parameter values appropriate to the scale of the assessment. In this section, we discuss the sources and the manner in which we manipulated the climate, soils, agricultural (i.e., cropping, land use, practice), and crop yield data used in the modeling and project methodology.

4.1 CLIMATE DIVISIONS AND DATA BASES

The models require monthly values for maximum and minimum temperature (CENTURY), or average temperature (DNDC) and total precipitation. These values are usually provided to the models as historically recorded input from a user-supplied file. In addition, CENTURY can also stochastically generate precipitation data using historical mean and skewness values computed from a user-supplied file or input directly by the user. The goal of this task was to develop the appropriate temperature and precipitation timeseries for the models at a spatial scale that would allow consideration of climate variability throughout the Study Region, would not require excessive project resources, and would be consistent with the spatial resolution of the soils and agricultural practice scenarios.

A collection of historical climate data for the United States (Wallis et al., 1991) was used to obtain 41 years (1948-1988) of monthly maximum and minimum temperature and total precipitation data for 589 climate stations (CS) in and near the Study Region; Figure 4.1 shows the locations of the climate stations. These stations are operated by the National Oceanic and Atmospheric Administration (NOAA) and are a subset of the original 1036 stations for which daily data were provided by the authors on CD-ROM. From these daily data, average monthly maximum temperature and average annual precipitation values were derived for each of the stations. A Geographic Information System (GIS) was used to create contour maps of the annual temperature and precipitation data, as shown in Figures 4.2 and 4.3, respectively. The temperature contours (using 2°C contour intervals) and precipitation contours (with 10-cm

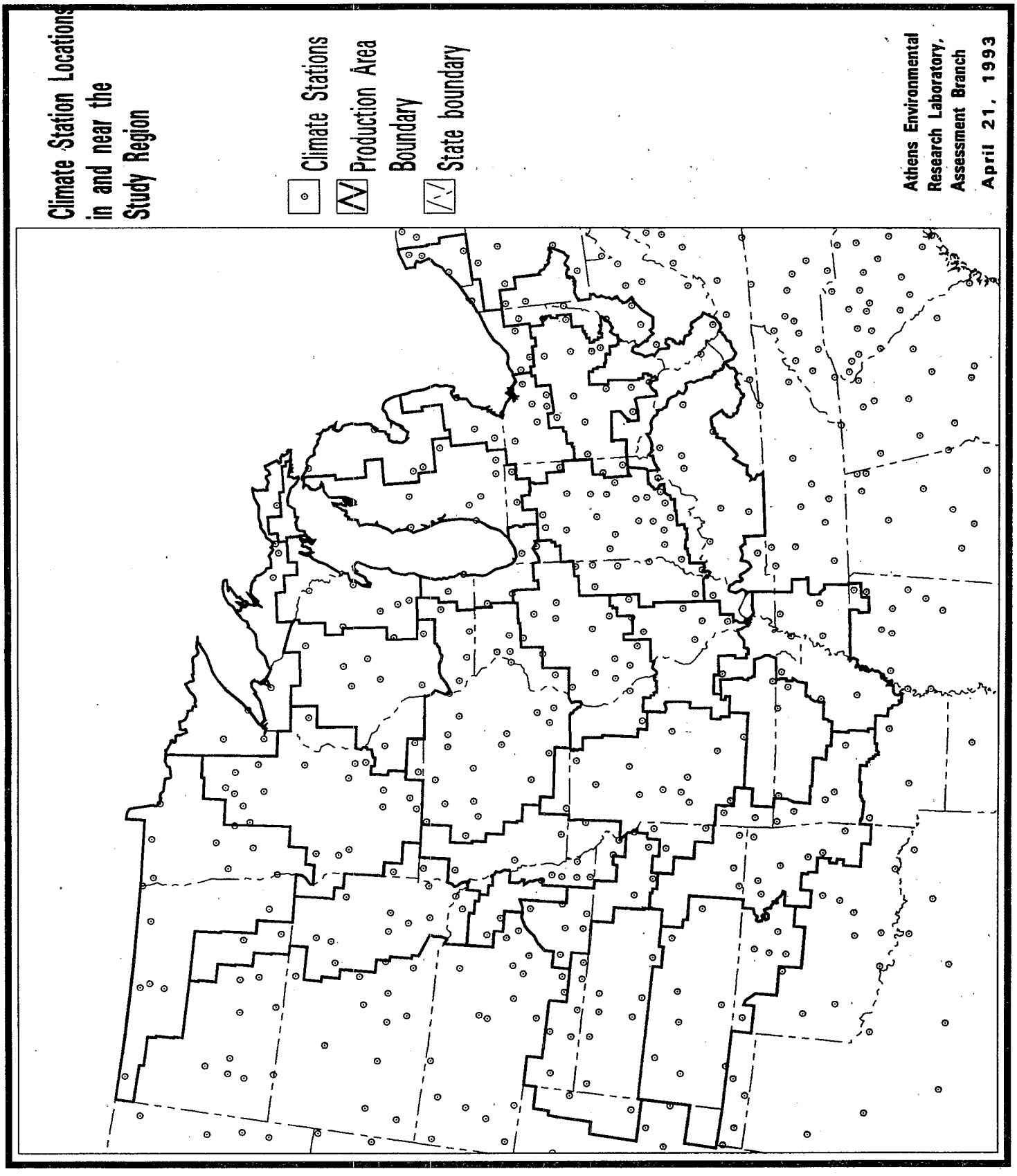


Figure 4.1 Climate station locations in and near the study region

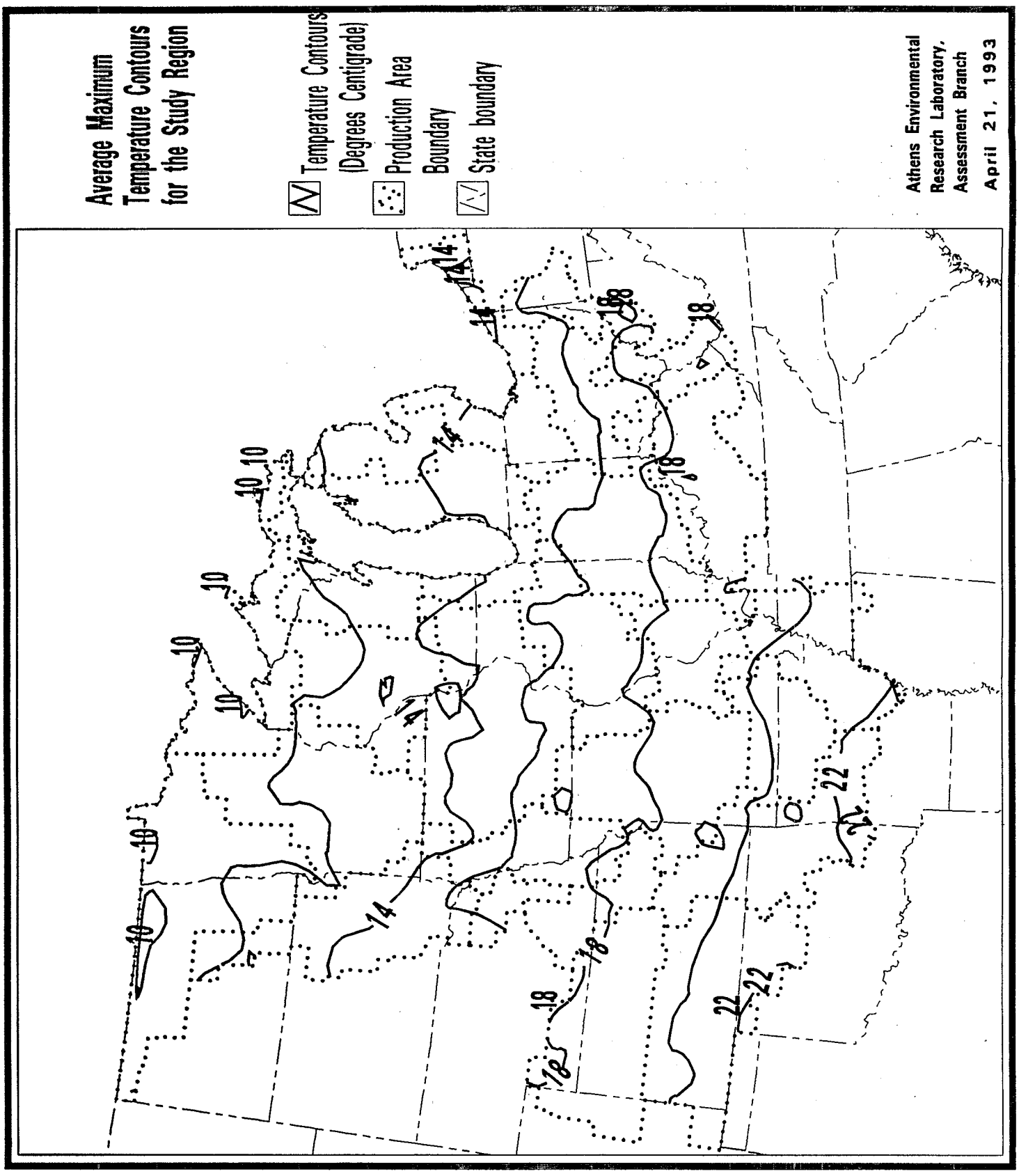


Figure 4.2 Average maximum temperature contours [°C] for the study region

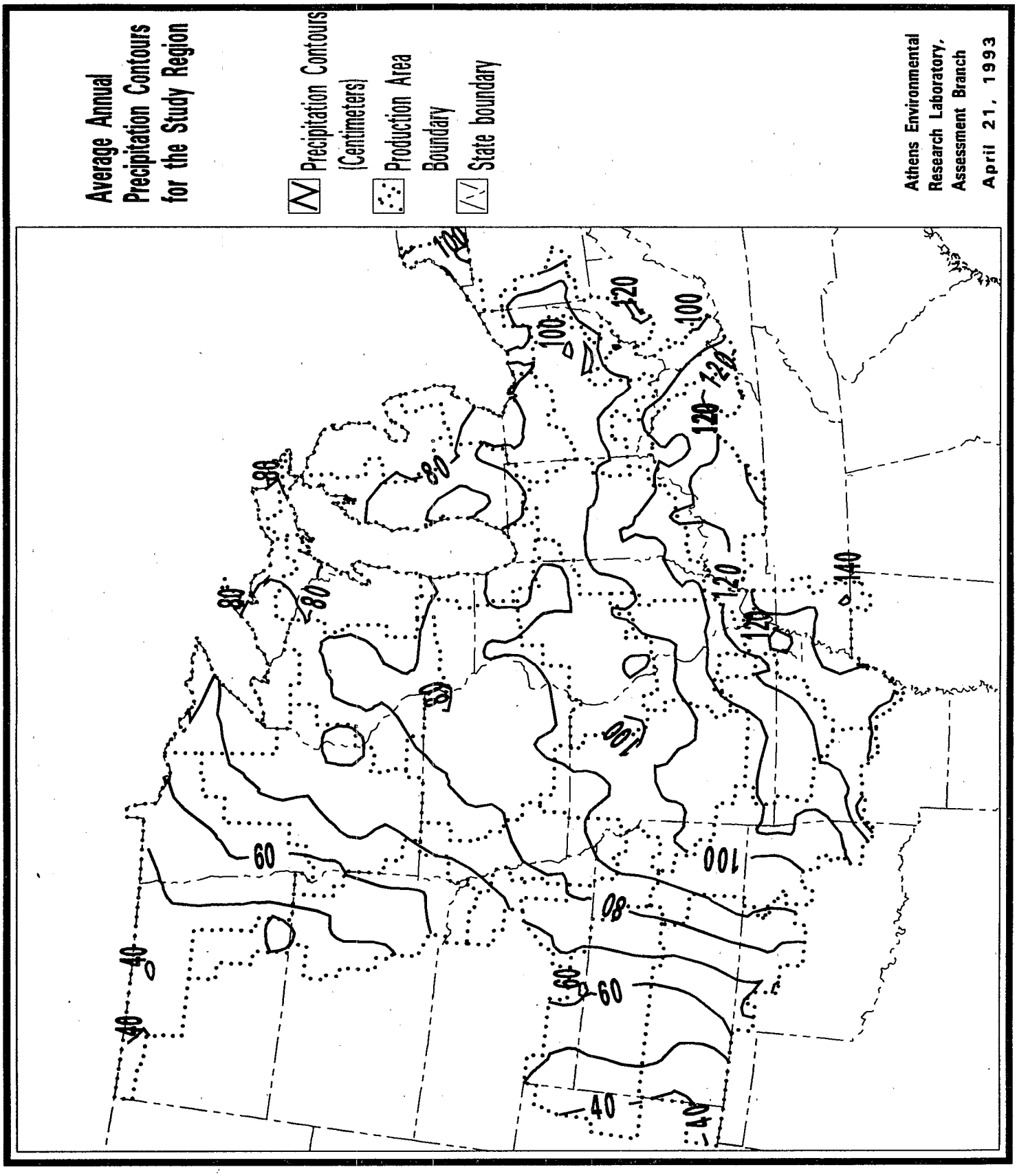


Figure 4.3 Average annual precipitation contours [cm] for the study region

contour intervals) were overlayed to produce areas of similar climate. Areas bounded by either type of contour were assumed to experience similar climate within the accuracy of the contour intervals. These values of 2°C temperature and 10-cm precipitation were derived from sensitivity analyses with CENTURY, recommendations and prior experience from the model authors (Burke et al., 1991), and prior experience in similar modeling investigations (Donigian and Mulkey, 1992).

The temperature and precipitation isopleths shown in Figures 4.2 and 4.3 were used to delineate the Climate Division (CD) boundaries, which were adjusted to coincide with county boundaries. This was done primarily to simplify analysis of the county-level soils data, and the allocation of the crop rotation and agricultural practice data from the PAs of the RAMS model to the CD. Direct overlay of the contours did identify subregions of similar climate; however, some of the regions were not contiguous and varied greatly in size and shape. Therefore, working from these GIS-created subregions, we altered the CD boundaries manually to follow and not cross PA boundaries. This resulted in each PA being divided into from two to six CDs, for a total of 80 CDs in the study region; Figure 4.4 shows the final CD boundaries, along with state and PA boundaries. As noted earlier, **the CDs are the basic spatial unit of analysis for this study.** They provide a reasonable compromise in spatial analysis between the detailed county-level soils data, the 589 CSs within the study region, and the relatively large PAs which supply the basic driving factors of the assessment.

To create a single climate data set for each CD, data from multiple CSs were averaged. Initially, all of the CSs that fell within the boundary of a CD were allocated to the CD for data averaging. However, when a CD did not encompass any CSs, or when their number and/or locations were not geographically representative of the entire CD, one or more additional nearby CSs were manually assigned to the CD to improve the basis for calculating the needed climate timeseries. For each CD the average of the monthly climate values from each of the allocated CSs was saved in a single file for input to the models.

Table 4.1 shows the minimum, maximum, average and standard deviations of the climate variables for the 41-year period for each CD in the Study Region. The precipitation values are derived from the average annual values of the CSs assigned to each CD for the 1948-1988 period. The minimum (MIN) and maximum (MAX) values are those of the CSs with the lowest and highest annual values that are assigned to the CD, while the average (AVE) and standard deviation (STD) are calculated from all the CS annual averages. The MAX-MIN column in Table 4.1 represents the range of average annual precipitation values calculated as the difference of the MAX and MIN columns (with some round off).

The temperature values are calculated in an analogous fashion based on average maximum monthly temperatures calculated from the daily temperatures for each CS for the 41-year period. Thus, in Table 4.1, the MIN column is the lowest maximum temperature and the MAX column is the highest maximum temperature for the CSs assigned to the CD. The AVE and STD columns are the statistics of average maximum values for the CSs, and the MAX-MIN column is the range within the CD.

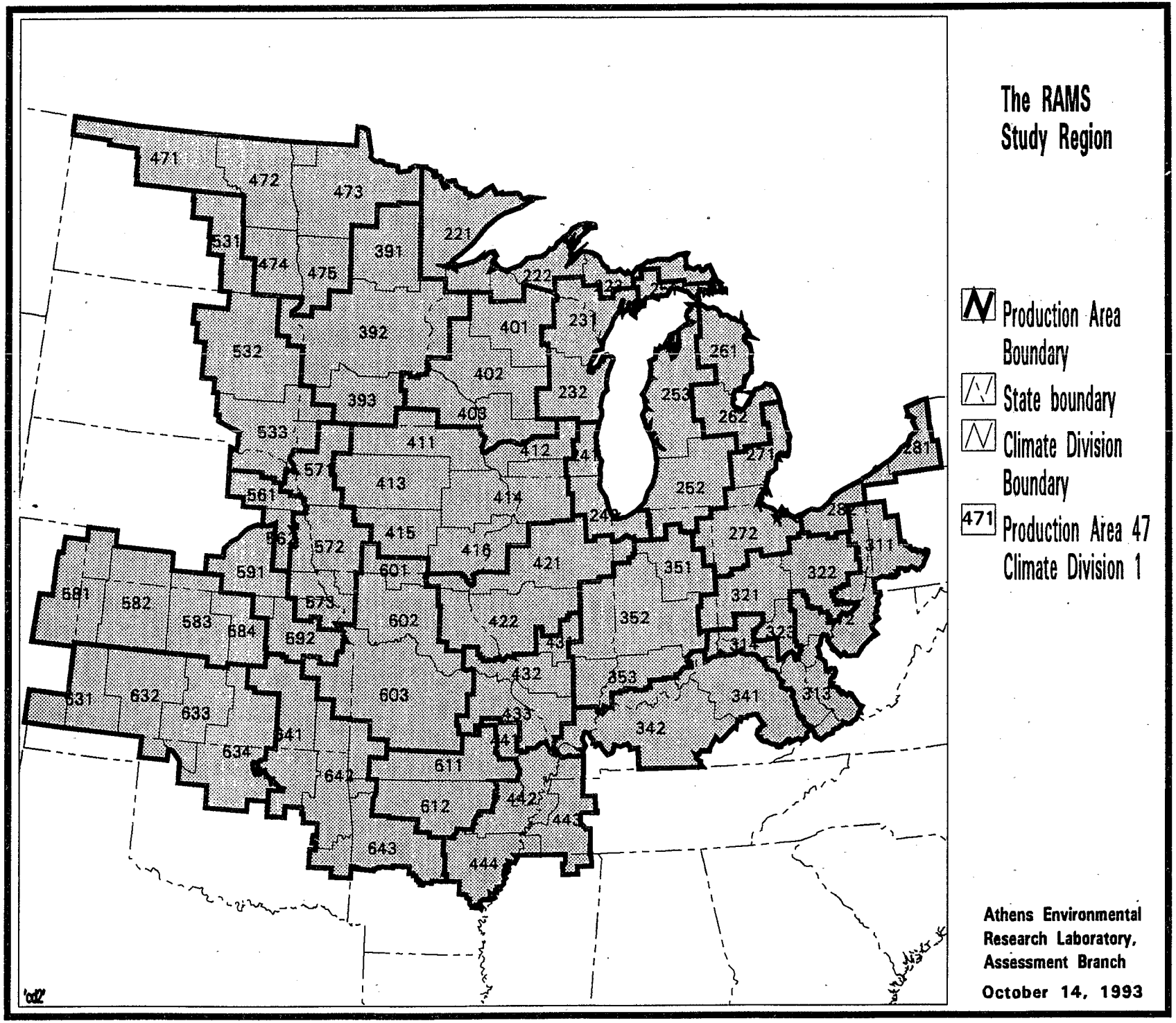


Figure 4.4 Climate division boundaries for the study region

Table 4.1 Statistics of Climate Variables for all Climate Divisions

	PRECIPITATION (cm)					MAXIMUM TEMPERATURE (°C)				
CD#	MIN.	MAX.	AVE.	STD.	MAX-MIN	MIN.	MAX.	AVE.	STD.	MAX-MIN
221	70.0	77.7	74.8	3.6	7.6	10.0	11.5	10.8	0.6	1.5
222	77.7	80.4	79.2	1.4	2.8	10.9	11.5	11.2	0.3	0.6
223	80.4	89.6	85.0	4.2	9.1	10.3	11.3	10.9	0.4	1.0
231	75.6	80.7	78.5	2.6	5.1	11.7	12.7	12.1	0.5	1.0
232	74.4	77.6	75.9	1.4	3.2	13.0	13.5	13.2	0.3	0.5
241	82.3	87.4	84.3	2.8	5.2	13.4	14.0	13.6	0.3	0.6
242	89.9	91.9	91.1	1.1	1.9	14.8	15.9	15.2	0.6	1.1
251	71.5	89.6	81.3	9.1	18.0	10.3	11.7	11.0	0.7	1.4
252	75.8	95.4	89.9	5.9	19.6	13.8	15.3	14.4	0.5	1.5
253	71.5	87.8	81.2	8.6	16.3	11.7	13.4	12.8	1.0	1.7
261	71.5	76.4	74.0	3.5	4.9	11.7	12.6	12.2	0.7	0.9
262	76.4	77.6	77.1	0.6	1.2	12.6	14.1	13.5	0.8	1.5
271	74.7	83.8	78.3	4.8	9.0	12.6	14.7	13.6	1.0	2.0
272	85.5	95.3	91.2	3.0	9.8	14.8	15.9	15.3	0.4	1.1
281	90.8	111.7	99.8	8.8	20.9	13.3	14.1	13.7	0.4	0.8
282	87.8	104.9	97.5	7.9	17.2	13.4	15.8	14.8	1.1	2.4
311	91.1	101.1	96.8	3.8	10.0	15.6	17.2	16.1	0.7	1.7
312	95.6	113.6	106.2	7.6	18.0	17.6	18.0	17.8	0.3	0.5
313	102.7	110.7	105.1	3.7	8.0	18.1	20.0	18.7	0.9	1.9
314	103.5	109.9	106.3	3.1	6.4	16.6	18.2	17.4	0.7	1.6
321	90.9	103.5	96.5	5.5	12.6	15.6	17.2	16.0	0.6	1.5
322	90.1	103.6	96.6	5.8	13.5	14.7	17.5	16.3	1.0	2.8
323	95.6	107.8	101.9	5.2	12.2	16.6	18.2	17.6	0.7	1.6
341	108.5	118.6	113.2	4.1	10.1	17.6	19.0	18.5	0.5	1.4
342	115.0	126.7	120.5	5.5	11.7	18.9	19.8	19.3	0.4	0.9
351	94.7	96.9	95.8	1.0	2.3	15.2	15.8	15.6	0.3	0.6
352	92.9	110.7	103.0	5.6	17.8	16.1	18.0	16.8	0.6	1.9
353	107.9	120.1	113.2	3.8	12.2	17.6	18.7	18.2	0.3	1.1
391	64.1	71.0	68.3	2.4	0.9	10.8	11.9	11.3	0.4	1.1
392	61.3	77.0	70.1	5.9	15.7	11.6	13.1	12.5	0.5	1.5
393	72.0	76.7	73.9	2.2	4.7	12.7	14.0	13.3	0.6	1.3
401	74.2	81.8	78.7	3.2	7.6	11.1	12.3	11.6	0.6	1.2
402	74.2	84.0	79.5	4.4	9.8	12.3	14.0	12.9	0.8	1.7
403	75.3	80.7	79.0	2.5	5.4	13.1	15.2	14.0	0.9	2.1
411	73.1	85.5	79.2	4.2	12.4	12.2	14.0	13.4	0.6	1.8
412	80.5	83.5	82.4	1.7	3.0	13.8	14.2	14.0	0.2	0.4
413	76.4	85.5	80.9	3.8	9.1	13.8	15.0	14.5	0.5	1.2
414	85.7	91.5	88.6	2.1	5.9	14.2	15.6	14.9	0.6	1.4
415	84.2	91.0	87.1	3.0	6.8	14.7	16.3	15.6	0.8	1.6
416	84.5	92.1	89.5	3.1	7.6	15.6	16.4	16.1	0.3	0.8
421	87.9	95.1	90.9	2.4	7.2	15.5	16.6	16.0	0.4	1.1
422	88.3	100.8	95.6	3.9	12.5	16.9	18.3	17.4	0.5	1.4
431	99.2	101.3	100.4	1.1	2.1	17.1	18.0	17.5	0.5	0.9
432	99.8	106.8	103.5	3.4	6.9	17.6	19.1	18.3	0.7	1.5
433	105.9	122.2	111.6	9.1	16.2	18.9	19.1	19.0	0.1	0.2
441	113.7	122.2	118.0	6.1	8.6	19.5	20.6	20.0	0.7	1.1
442	120.3	126.1	122.5	2.5	5.7	19.0	21.1	20.3	0.9	2.1
443	131.1	132.9	132.1	0.9	1.9	19.5	21.8	20.5	1.0	2.3

Table 4.1 (contd.)

	PRECIPITATION (cm)					MAXIMUM TEMPERATURE (°C)				
CD#	MIN.	MAX.	AVE.	STD.	MAX-MIN	MIN.	MAX.	AVE.	STD.	MAX-MIN
443	131.6	132.9	132.1	0.9	1.9	19.5	21.8	20.5	1.0	2.3
444	126.1	132.9	129.9	2.7	6.9	20.5	22.5	21.7	0.9	2.0
471	36.7	44.4	40.8	3.2	7.8	9.9	11.6	10.9	0.8	1.7
472	46.2	58.5	50.2	5.7	12.3	9.7	12.0	10.5	1.0	2.3
473	51.5	68.7	59.0	6.2	17.1	9.9	12.0	10.9	0.8	2.1
474	44.3	55.3	49.7	5.5	11.0	12.0	12.8	12.4	0.4	0.7
475	55.3	62.9	59.5	3.3	7.5	10.8	12.5	11.7	0.7	1.7
531	41.6	52.4	46.1	5.6	10.7	11.4	13.0	12.1	0.8	1.6
532	46.1	55.5	51.2	4.5	9.4	12.2	14.6	13.7	0.9	2.4
533	55.2	66.8	62.4	3.8	11.6	13.0	16.2	15.1	1.1	3.2
561	64.1	78.9	68.6	6.9	14.8	15.6	16.3	16.0	0.3	0.6
562	67.1	77.7	74.1	4.8	10.6	16.3	17.3	16.6	0.4	0.9
571	68.2	78.9	74.1	4.6	10.6	13.4	16.1	14.7	1.3	2.7
572	78.9	90.0	84.2	5.3	11.2	16.1	17.2	16.8	0.4	1.0
573	84.9	94.4	88.5	4.6	9.4	17.3	18.3	17.8	0.4	1.1
581	39.2	48.6	44.2	3.9	9.5	17.8	19.3	18.7	0.7	1.5
582	52.2	59.1	55.3	2.9	6.9	18.2	19.4	18.7	0.5	1.1
583	57.1	70.4	63.1	5.3	13.3	18.0	19.5	18.7	0.7	1.5
584	66.6	85.1	74.8	8.1	18.5	17.1	19.5	18.3	1.1	2.5
591	69.9	77.7	74.8	2.8	7.9	16.3	17.3	17.0	0.3	0.9
592	85.1	99.4	92.8	6.3	14.4	18.2	18.8	18.5	0.3	0.6
601	85.6	92.0	89.5	3.5	6.4	16.0	16.3	16.2	0.2	0.4
602	88.3	99.8	94.2	5.8	11.5	17.0	17.9	17.5	0.4	1.0
603	94.8	107.1	101.6	4.3	12.2	17.7	20.1	19.0	0.7	2.4
611	107.1	122.2	114.1	6.2	15.2	18.8	20.6	19.8	0.8	1.7
612	113.2	126.1	119.2	6.3	12.8	20.2	21.1	20.8	0.4	0.9
631	38.1	48.5	42.8	4.3	10.4	19.8	21.3	20.5	0.7	1.5
632	51.7	69.9	59.2	7.9	18.2	19.8	22.3	20.6	1.2	2.5
633	59.9	75.9	67.3	7.2	16.0	19.4	20.7	19.9	0.6	1.3
634	75.9	87.3	80.8	4.3	11.4	19.4	21.8	20.9	1.1	2.4
641	75.9	99.4	92.3	8.0	23.5	18.4	21.4	20.3	1.1	3.0
642	104.5	113.2	107.8	2.9	8.7	18.6	21.5	20.4	1.0	2.8
643	110.6	125.7	115.4	6.0	15.1	19.9	22.3	21.6	1.0	2.4
Mean	80.5	90.8	85.7	4.4	10.3	15.2	16.7	16.0	0.6	1.5
Max.	131.1	132.9	132.1	9.1	23.5	20.5	22.5	21.7	1.3	3.2
Min.	36.7	44.4	40.8	0.6	1.2	9.7	11.3	10.5	0.1	0.2

The bottom three lines of Table 4.1 show the averages of the climate variables for all CDs. The average differences between the minimum and maximum values of the annual precipitation and maximum temperature are 10.3 cm and 1.48 °C, respectively; the associated ranges are about 2 to 23 cm for precipitation and 0.4 to 3.2 °C. We believe these differences provide reasonably uniform climate conditions consistent with the spatial scale of the assessment.

4.2 SOILS DATA DEVELOPMENT

CENTURY and DNDC require input data on soil texture (percent sand, silt, and clay), bulk density, field capacity, wilting point, and initial soil C and N levels. This section discusses the soils, data bases, and associated model parameters, and Section 5.2 describes the procedures for estimating initial soil carbon and nutrient levels.

County resolution information was acquired for all of the soil data. The data were taken from three soils data bases -- Data Base Analyzer and Parameter Estimator (DBAPE) (Imhoff et al., 1991), the 1982 National Resources Inventory (NRI) (Goebel and Dorsch, 1982), and the 1987 NRI/Soils-5 data base (Goebel, 1987). To develop soil texture information for the entire Study Region, the three data bases were utilized independently, meaning that DBAPE data were used for all counties contained in the data base (Figure 4.5), and data for any missing counties were obtained from either the 1982 NRI data (Figure 4.6), or 1987 NRI/Soils-5 data (Figure 4.7). Data extracted from the each data base were limited to agricultural soils classes (i.e. PO, P1, and P4 categories), including agricultural soils under both irrigated and nonirrigated conditions.

The soil texture information taken from the 1982 NRI Data base was contained in the 1982 NRI/Soils-5 identification block (fields 76-78) in the 1982 NRI file. The file contained a code for which a texture could be determined from the National Soils Handbook (Soil Conservation Service, 1983). Texture information in both DBAPE and the 1987 NRI data bases was listed as ranges of percent sand and clay. To assign a textural classification for the surface 20-cm layer, the high and low values from these ranges were averaged and their sum subtracted from 100 to obtain percent silt. This was done for each layer of soil for every soil type in the counties of the study region identified in DBAPE and the 1982 NRI data bases. Where multiple soil layers comprised the 20 cm depth, the soil texture values were averaged using depth-weighting (i.e., using the soil layer depth as the weight) of percent sand, silt, or clay to the 20-cm depth from the surface of the soil. The resulting depth-weighted sand, silt, and clay percentages were then used with the Soil Conservation Service Textural Triangle, Figure 4.8, (Brady, 1990) to assign one of the twelve textural classes based on the depth-weighted distribution.

Combining the files developed from the three data bases entailed only the sorting of county federal information processing (FIPS) codes, a unique numerical code for each county within the United States. Since each of the data bases provided information on the area of each soil within the county, and each soil had an associated texture class (as described above), we could determine the area (and distribution) of soil textures in each county of the Study Region. The

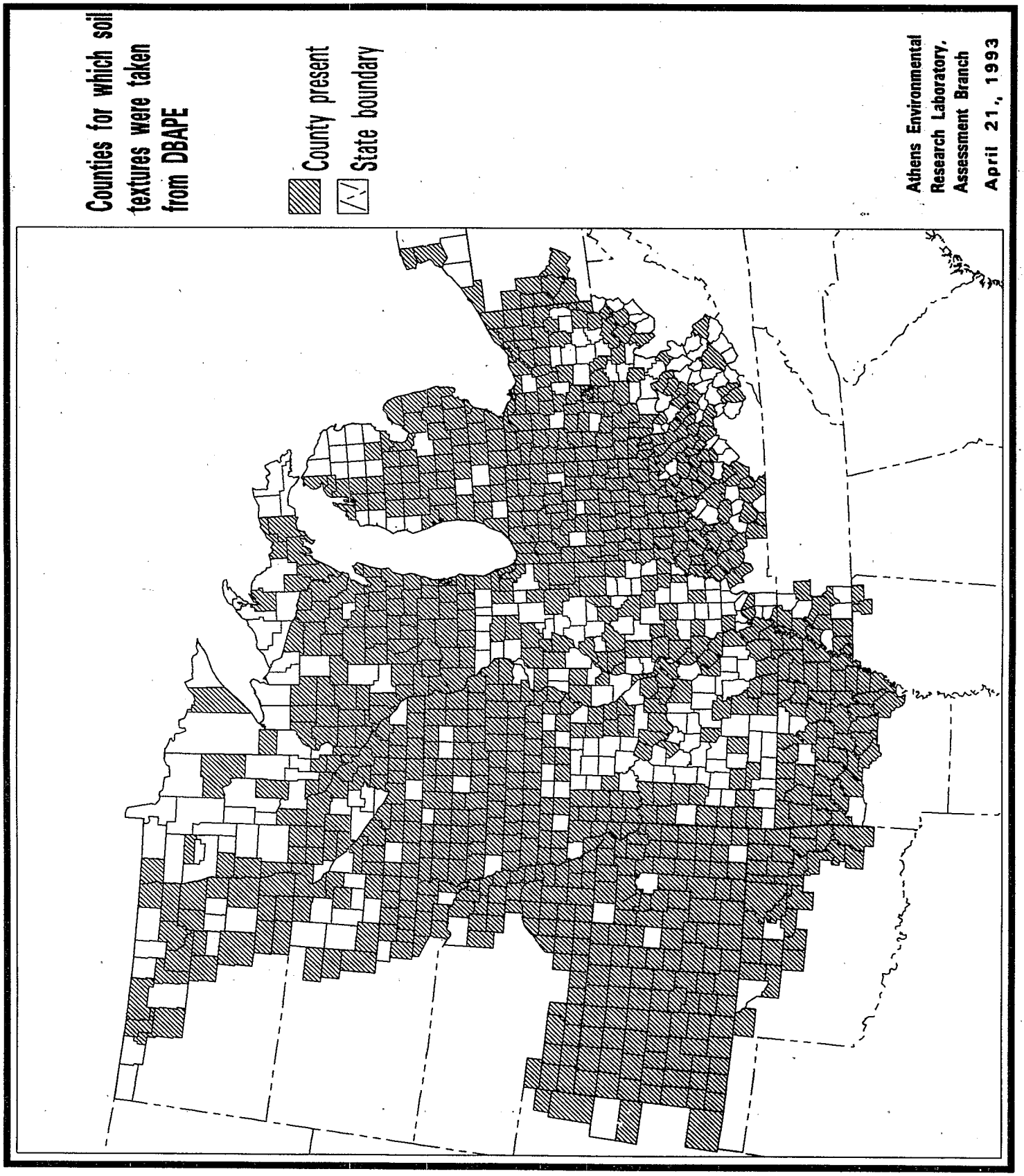


Figure 4.5 Counties for which soil textures were taken from DBAPE

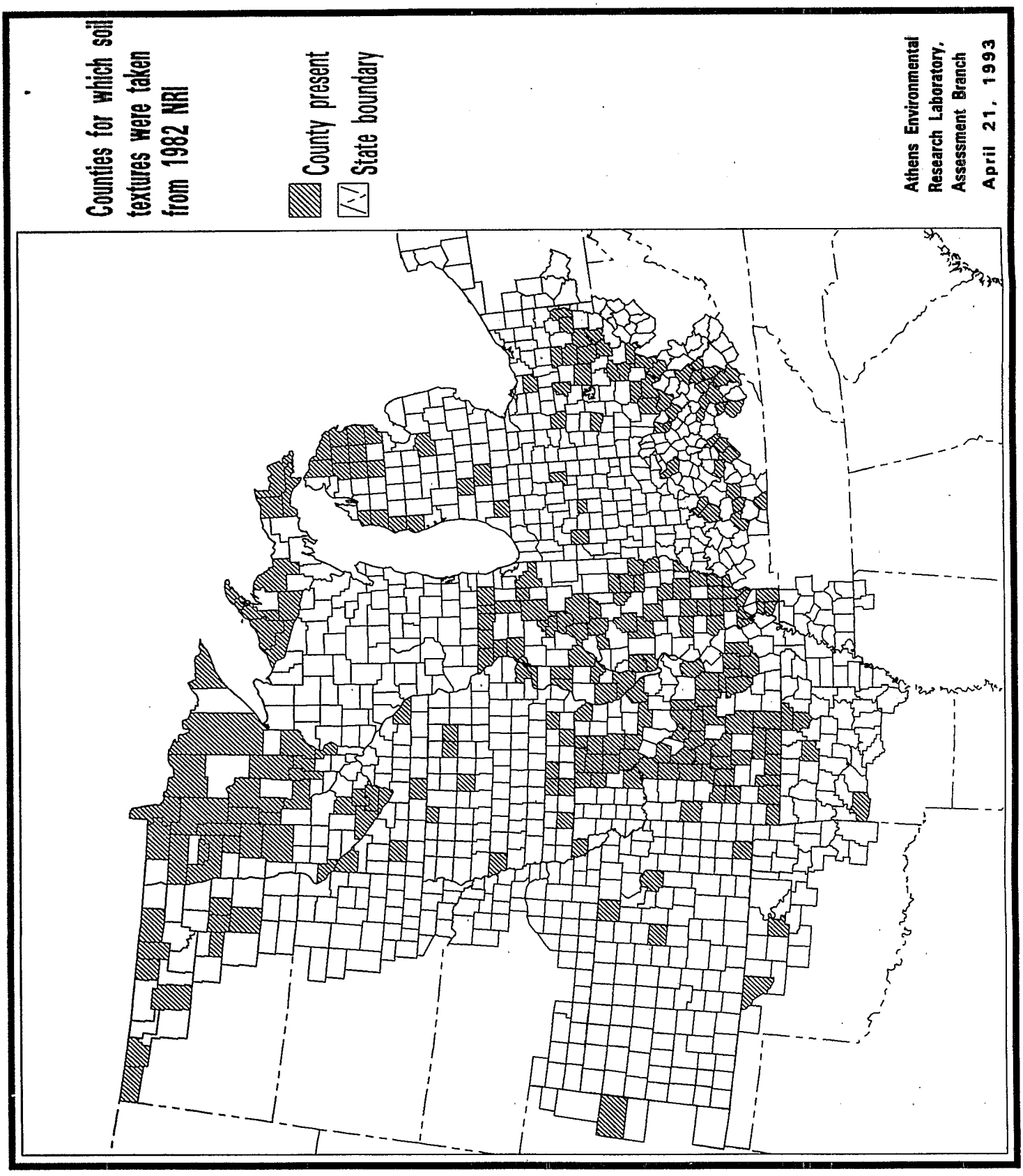


Figure 4.6 Counties for which soil textures were taken from 1982 NRI

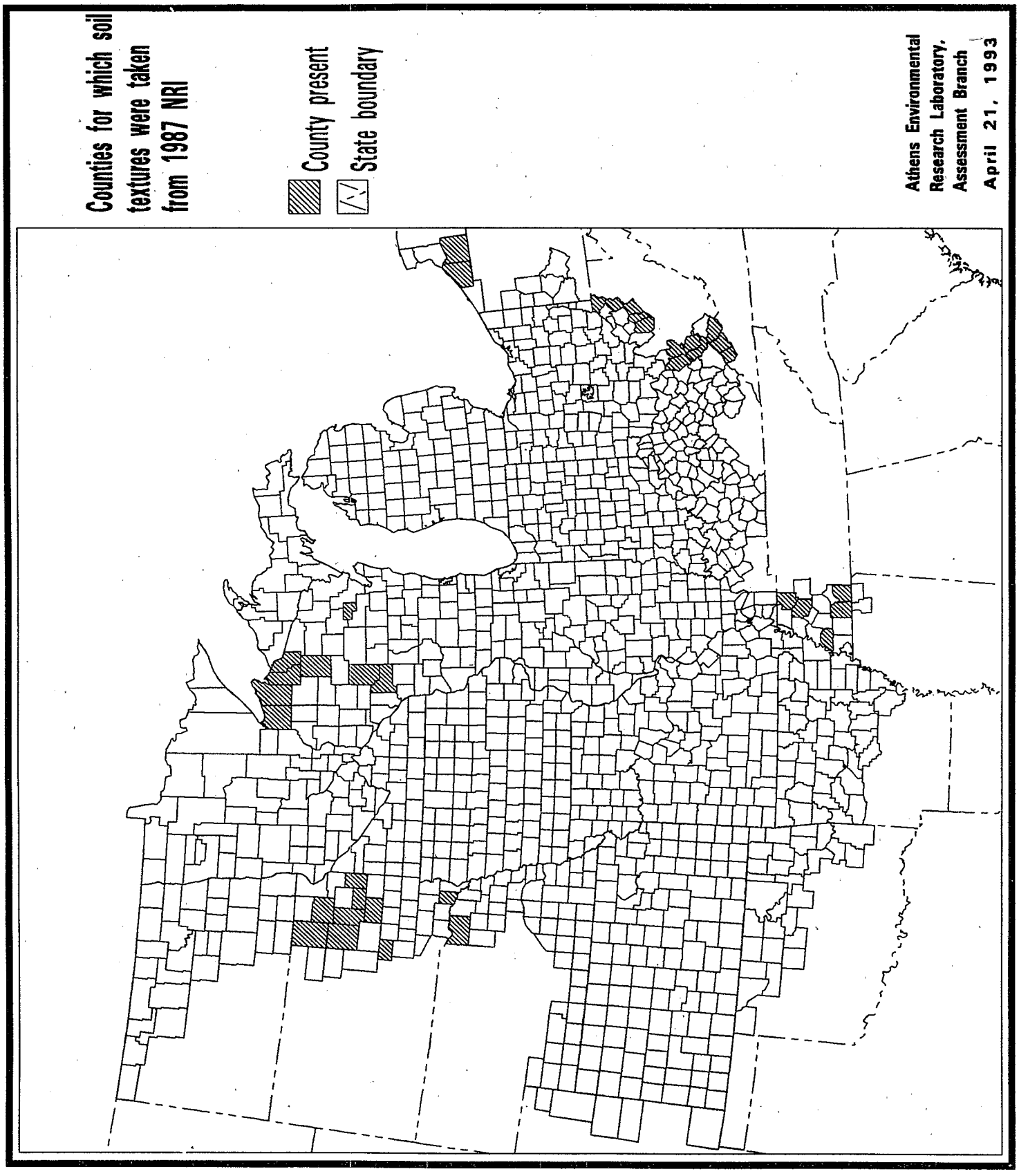
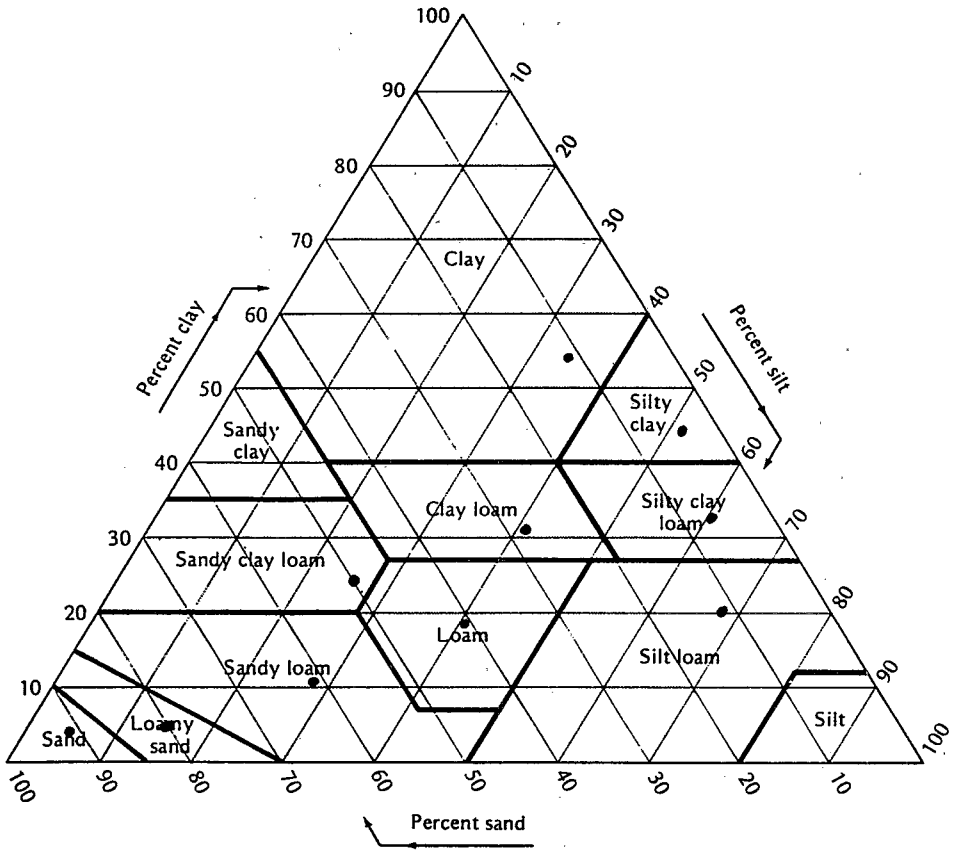


Figure 4.7 Counties for which soil textures were taken from 1987 NRI



• – Weighted textural distribution

Figure 4.8 USDA soil textural triangle showing weighted textural distribution

format of the final result was " County FIPS, Texture, Area " for all of the counties in the Study Region (i.e., each county could potentially have from 1 to 12 different soil textures).

Table 4.2 lists the percentage of the agricultural soils in RAMS study area defined by each of the twelve soil textural classes; note that the textural classes of Silt and Sandy Clay are not present in the Study Region. The distribution of the soil textural percentages shown in Table 4.2 was generally consistent for all the states within the RAMS study region. Table 4.2 also shows the range of percentages from a state-level analysis; the Study Region consists of 21 states. For the Study Region as a whole, the dominant textures are sandy loam, loam, silt loam, and silty clay loam. The state-level percentages show that significant areas of some states are also represented by sand, loamy sand, and silty clay textures. Based on this analysis, and the need to represent the full range of textural classes, we combined the soils into the six texture groups, as shown in Table 4.3. The following criteria were used to develop the six soil textural groups:

a. Percent distribution each soil textural class within the entire RAMS Study Region;
b. Proximity of the grouped soil textural classes on the Soil Conservation Service Textural Triangle;
c. Sensitivity of CENTURY model to percent sand, silt, and clay; and
d. Burke et al.'s (1990) application of CENTURY for regional analysis of grassland biogeochemistry where the authors assigned five soil textural groups based on sand percentage of 0-20%, 20-40%, etc.

Table 4.2 Soil Textural Distribution of Agricultural Soils in RAMS Study Region

Texture	Percentage of RAMS Study Area	Range of Percentages from All States in Study Region
Sand	1	0 - 17
Loamy Sand	5	1 - 26
Sandy Loam	20	5 - 39
Sandy Clay Loam	1	0 - 1
Loam	13	1 - 29
Silt	0	0
Silt Loam	42	11 - 72
Silty Clay Loam	11	4 - 26
Silty Clay	3	1 - 13
Sandy Clay	0	0
Clay Loam	2	0 - 7
Clay	3	0 - 4

Table 4.3 Texture Categories and Groups for RAMS Study Region

Texture Categories*	Combined Texture Groups*
Sand	
Loamy_Sand	Sand/Loamy_Sand
Sandy_Loam	
Sandy_Clay_Loam	Sandy_Loam/Sandy_Clay_Loam
Loam	Loam
Silty_Loam	Silty_Loam
Silty_Clay_Loam	
Silty_Clay	Silty_Clay_Loam/Silty_Clay
Clay_Loam	
Clay	Clay/Clay_Loam

* Note: Sandy_Clay and Silt were not found in the study area.

4.2.1 Derivation of Model Soil Parameters

The overall approach to developing model soil parameters was to estimate appropriate values for the ten SCS soil texture classifications listed in Table 4.3, before transforming the parameter values to the six texture groupings used in this study. As noted above, the analysis of the soils data resulted in " County FIPS, Texture, and Area " for all the counties in the Study Region. The data from counties in each CD were then grouped together to obtain the distribution of the area in each of the possible ten soil textural classes for all 80 CD's. The next step involved the calculation of the following soil physical properties for the ten soil textural classes found in the RAMS Study Area:

1. Percent Sand
2. Percent Silt
3. Percent Clay
4. Bulk Density
5. Field Capacity
6. Wilting Point

Flach (1992, personal communications) analyzed the SCS-USDA (1991) soils data base for the states in the Study Region to estimate the soil physical properties listed above. He calculated the mean distributions (i.e., % sand, % silt, % clay) for almost 2300 soils within the Study Region, for each of the 10 textural classes. He then mapped the values for each of the 2300 soils onto the SCS soil textural triangle to demonstrate that the textural distribution of 'real-world' soils are not evenly distributed throughout the soil triangle. Figure 4.8 depicts the calculated means of percent sand, silt, and clay for all the textural classes. Note that the sand,

silt, and clay percentages of the soil textural groups, for the soils in our Study Region, do not often fall at the center of the textural class. Table 4.4 lists the percent sand, silt, and clay associated with each soil textural class along with the field capacity, wilting point, and bulk density estimated from the SCS-USDA (1991) soils database.

The next step consisted of calculating soil physical properties for each CD from the values listed in Table 4.4. Instead of averaging the properties for the classes included in the six soil textural groups listed in Table 4.3, we calculated area-weighted soil physical properties for all the combined soil textural groups. For example, if the 'sand/loamy, sandy' soil group was comprised of 20% sand and 80% sandy loam in a specific CD, we would use these percentages to calculate weighted properties for that CD. Table 4.5 lists the weighted soil physical properties calculated for a few selected CD's; a complete listing for all the CD's can be found in Appendix E. In Table 4.5 we also list the ranking and the weights for each of the six soil textural classes. The ranking refers to the areal distribution of a particular soil texture in a CD. A rank of 1 was given to the most common soil texture in the CD, and a rank of six was given to the least common soil texture. The weight column in Table 4.5 refers to the percent of the area expressed as the fraction occupied by each soil textural group in the CD. The relation between ranking and weight is that the highest weight is assigned a rank of 1 in a CD and vice versa. This ranking and weight information was needed for the calibration of the CENTURY-simulated yields with historical observed yields, and is explained in detail in Section 5.0.

4.3 CROPPING, LAND USE, AND AGRICULTURAL PRACTICE DATA

All cropping, land use and agricultural practice data for each policy option were provided by CARD as part of the RAMS output. Table 3.1 in Section 3.3 listed the crop production activities included in RAMS specifying the crop rotation, tillage category, contour category, and irrigation conditions. Except for the contour category, the remaining characteristics are discussed in Section 5.2 under the discussion of 'modeling agricultural production systems'. Essentially RAMS provided the area for each crop rotation practiced in each PA, along with the required tillage and irrigation categories needed to accurately model the rotations. The information from RAMS is current as of the 1990-91 crop year; thus it provides an appropriate starting point for projection of soil carbon changes over the next 40 years.

The contour categories are not represented in the models because their primary impact is on erosion control, and erosion is not explicitly represented in the modeling methodology. Section 7.1 includes a discussion of the reasons and effects of ignoring the impacts of erosion in this study of atmospheric carbon emissions from agriculture.

Since all the crop production information from RAMS is developed on a PA basis, it was necessary to transform or disaggregate the information to a CD level for use in the assessment. As noted earlier, the CD boundaries were specifically adjusted to coincide with both county and PA boundaries so that the CDs are entirely contained within one PA. Consequently, the transformation is simply to determine how the information for each PA is to be distributed to each of the enclosed CDs. This disaggregation is based on the distribution of harvested cropland

Table 4.4 Selected Physical Properties for the Soil Textural Classes in the RAMS Study Area

Texture	Sand	Silt	Clay	Bulk Density	Field Capacity	Wilting Point
	%	%	%	g/cc	%	%
Sand	92	5	3	1.58	11.0	3.5
Loamy Sand	81	13	5	1.54	13.9	5.3
Sandy Loam	61	27	12	1.52	23.5	8.9
Loam	41	41	19	1.42	30.0	12.0
Silty Loam	12	68	20	1.43	33.0	13.0
Sandy Clay Loam	51	25	24	1.41	32.5	18.2
Clay Loam	28	41	31	1.41	32.3	17.1
Silty Clay Loam	7	60	32	1.37	36.1	19.8
Silty Clay	6	48	46	1.28	41.6	26.0
Clay	11	35	55	1.18	44.7	28.3

Source: Flach, 1992, personal communication

in the CD compared to the PA; thus the ratio of the cropland within a CD to the cropland within the PA was used to transform all the RAMS information on crop rotations and practices to the CD level. County-level cropland area and PA area data from the 1987 Census of Agriculture (DOC/COA, 1987) was used, in conjunction with a listing of the counties contained within each CD and PA, to calculate the appropriate transformation factors. This approach assumes that the cropland distribution is a reasonable surrogate for all the cropping, rotation, irrigation, and tillage practices used within the PA; we believe this is an appropriate assumption for the scale of this assessment.

Section 5.0 describes the details of the cropping, land use, and practice information from RAMS as part of the methodology for modeling the range of agricultural production systems within the Study Region.

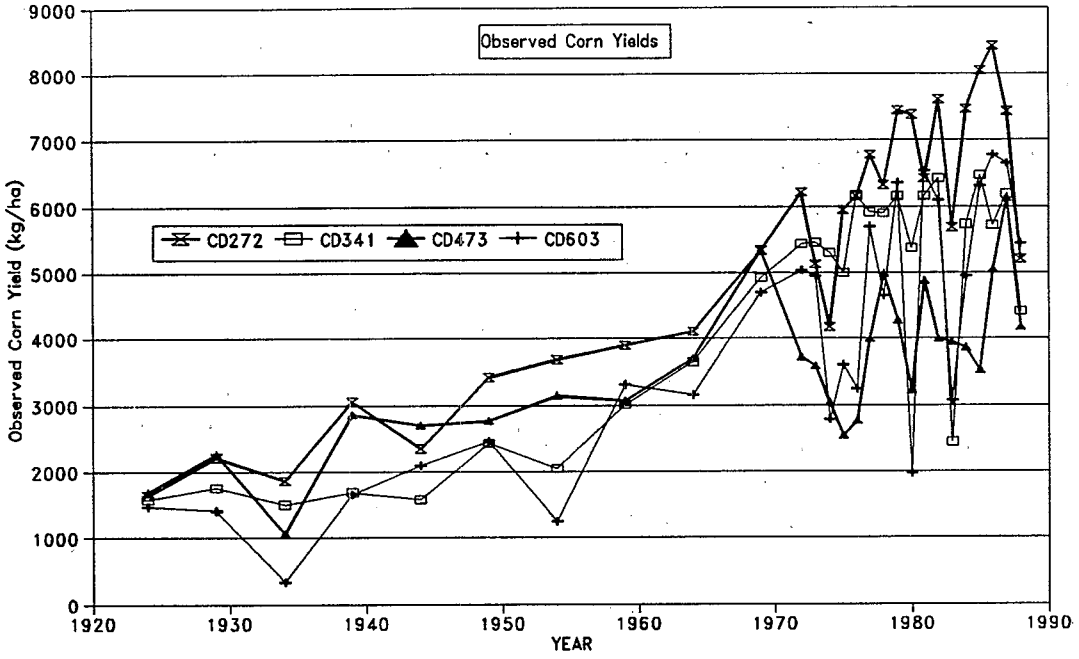
Table 4.5 Soil Physical Properties, Weights, and Ranks for Selected CD's

	% Sand	% Silt	% Clay	BD	FC	WP	Weight	Rank
CD-221								
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	0.10	4
Loam	41	41	18	1.42	0.30	0.12	0.24	2
Loamy Sand/Sand	85	10	5	1.56	0.13	0.05	0.08	5
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	0.20	3
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	0.07	6
Silt Loam	12	68	20	1.43	0.33	0.13	0.31	1
CD-272								
Clay/Clay Loam	13	36	52	1.20	0.44	0.27	0.22	2
Loam	41	41	18	1.42	0.30	0.12	0.07	6
Loamy Sand/Sand	83	11	5	1.55	0.13	0.05	0.09	5
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	0.32	1
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	0.15	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.15	3
CD-341								
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	0.02	6
Loam	41	41	18	1.42	0.30	0.12	0.15	3
Loamy Sand/Sand	91	6	3	1.58	0.11	0.04	0.10	5
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	0.29	2
Silty Clay/Silty Clay Loam	7	57	37	1.34	0.38	0.22	0.14	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.30	1
CD-413								
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	0.02	5
Loam	41	41	18	1.42	0.30	0.12	0.34	2
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	0.01	6
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	0.20	3
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	0.04	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.39	1
CD-562								
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	0.03	5
Loam	41	41	18	1.42	0.30	0.12	0.18	2
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	0.01	6
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	0.17	3
Silty Clay/Silty Clay Loam	7	50	44	1.29	0.41	0.25	0.07	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.54	1
CD-603								
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	0.02	5
Loam	41	41	18	1.42	0.30	0.12	0.18	3
Sandy Clay Loam/Sandy Loam	60	27	13	1.51	0.24	0.10	0.25	2
Silty Clay/Silty Clay Loam	7	56	37	1.34	0.38	0.22	0.10	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.45	1
CD-643								
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	0.01	5
Loam	41	41	18	1.42	0.30	0.12	0.34	2
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	0.39	1
Silty Clay/Silty Clay Loam	7	58	36	1.35	0.37	0.21	0.05	4
Silt Loam	12	68	20	1.43	0.33	0.13	0.21	3

4.4 CROP YIELD INFORMATION

As noted in the Project Methodology (Section 3.5), historical crop yield data were needed as part of the procedures for estimating initial soil carbon levels in order to predict changes through the projection period; Section 5.2 discusses the details of these procedures. The historical yield data at a state level of resolution were obtained for corn, corn-silage, soybean, wheat, and hay for the period beginning in 1928 and ending in 1988 on 5-year intervals from United States Department of Agriculture - National Agricultural Statistics Service (NASS)(1928-88) and U.S. Department of Commerce CENSUS of Agriculture (1972-88) for all the states associated in the study region. However, for the period beginning in 1972 and ending in 1988, yearly county level yield data were obtained for all crops listed above from NASS computer tapes (USDA-NASS Tapes, 1988). The yearly county level hay yield was only available for the period 1982 to 1988.

The next step consisted of calculating CD-level yield data. The state level yield data were assigned as is to CDs that were entirely encompassed within a state; however, if the CD crossed state boundaries, an area-weighted (based on the area of the CD in each state) yield was estimated for all the crops in the period from 1924 to 1971. The yearly county level yield data were averaged for all the counties that were associated with a given CD. These two data sets were then combined to obtain a single observed yield data set for all the crops grown in all of the 80 CD's. The observed yield data for selected CDs are shown in Figure 4.9 for corn and Soybeans, and Figure 4.10 for wheat and hay.



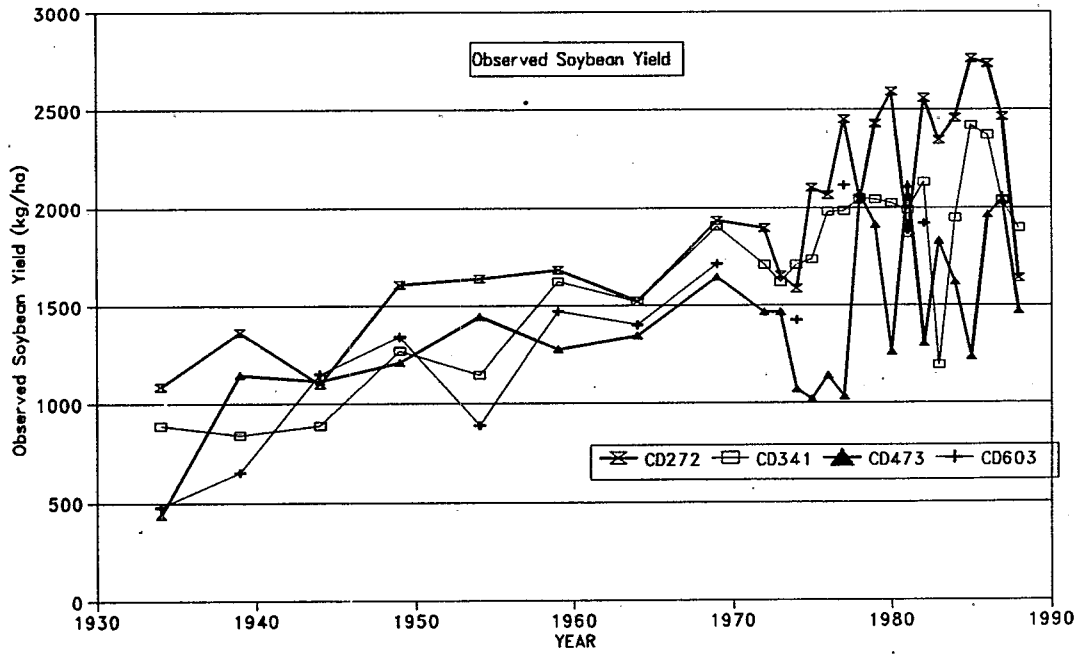
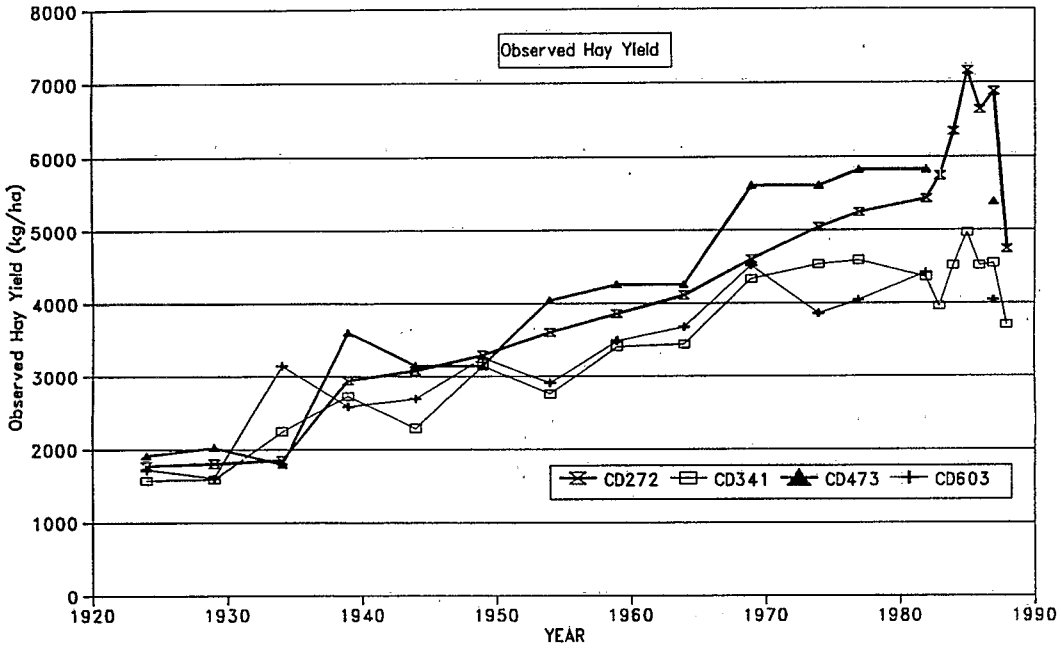


Figure 4.9 Observed Corn and Soybean Yield



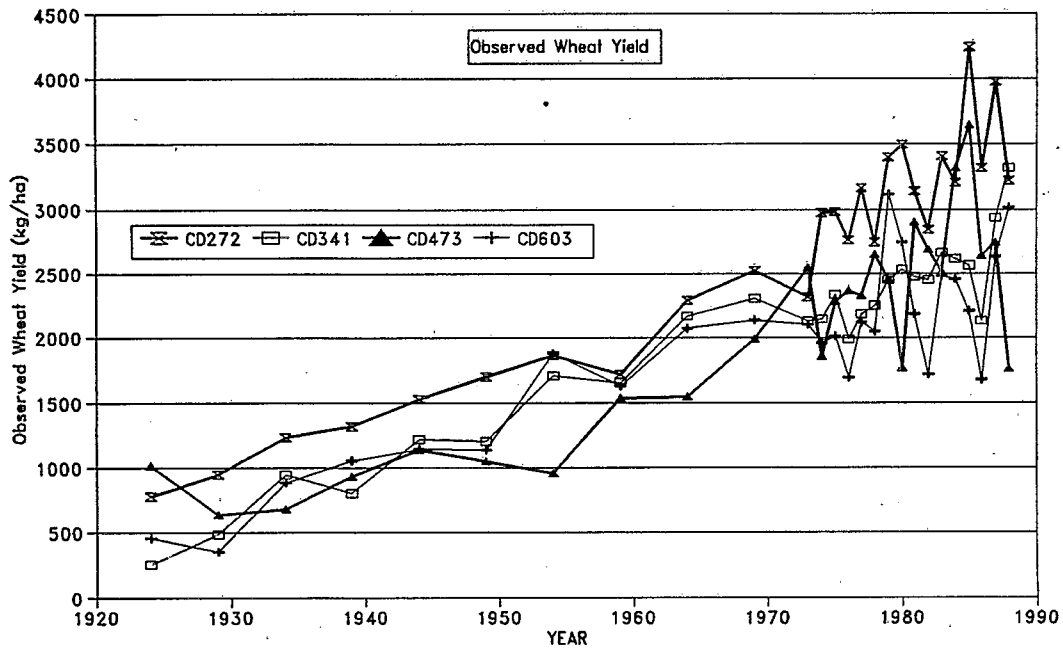


Figure 4.10 Observed Hay and Wheat Yield

SECTION 5.0

MODELING SCENARIOS - BASELINE AND ALTERNATIVES

This section describes our approach to representing agricultural production systems within the Study Region using the CENTURY model and the underlying assumptions and procedures used to assess SOC changes. We discuss the definition and parameterization of agricultural production systems, the estimation of initial soil carbon (and nitrogen) values as a basis for projecting future changes, the assumptions used to define both baseline (i.e., current) and alternative future conditions reflecting the modeling scenarios developed by RAMS, and the operational procedures employed for the CENTURY model runs. The focus is on how the models are used, including underlying model assumptions, application assumptions, and parameter adjustments, to approximate expected future conditions associated with each defined scenario.

5.1 MODELING AGRICULTURAL PRODUCTION SYSTEMS

An 'agricultural production system' is a complex combination of (1) specific crops grown in defined rotation patterns; (2) seasonally defined tillage and harvest practices using specified implements (equipment) that control the soil, crop, and residue disposition; and (3) agronomic inputs including fertilizers, manure, and/or organic amendments along with irrigation water and pesticides, as appropriate. All these components are integrated within the local climate and soil resource environment, and are ultimately influenced by the policy and market (economic) mechanisms that drive the demand for the products produced by the system.

This section describes the details of our approach for representing the physical aspects of agricultural production systems within the RAMS study region using the CENTURY model; the policy and market mechanisms are represented by RAMS and are discussed in Sections 5.3 and 5.4. The following subsections describe each of the **three major components** of these systems noted above -- crops and rotations, tillage and residue management, inputs -- within the limitations of the modeling capabilities and data available for this investigation. Clearly, as in any modeling exercise, representing agriculture on 216 million acres with 100,000 farms or more, requires some simplification of the 'real system' to make the assessment feasible. Thus, our approach was to focus on the **dominant** crops, rotations, and tillage practices, and represent the soil carbon impacts of these combinations within the spatial variability of the climate and soils conditions of the Study Region.

5.1.1 Crops and Rotations

Cropping information for the RAMS Study Region was provided by CARD for each modeling scenario. Figure 5.1 shows the cropland distribution by CD for the Study Region; this distribution was used for all policy scenarios. Table 5.1 tabulates the crop distribution by PA, i.e., % of PA area for each crop, for the Status Quo scenario, along with the corresponding distribution for the study region; the '% cropland' in each PA mapped in Figure 5.1 is also listed. As expected, the dominant crops include corn, soybeans, hay, and wheat which collectively comprise almost 90% of the cropland in the study region. Combining this information with the crop modeling capability of CENTURY was the basis for identifying the specific crops to be simulated.

Unfortunately, not all crops are currently included in CENTURY i.e., appropriate parameter values have not been developed, tested, and confirmed with field site applications. Based on past and current model testing, similarities of crop species, and the cropping patterns of the study region, we selected six crops for simulation. We've noted below how the parameters for these crops are used to represent other crops lacking parameter values:

Corn	Corn is used to represent all corn, sorghum, and other crops occupying minor areas within the PAs (.e.g., cotton, sunflowers). Different crop parameter values are used for Corn-Grain and Corn-Silage due to the difference in biomass produced. Appendix B reports on CENTURY testing on a continuous corn site in Lexington, KY.
Soybean	Soybean parameters were initially developed and tested by NREL as part of this study; further testing is needed and planned, possibly on a corn-soybean rotation site in Iowa.
Wheat	Wheat parameters are used to represent all small grains, e.g., wheat, oats, and barley. CENTURY has been extensively tested for various wheat species, including some testing on a site in Sydney, NE as part of this study (see Appendix A)
Legume-Hay	Legume hay parameters were developed and tested by NREL for selected temperate grasses with N fixation characteristics.
Non-Legume Hay	Non-legume hay parameters were developed by NREL for selected temperate grasses.
Grassland	Grassland parameter values have been developed by NREL for numerous species over a number of years of model testing. These parameters are used in the CRP scenario.

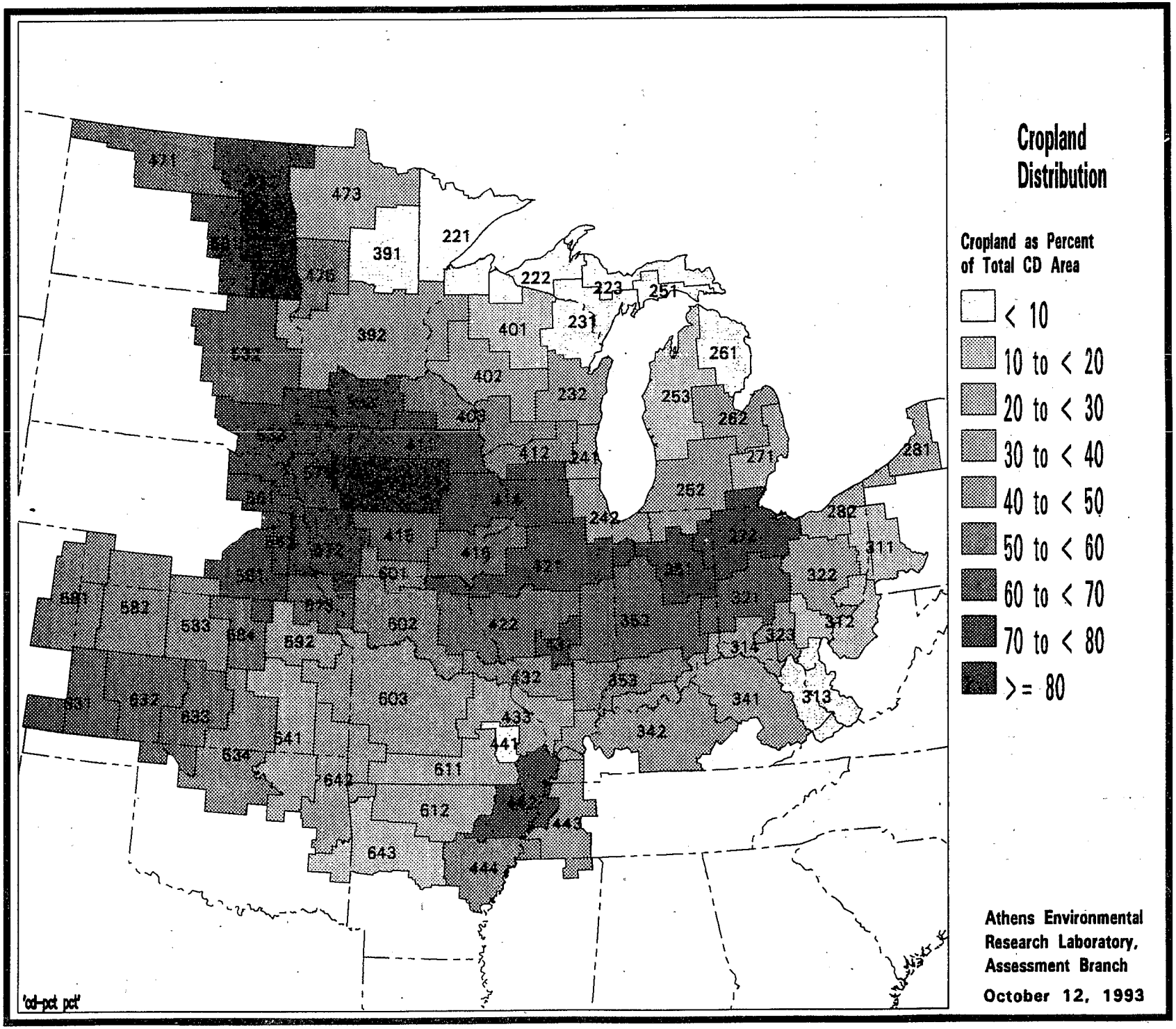


Figure 5.1 Cropland distribution for the study region

Table 5.1 Crop and Cropland Distribution for Each PA in the RAMS Study Region

PA	BAR	CRN	CSL	COT	HLH	NLH	OTS	SRG	SSL	SOY	SMF	SUN	SWT	WWT	TOTAL %	%Cropland
22		0.4	66.3		8.3								25.0		100.0	2.73
23	2.2	27.9	18.5		33.5	3.4	12.3						2.2		100.0	25.39
24		55.1	2.3		10.0	1.2	2.3			23.7				5.4	100.0	40.79
25		42.2			22.7	2.6	3.0			21.4				8.1	100.0	25.49
26		34.3	7.4		23.4	11.3	11.6						11.9		100.0	28.55
27		39.7	2.8		10.0	1.6	2.3			31.3				12.3	100.0	60.72
28		12.7			42.6	28.9	4.0			8.1				3.4	100.0	22.85
31		19.0	11.0		12.4	35.9	4.4			13.5				3.7	100.0	15.06
32		29.5			28.0	7.6	3.8			21.9				9.3	100.0	47.13
34	17.4	38.4			34.9	9.2		0.1		0.1					100.0	25.10
35		45.4			2.6	2.1	0.7			42.4				6.8	100.0	64.56
39	0.8	43.2	3.9		7.8	4.4	3.5			31.8				4.5	100.0	42.55
40	0.5	45.8	7.0		26.5	4.3	6.2			9.4			0.4		100.0	30.77
41		50.9	2.1		10.1	1.2	2.9	0.0		32.2				0.6	100.0	70.77
42		54.4	0.5		4.1	1.4	0.6	0.6		32.7				5.7	100.0	69.26
43		34.5	0.6		4.9	7.8	0.6	3.0		31.3				17.3	100.0	40.46
44		8.9		13.7	0.3	3.2	0.3	7.5		48.9				17.3	100.0	50.02
47	17.3	5.1	1.1		4.4	4.5	1.6			8.8	18.3	3.3	35.7		100.0	56.98
53	4.6	22.2	2.8		4.6	15.5	6.8	0.4			21.6	2.8	18.8		100.0	60.25
56		47.8	2.4		6.5	2.1	3.5	6.3	0.3	28.2				2.8	100.0	63.46
57		52.1			8.1	3.5	1.6	3.6		27.2				4.0	100.0	71.18
58		17.6	0.6		2.9	60.2	0.6	4.6		1.5				12.0	100.0	53.30
59		44.3	1.2		4.3	6.6	0.6	22.9		13.7				6.5	100.0	57.47
60		20.1			5.5	35.0		4.4		24.1				10.9	100.0	34.18
61		1.6	0.2		6.1	45.3	0.1	12.5	0.1	23.6				10.5	100.0	6.74
63	0.2	3.1			75.3	2.9		3.8	0.3	3.3				11.0	100.0	58.87
64		48.0			4.2	0.9	0.3	8.3		23.3				14.9	100.0	16.25

BAR - Barley
OTS - Oats
SWT - Spring Wheat
HLH - Legume Hay
NLH - Non-Legume Hay
SUN - Sunflower
COT - Cotton
SOY - Soybeans
SMF - Summer Fallow
CSL - Corn Silage
SSL - Sorghum Silage
CRN - Corn
SRG - Sorghum Grain
WWT - Winter Wheat

Since crops are primarily grown within a specific rotation sequence, the next step was to identify the rotation sequences practiced in the region. Table 5.2 shows the crop rotations for the study region obtained from the RAMS output, along with their acreage and '% of Study Area'; more than 80 different rotations are used in different PAs of the region, ranging from continuous cropping (usually only for corn, hay, wheat or sorghum) to 2- to 6- year rotations of up to 14 different crops. However, only 18 different rotations exceed 1.0% of the cropland area in the region, and the most prevalent rotation is **corn-soybean** which makes up 23.9%.

Considering the specific crops simulated by CENTURY, we analyzed the crop rotation information and developed rotation combinations, or groupings, to minimize the number of individual rotations that must be simulated for each defined subregion, i.e., climate division. Table 5.3 shows the final list of 35 rotations selected for simulation, reduced from the original 80 rotations listed in Table 5.2. Table 5.4 lists the original rotations included with the modeled rotations.

Our general approach to grouping the less frequent rotations was to **eliminate any rotation that was less than 5% of a PA**, unless it was a significant rotation (i.e., more than 5%) in another PA, and would therefore have to be simulated anyway. With this final list, each PA contains 2 to 8 rotations, and most have only 4 or 5. Table 5.3 also shows the grouped acreage and the corresponding '% of Study Region' resulting from the grouping. Although we have retained the designations for barley, oats, and sorghum in Table 5.3, as noted above, barley and oats are represented with the wheat parameters and sorghum uses the corn parameters in CENTURY.

5.1.2 Tillage and Residue Management Practices

Soil carbon is a direct function of the carbon inputs to the soil derived from the crop or vegetation, both as roots and crop residues. Thus, the impacts of tillage and harvest practices that control the disposition of the crop biomass, and associated carbon, must be accurately represented to mimic the carbon balance of the soil. This section discusses the procedures and parameters used to model the impacts of tillage and harvest practices for the crops and rotations in the Study Region.

An overview of the crop model is needed in order to understand the potential impacts of the model parameters. Figure 5.2 is a diagram of the crop model in CENTURY identifying the various carbon pools represented; each pool also has an associated N pool (and other nutrients). The various pools can be grouped as follows:

Live Plant Material	Dead Plant Residue
Above Ground	
- Grain	- Standing dead
- Shoots	- Surface litter
Below Ground	
- Roots	- Root residue

Table 5.2 Complete List of Crop Rotations in the Study Region

CR #	Crop Rotation	Acreages	% of Study Region
2	BAR,BAR,SOY	4,190,350	1.9
4	BAR,BAR,SMF	390,970	0.2
8	BAR,CRN,CRN,CRN	395,228	0.2
11	BAR, CSL	63,860	0.0
14	BAR,CSL,CSL *	0	0
21	BAR,HLH,HLH,CRN,CRN	4,464,886	2.1
70	BAR,SOY	58,495	0.0
78	BAR,SUN,SMF,SWT	1,584,520	0.7
80	BAR,SWT	124,394	0.1
81	BAR,SWT,SUN,SWT	2,611,154	1.2
100	CRN	18,097,382	8.4
105	CRN,CRN,CRN,OTS,HLH,HLH *	0	0
107	CRN,CRN,CRN,OTS,NLH,NLH	216,102	0.1
109	CRN,CRN,CRN,SWT	2,695	0.0
111	CRN,CRN,CRN,WWT,HLH	155,153	0.1
115	CRN,CRN,CRN,HLH,HLH,HLH	713,294	0.3
122	CRN,CRN,OTS,HLH,HLH	244,365	0.1
123	CRN,CRN,OTS,HLH,HLH,HLH	2,316,860	1.1
125	CRN,CRN,OTS,NLH,NLH	1,164,545	0.5
131	CRN,CRN,SOY	15,395,588	7.1
132	CRN,CRN,SOY,OTS,HLH	2,666,886	1.2
133	CRN,CRN,SOY,OTS,HLH,HLH *	0	0
136	CRN,CRN,SOY,SRG	574,704	0.3
137	CRN,CRN,SOY,WWT	552,384	0.3
138	CRN,CRN,SOY,WWT,HLH	2,008,010	0.9
142	CRN,CRN,WWT *	0	0
144	CRN,CRN,WWT,HLH,HLH	1,747,290	0.8
145	CRN,CRN,WWT,HLH,HLH,HLH	604,068	0.3
162	CRN,OTS,HLH,HLH,HLH	861,163	0.4
168	CRN,OTS,NLH,NLH,NLH	172,299	0.1
170	CRN,OTS,WWT	101,876	0.0
178	CRN,SRG	116,479	0.1
186	CRN,SOY	51,681,598	23.9
189	CRN,SOY,CRN,WWT,HLH,HLH	1,325,780	0.6
196	CRN,SOY,OTS,NLH,NLH	588,494	0.3
201	CRN,SOY,WWT	12,991,752	6.0
202	CRN,SOY,WWT,HLH *	0	0
203	CRN,SOY,WWT,HLH,HLH,HLH	3,447,955	1.6
210	CRN,SWT	223,820	0.1

Table 5.2 (contd.)

CR #	Crop Rotation	Acreages	% of Study Region
215	CRN,SWT,SWT	2,190,769	1.0
218	CRN,WWT	746,696	0.3
231	CRN,NLH,NLH	227,696	0.1
232	CRN,NLH,NLH,NLH	423,464	0.2
235	CSL	527,634	0.2
239	CSL,CSL,CSL,SWT	414,132	0.2
242	CSL,CSL,OTS,HLH	916,740	0.4
243	CSL,CSL,OTS,HLH,HLH	1,631,370	0.8
244	CSL,CSL,OTS,HLH,HLH,HLH	1,353,307	0.6
246	CSL,CSL,OTS,NLH,NLH	255,575	0.1
250	CSL,CSL,SOY	447,257	0.2
252	CSL,CSL,WWT,NLH,NLH	5,290	0.0
259	CSL,OTS	541,752	0.3
261	CSL,OTS,HLH,HLH	284,299	0.1
262	CSL,OTS,HLH,HLH,HLH	1,677,935	0.8
265	CSL,OTS,HLH,HLH,SWT	428,316	0.2
276	CSL,SOY,CSL,OTS,NLH,NLH	87,435	0.0
277	CSL,SOY,HLH,HLH,HLH,HLH	444,915	0.2
280	CSL,SWT	411,200	0.2
325	COT,SOY	2,455,120	1.1
339	HLH,HLH,HLH,HLH,SRG,SOY	941,592	0.4
350	OTS,HLH,HLH,HLH	809,412	0.4
354	OTS,HLH,HLH,HLH,SRG,SRG	451,784	0.2
366	OTS,NLH,NLH,NLH	2,294,135	1.1
372	OTS,NLH,NLH,NLH,SOY	137,963	0.1
379	OTS,NLH,NLH,SSL,SOY,SSL	20,359	0.0
384	OTS,OTS,SMF	1,090,070	0.5
409	SRG	1,211,234	0.6
410	SRG,SRG,SOY *	0	0
411	SRG,SRG,SOY,WWT *	0	0
415	SRG,SOY	1,483,385	0.7
416	SRG,SOY,SOY	1,987,066	0.9
417	SRG,SOY,WWT	224,954	0.1
419	SRG,SOY,HLH,HLH,HLH,HLH	202,938	0.1
424	SRG,WWT	3,304,256	1.5
432	SRG,NLH,NLH	23,971	0.0
434	SSL,SSL,WWT,NLH,NLH	3,110	0.0
439	SSL,WWT	99,701	0.1
452	SOY,SWT,SWT	1,051,320	0.5
454	SOY,WWT	260,553	0.1

Table 5.2 (contd.)

CR #	Crop Rotation	Acreages	% of Study Region
458	SOY,WWT,SOY	884,594	0.4
459	SOY,WWT,WWT,WWT	1,677,812	0.8
462	SMF,NLH,NLH,NLH,NLH	43,065	0.0
463	SMF,SWT	11,744,092	5.4
471	SMF,WWT *	0	0
478	SWT,HLH,HLH,HLH	51,908	0.0
490	WWT	2,848,742	1.3
503	HLH,HLH,HLH,HLH	18,250,303	8.4
508	NLH,NLH,NLH,NLH	18,057,440	8.3
Total RAMS Study Area =		216,481,059	100.0

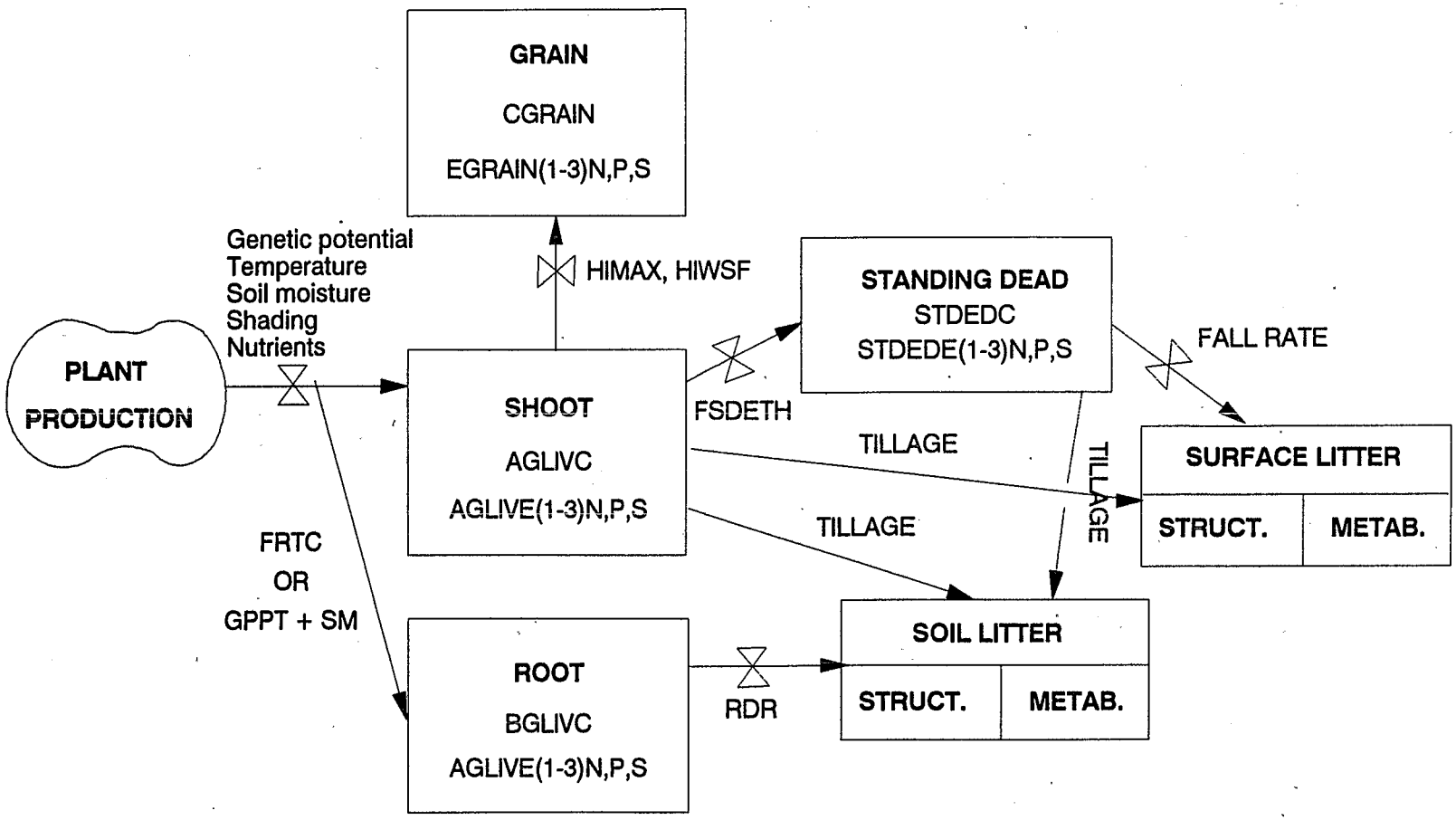
* - Modeled under Tillage and Cover Crop Policies

Table 5.3 Final List of Crop Rotations for Modeling with CENTURY

CR #	Crop Rotation	Acreages	% of Study Region
2	BAR,BAR,SOY	5,241,670	2.4
4	BAR,BAR,SMF	3,065,560	1.4
100	CRN	19,425,089	9.0
115	CRN,CRN,CRN,HLH,HLH,HLH	713,294	0.3
125	CRN,CRN,OTS,NLH,NLH	1,552,951	0.7
131	CRN,CRN,SOY	16,365,526	7.6
138	CRN,CRN,SOY,WWT,HLH	5,382,433	2.5
144	CRN,CRN,WWT,HLH,HLH	6,456,545	3.0
145	CRN,CRN,WWT,HLH,HLH,HLH	4,117,983	1.9
186	CRN,SOY	55,678,535	25.7
189	CRN,SOY,CRN,WWT,HLH,HLH	1,325,780	0.6
196	CRN,SOY,OTS,NLH,NLH	588,494	0.3
201	CRN,SOY,WWT	13,216,715	6.1
203	CRN,SOY,WWT,HLH,HLH,HLH	3,447,955	1.6
215	CRN,SWT,SWT	5,025,740	2.3
218	CRN,WWT	4,252,531	2.0
232	CRN,NLH,NLH,NLH	651,160	0.3
235	CSL	527,634	0.2
239	CSL,CSL,CSL,SWT	416,827	0.2
243	CSL,CSL,OTS,HLH,HLH	2,548,110	1.2
244	CSL,CSL,OTS,HLH,HLH,HLH	2,055,728	0.9
246	CSL,CSL,OTS,NLH,NLH	571,056	0.3
250	CSL,CSL,SOY	447,257	0.2
262	CSL,OTS,HLH,HLH,HLH	1,928,414	0.9
280	CSL,SWT	1,016,813	0.5
339	HLH,HLH,HLH,HLH,SRG,SOY	1,144,530	0.5
350	OTS,HLH,HLH,HLH	861,321	0.4
366	OTS,NLH,NLH,NLH	2,294,135	1.1
416	SRG,SOY,SOY	1,987,066	0.9
458	SOY,WWT,SOY	1,145,147	0.5
459	SPY,WWT,WWT,WWT	1,677,812	0.8
463	SMF,SWT	11,744,092	5.4
490	WWT	2,848,742	1.3
503	HLH,HLH,HLH,HLH	18,695,218	8.6
508	NLH,NLH,NLH,NLH	18,065,842	8.3
Total RAMS Study Area =		216,481,020	100.0

Table 5.4. List of Modeled and Original Crop Rotation Numbers and Crop Sequence

Modeled Rotation Number	Original Rotation Number	Crop Rotation Modeled
2	2,452	BAR,BAR,SOY
4	4,78,384	BAR,BAR,SMF
100	100,178,409	CRN
115	115,105	CRN,CRN,CRN,HLH,HLH,HLH
125	125,107,168	CRN,CRN,OTS,NLH,NLH
131	131,8,136,142,410,411	CRN,CRN,SOY
138	138,111,132,137,133	CRN,CRN,SOY,WWT,HLH
137	137	CRN,CRN,SOY,WWT
144	144,21,122	CRN,CRN,WWT,HLH,HLH
145	145,80,123,162,354	CRN,CRN,WWT,HLH,HLH,HLH
186	186,70,325,415	CRN,SOY
189	189	CRN,SOY,CRN,WWT,HLH,HLH
196	196	CRN,SOY,OTS,NLH,NLH
201	201,417,202	CRN,SOY,WWT
203	203	CRN,SOY,WWT,HLH,HLH,HLH
215	215,81,210	CRN,SWT,SWT
218	218,170,424,439	CRN,WWT
232	232,231	CRN,NLH,NLH,NLH
235	235	CSL
239	239,109	CSL,CSL,CSL,SWT
243	243,242	CSL,CSL,OTS,HLH,HLH
244	244,265	CSL,CSL,OTS,HLH,HLH,HLH
246	246,276,379,434,252	CSL,CSL,OTS,NLH,NLH
250	250	CSL,CSL,SOY
262	262,261	CSL,OTS,HLH,HLH,HLH
277	277	CSL,SOY,HLH,HLH,HLH,HLH
280	280,11,259,14	CSL,SWT
339	339,419	HLH,HLH,HLH,HLH,SRG,SOY
350	350,478	OTS,HLH,HLH,HLH
366	366,372,432,462	OTS,NLH,NLH,NLH
416	416	SRG,SOY,SOY
458	458,454	SOY,WWT,SOY
459	459	SOY,WWT,WWT,WWT
463	463,471	SMF,SWT
490	490	WWT
503	503,277	HLH,HLH,HLH,HLH
508	508,252,434	NLH,NLH,NLH,NLH



GPPT = Grow Season Precipitation
SM = Initial Soil Moisture
FSDETH = Shoot Death Rate
FRTC = Fraction Root Carbon
RDR = Root Death Rate
HIMAX = Harvest Index Maximum
HIWSF = Harvest Index Water Stress Factor

CPRODA = Annual Total Production
AGCACC = Above Ground Growing Season Production
BGCACC = Below Ground Growing Season Production

Figure 5.2 CENTURY crop model diagram (Agroecosystem Version 4.0, from Metherell et al., 1993)

Through the various tillage and harvest parameters in CENTURY, we identify the impact on, and disposition of, the C and N content of these pools for specific operations. Since these parameters control the amount of C input to the soil from the plant, they have a major impact on SOC; thus, their values are critical to adequately representing the SOC impacts of cropping and tillage practices.

Tillage Parameters and Practices -

The CENTURY model allows the user to define the impacts of individual tillage operations through a suite of model parameters that define the amount, or fractions, of plant biomass, and associated C and N contents, that are transferred between the various above and below ground pools as a result of the tillage operation. Table 5.5 shows the parameter values used to represent a variety of tillage equipment typically associated with conventional, reduced tillage and no tillage practices. Thus, for example, a mold board plowing operation would transfer 90% of the live and dead plant material to the soil layer and 10% would remain on the soil surface; whereas, a chisel plow leaves 58% of the plant residue on the surface and incorporates 42% into the soil layer. Most of these parameter values were developed by the CENTURY authors through model applications for grassland and wheat systems. The parameters for tillage equipment associated more with other cropping systems (i.e., corn, soybeans) were added under this study based on similar parameters from the EPIC model (Sharpley and Williams, 1990).

In addition to the impact of individual tillage operations, the timing and frequency of all operations -- primary tillage, planting, cultivation, harvest -- must be defined throughout the year for all crops in each rotation. The frequency of tillage operations is shown in Table 5.6 for both the historical time period, 1907-1988, and the projection period, 1989-2030. The practices simulated for the projection period, based on the categories defined by RAMS, include:

Conventional Tillage (Fall Plow)	-	CTFP
Conventional Tillage (Spring Plow)	-	CTSP
Reduced Tillage	-	RT
No-Till	-	NT

For each of theses practices, the number of times a specific tillage operation is performed is shown by the numbers in Table 5.6; thus, **conventional tillage** includes two disk cultivations, for seedbed preparation, and two row cultivations for weed control during the growing season, while **reduced tillage** uses a chisel plow plus one operation each of disk and row cultivation. The **no-till** practice uses herbicides, a no-till drill operation, and no other tillage operations. These assumptions for the type and number of operations were developed through consultation with agronomy experts at Colorado State and Iowa State during discussions with the study team. They are meant to represent the general nature and frequency of tillage operations for the crops grown in the study region, not the exact practices and variations utilized by all the individual farmers.

Table 5.5 Tillage Parameters Used in the CENTURY Model

	From	To	Tillage Options[1] MBP	CP	PDC	DC	RC	NTD	HB	D
	Live	Dead	0.00	0.00	0.00	0.00	0.00	0.05	1.00	0.05
		Surface	0.10	0.58	0.05	0.50	0.00	0.05	0.00	0.05
		Soil	0.90	0.42	0.95	0.50	0.00	0.00	0.00	0.10
Fraction										
	Dead	Surface	0.10	0.58	0.05	0.50	0.00	0.05	0.00	0.05
transferred		Soil	0.90	0.42	0.95	0.50	0.00	0.05	0.00	0.15
	Surface	Soil	0.90	0.42	0.95	0.50	0.50	0.05	0.00	0.20
	Roots	Soil	1.00	1.00	1.00	1.00	0.00	0.10	1.00	0.20
Multiplicative Effect on Soil Decomposition			1.60	1.40	1.60	1.60	1.30	1.00	1.00	1.10

[1] - Abbreviations:

MBP	-	Mold Board Plow
CP	-	Chisel Plow
PDC	-	Combined Mold Board Plow and Disk Cultivator
DC	-	Disk Cultivator
RC	-	Row Cultivator
NTD	-	No-Till Drill
HB	-	Herbicide
D	-	Planting Drill

Table 5.6 Type and Number of Tillage Operations for 1907-2030

Time Period	1907-70	1971-88	1989-2030				
Tillage			CTSP	CTFP	RT	NT	CC
Mold Board Plow (fall)	1	1	-	1	-	-	-
Mold Board Plow (spring)	-	-	1	-	-	-	-
Chisel Plow	-	-	-	-	1	-	-
Disk Cultivator	2	1	2	2	1	-	-
Planting Drill	-	1	-	-	-	-	1
Row Cultivator	2	1	2	2	1	-	-
Herbicide	-	-	-	-	-	1	-
No Till Drill	-	-	-	-	-	1	-

Note: The numbers in the column under a particular tillage practice reflect the number of times a particular tillage operation will be performed.

Abbreviations:

CTSP - Conventional Till Spring Plow
CTFP - Conventional Till Fall Plow
RT - Reduced Till
NT - No Till
CC - Crop Rotations with Cover Crops

The timing of operations was developed in relation to expected planting and harvesting dates for each of the simulated crops for each Climate Division (CD). The U.S.D.A Handbook No. 628, Usual Planting and Harvesting Dates for U.S. Field Crops, (U.S.D.A., 1984) provided this information for the Study Region for each individual state. Plowing was set in the month either prior to planting, for spring plowing, or following harvest for fall plowing. Field cultivations were set at monthly intervals following planting. The monthly time step in CENTURY precluded a more accurate representation of the seasonal variation in planting and harvesting dates across the Study Region since the dates had to be adjusted to the most appropriate month, although differences of a few weeks were common among the CDs. Consequently, the timing of operations was essentially the same in much of the study region, except for earlier planting in a few of the southern CDs. Table 5.7 summarizes the planting and harvesting date information.

Table 5.7 Summary of Planting and Harvesting Dates for RAMS Study Region

	Northern CDs		Southern CDs*	
Crops	CENTURY Planting Date	CENTURY Harvesting Date	CENTURY Planting Date	CENTURY Harvesting Date
CRN	5/1	10/1	4/1	9/1
CSL	5/1	10/1	4/1	9/1
SOY	5/1	10/1	5/1	10/1
SWT	5/1	9/1	3/1	7/1
WWT	11/1	8/1	10/1	7/1
HAY	4/1	6/1,8/1,10/1**	3/1	6/1,8/1,10/1**

* - Represents CDs in Arkansas, Kansas, Missouri, Oklahoma and Tennessee. All other CDs are represented as Northern CDs.

** - Represents three harvest events.

Abbrevations:

CRN - Corn
CSL - Corn Silage
SOY - Soybean
SWT - Spring Wheat
WWT - Winter Wheat
HAY - Legume and Non-Legume Hay

Harvest and 'Grazing' Parameters -

The harvest and grazing parameters in CENTURY are used to specify the disposition of the total crop biomass, including both grain and shoots, as a result of harvest operations for both forage and non-forage crops. These parameters have a major impact on soil carbon because they determine the amount of plant material remaining after harvest that is subsequently available to replenish or increase soil carbon levels. For **non-forage crops**, like corn-grain, soybeans, and small grains, we assume that all the grain is removed during the harvest operation, that none of the plant residue is removed, and that 50% of the residue remaining after the operation is left in the 'standing dead' pool (see Figure 5.2). These assumptions are reflected in the harvest parameter values shown in Table 5.8. The values shown were developed primarily based on experience with wheat in the Great Plains, but they are generally appropriate for other crops and regions. The assumption that none of the plant residue is removed has the most impact on soil carbon levels as this allows all plant material, except the harvested grain, to ultimately return to the soil. The assumption that 50% of the residue remains as standing dead has little impact since subsequent tillage operations re-distribute the residue among the various pools, except for No-Till, which lacks the operations for residue incorporation.

Table 5.8 Harvest parameters for Corn-Grain, Soybeans, and Small Grains (Wheat, Barley, and Oats) (assuming only GRAINS are harvested)

Model Parameter	Definition	Value
AGLREM	Fraction of above ground live which will not be affected by harvest operations	0.00
BGLREM	Fraction of below ground live which will not be affected by harvest operations	0.00
FLGHRV	Flag for grain harvest (indicating harvest of grains)	1
RMVSTR	Fraction of the above ground residue that will be removed	0.00
REMWSD	Fraction of the remaining residue that will be left standing	0.50
HIBG	Fraction of roots that will be harvested	0.00

For the forage crops, i.e., corn-silage and hay, a different approach was used. Since these crops are grown primarily for animal (cattle, hogs) production, we devised an approach that attempts to account for the animal waste returned to the field from use of these crops as animal feed. Unfortunately, we were unable to locate or identify any regional or national scale data base that would allow us to define animal waste application rates (C and N) for all the cropland in our CDs. However, there is a clear correlation between animal populations and forage crop acres for counties in our study region. Based on this information, **we assumed that all forage crops grown within a CD are fed to animals within the same CD and the resulting waste is returned to the same forage cropland as fertilizer.** Although this is an approximation, it is appropriate for the scale of our assessment, and it allows us to maintain a mass balance for C and N for these crops that is consistent with the available data.

The NREL staff recommended the use of the 'grazing option' in CENTURY to represent the direct return of animal waste derived from the harvested forage crops. Table 5.9 shows the parameter values used to represent the internal link between the harvested forage crops and the animal waste C and N returned to the field. In effect, the values were set to represent a pseudo-harvest, or grazing, event as removing 90% of the crop and returning 40% of the N content,

Table 5.9 Harvest (Grazing) parameters for Corn-Silage and Hay.

Model Parameter	Definition	Value
FLGREM	Fraction of live shoots removed by a grazing event	0.90
FDGREM	Fraction of standing dead removed by a grazing event	0.90
GFCRET	Fraction of removed material returned by a grazing event for carbon	0.20 (corn) 0.30 (hay)
GRET(1)	Fraction of N in removed material returned by a grazing event	0.40
GRZEFF	Effect of grazing on production 0 - No direct effect 1 - Moderate effect (linear decrease in production) 2 - Intensively grazed production effect (quadratic effect on production)	0.0
FECF(1)	Fraction of N in material returned as feces (added to litter pool, rest added to mineral N)	0.80
FECLIG	Lignin content of feces	0.25

and 20% to 30% of the C content to the field; the value of 20% was used for corn-silage and 30% for hay, due to the larger biomass and C/N ratio of the corn-silage.

The return percentages were derived from a brief review of the limited literature on this subject -- primarily reports of N losses associated with the transformation of feed to animal waste and its return to the field. In studies on N balances for grasslands, Woodmansee (1979) cites literature to support a 17% uptake of N from ingested feed, with the remaining 83% eliminated in the waste. He also assumed a 50% loss due to volatilization of the inorganic N (primarily NH_3), which is consistent with estimates of handling and application losses by Donigian et al. (1991) and Mosier (personal communication, 1992). Further assuming a minimal 5% loss for runoff/leaching from feedlots, we see that the three loss mechanisms combine to produce about 40% of crop N returned in the applied waste (i.e., 0.83 x 0.50 x 0.95 = 0.39, rounded to 40%.). Using estimated C/N ratios for corn-silage (30-40), hay (20-30), and animal waste (15-20), we estimated a 20% return of C for corn-silage and 30% return for hay.

Clearly, this approach is an approximation to the complex transformations of C and N in animal wastes, and the impacts of potential feed and waste transfers (and associated C balances) among the counties and subregions of the study area. Further refinement of this approach, or an alternative, possibly integrating animal population data and use of small grains as feed stocks, should be investigated in future efforts. However, for this initial effort, we believe this simplified assessment is reasonable for the scale of our CDs and the limited extent of corn-silage and hay croplands in the study region.

5.1.3 Fertilizer and Irrigation Inputs

The primary inputs to agricultural production systems that affect soil carbon levels include fertilizers, animal waste, pesticides, and irrigation. The procedures for accommodating animal waste applications and use of pesticides (primarily herbicides) to replace tillage operations were described above. This section discusses the procedures used to represent fertilizer and irrigation applications. For both of these inputs, CENTURY allows the user to select 'automatic' options that allow the model to calculate nutrient and water inputs as a function of crop and soil moisture conditions, associated crop needs, and selected fractions of optimum levels (farmer control) during the growing season. Thus, based on model parameter values selected by the user, CENTURY calculates the needed nutrient and irrigation water inputs and makes them available to the crop.

For the **automatic fertilizer option**, CENTURY allows the user to define the fraction of maximum potential carbon production desired and then determines the nutrient application rate needed to attain that level while maintaining crop nutrient concentrations at appropriate levels. Thus, if the user desires a fertilization level corresponding to 80% of maximum crop (i.e., carbon) production, he sets the input parameter (aufert=A80) to indicate 80% of production and the model applies the appropriate amount of nutrient. Since we are only modeling C and N in this study, N was the only nutrient added as fertilizer.

Similarly for the **automatic irrigation option,** CENTURY allows the user to define the soil moisture level, as a fraction of available water holding capacity(AWC), at which irrigation will be applied to raise the level to field capacity. Thus, if the user defines the trigger level at 50%, the model will add enough water whenever the moisture level reaches 50% of AWC to raise the level to field capacity. This option was only used for the CDs and crop rotations receiving supplemental irrigation as identified by the RAMS model.

CENTURY provides a number of other options, including defining specific fertilizer and irrigation applications; however, the options described above were the ones chosen for this study. The lack of reliable, comprehensive data bases for fertilizer and irrigation (as with animal waste) applications for all crops, rotations, and regions of the study area precluded any possible reliance on use of actual data for these inputs. The study team decided that the use of these automatic options within CENTURY were reasonable and appropriate for the purposes of this study.

5.2 DEVELOPMENT OF INITIAL SOC CONDITIONS AND BASELINE PROJECTIONS

Significant changes in soil organic matter, either depletion or accumulation, usually occur slowly in agricultural systems with timeframes on the order of decades. In estimating equilibrium soil carbon levels under native grassland and rangeland conditions, the CENTURY model is often run for 5000 to 10,000 years in order to calculate stable values (Parton et al., 1989; Burke et al., 1990). In agricultural systems, changes in soil carbon depend on soil texture, regional climate, and carbon inputs to the soil, which are determined by cropping practices, crop yields, and management (i.e., rotations, tillage, fertilizer applications, residue/harvest practices). The challenge for this study was to develop a procedure for estimating initial soil carbon levels for each of our CDs, consistent with historical agricultural practices within each CD, as a basis for projecting future changes in SOC under both baseline (Status Quo) and alternative policy scenarios. A correlated issue is how to define the assumptions that establish the baseline condition over the projection period, i.e., do we assume agricultural practices will not change over the next 40 years or do we incorporate changes that are expected even without additional policy changes? Both issues are discussed below.

Although a number of soils data bases exist that include soil carbon, or organic matter, their utility for estimating initial soil carbon levels is limited. The primary limitation is that the data are usually associated with a specific soil series but without any definition of the variation in SOC due to the specific historical practices. Pedon data bases that provide values for defined sample sites also suffer from not having a history of the land use at the site. Moreover, the values in the data bases are derived from samples collected over the past 10 to 20 years, so they are not really 'current' conditions. Even if appropriate soil carbon data were available, assigning values to the individual carbon pools in CENTURY would be difficult because the pools are conceptually defined based on turnover rates.

The approach developed to estimate starting SOC conditions was suggested by Dr. Vern Cole of the USDA Agricultural Research Service (Fort Collins, CO) based partly on his past work with CENTURY (Cole et al., 1989), studies by Paustian et al. (1992) on impacts of carbon inputs on soil carbon, and current studies modeling historical yields and SOC on wheat-fallow systems in Colorado (V. Cole, personal communication, 1992). The underlying concept is to model a prior historic time period of agricultural activity, and calibrate to historic crop yields, so that the carbon inputs to the soil, the major factor determining soil carbon levels, are accurately represented.

To apply this general concept to the study region, we developed historical scenarios for cropping practices, tillage practices, fertilizer use, and harvest practices, and then attempted to match historical yield trends within each CD so that carbon inputs and SOC could be estimated with CENTURY. The overall steps in the methodology for estimating starting conditions are listed below, followed by a discussion of the underlying assumptions:

1. Use the IVAUTO option in CENTURY to start model runs in 1907 assuming a native grassland condition prior to the onset of agriculture. The IVAUTO option allows the user to estimate beginning (1907) SOC conditions based on regression models developed by Burke et al. (1989) that estimate SOC as a function of soil texture and regional climate. Although the data used by Burke et al covered only the western fringes of our Study Region, we believe the 81-year simulation period from 1907 to 1988 will minimize the impact of any discrepanices in the 1989 starting values for our projection period.

2. Identify and select the **dominant rotation** in each of the CDs based on the distribution and area of rotations provided by RAMS. Table 5.10 lists the dominant rotations for each PA, the corresponding CDs within the PA, and the percent of PA cropland occupied by the dominant rotation.

3. Run CENTURY for each dominant rotation in each CD for each of the **6 soil texture groups** existing in the CD for the period 1907 to 2030; Table 5.11 lists the primary assumptions for weather data and historical management practices for defined time periods, which are discussed further below.

4. Calibrate the CENTURY model crop parameters to historic crop yield data for the 1907 to 1988 time period, for all crops and for the dominant soil type within each rotation, so that historic carbon inputs are represented.

5. Use the 1988 year-end conditions for SOC (and all other CENTURY required state variables) for each soil texture group and rotation as **the starting conditions for the 1989-2030 projections;** starting in 1989 allows a 1- to 2-year period to adjust any inconsistencies between the initial conditions and the simulated scenario.

Table 5.10 Dominant Crop Rotations within Each PA

PA #	CD #	CR #	Crop Rotation Sequence	% of PA Area
22	221 to 223	CR239	CSL,CSL,CSL,SWT	88.9
23	231 to 232	CR145	CRN,CRN,WWT,HLH,HLH,HLH	45.0
24	241 to 242	CR100	CRN	25.5
25	251 to 253	CR186	CRN,SOY	42.8
26	261 to 262	CR145	CRN,CRN,WWT,HLH,HLH,HLH	46.8
27	271 to 272	CR186	CRN,SOY	38.4
28	281 to 282	CR503	HLH,HLH,HLH,HLH	35.0
31	311 to 314	CR508	NLH,NLH,NLH,NLH	27.2
32	321 to 323	CR203	CRN,SOY,WWT,HLH,HLH,HLH	56.0
34	341 to 342	CR144	CRN,CRN,WWT,HLH,HLH	87.1
35	351 to 353	CR186	CRN,SOY	71.2
39	391 to 393	CR186	CRN,SOY	40.4
40	401 to 403	CR100	CRN	36.4
41	411 to 416	CR186	CRN,SOY	58.6
42	421 to 422	CR186	CRN,SOY	54.1
43	431 to 433	CR201	CRN,SOY,WWT	51.8
44	441 to 444	CR186	CRN,SOY	45.1
47	471 to 475	CR463	SMF,SWT	36.6
53	531 to 533	CR463	SMF,SWT	30.9
56	561 to 562	CR131	CRN,CRN,SOY	71.8
57	571 to 573	CR131	CRN,CRN,SOY	70.5
58	581 to 584	CR508	NLH,NLH,NLH,NLH	60.2
59	591 to 592	CR100	CRN	53.4
60	601 to 603	CR508	NLH,NLH,NLH,NLH	35.0
61	611 to 612	CR508	NLH,NLH,NLH,NLH	45.8
63	631 to 634	CR503	HLH,HLH,HLH,HLH	75.3
64	641 to 643	CR131	CRN,CRN,SOY	70.0

Table 5.11 Schedule of Climate and Management Practices for Estimating Soil Organic Carbon

Time Period	Weather Data[1]	Crop Varieties	Tillage Practices[2]	Irrigation	Fertilizer	Grazing/ Manure[3]	Harvest
1907-35	1948-76	Low Yld.	Conventional	None	None	Manure Return for Forage Crops	GS[4]
1936-47	1977-88	Low Yld.	Conventional	None	A50[5]	"	G[6]
1948-70	Historical	Medium Yld.	Conventional	Irrigated[7]	A80[5]	"	G[6]
1971-88	Historical	High Yld.	Limited Conservation	"	A[8]	"	G[6]
1989-2030	1948-88	Higher Yld.[9]	Policy Scenario	"	A[8]	"	G[6]

1 - 1948-88 Site meteorological data was used for the periods, prior to and following the historical period.
2 - See Table 5.6 for specific tillage operations in each time period.
3 - Grazing/Manure represented manure returned from forage crops (i.e. Legume and Non-Legume Hay and Corn Silage) used for animal feed stocks.
4 - At harvest 50 percent of straw is removed along with grains.
5 - Automatic Fertilizer application to maintain crop production at 50% (A50), 80% (A80) of Potential Maximum Production, without increasing plant nutrient concentration above the minimum level.
6 - Only grains harvested.
7 - Irrigation was applied when 50% of the available water was depleted, the soil water status was brought to field capacity after each irrigation. Irrigation started in 1948.
8 - Automatic Fertilizer application to maintain crop production at 100% (A) of Potential Maximum Production, and increase plant nutrient concentrations to the maximum level.
9 - Crop production parameter (PRDX) adjusted to reflect 1.5% yearly increase in yield for the projection period; impacts of alternative annual increases (i.e. 1.0% and 0.5%) are discussed in Section 6.4.

6. Run CENTURY for the 1989-2030 projection period **for all rotations within the CD based on the RAMS data,** using the starting conditions from 1988 (Step 5 above). For the projection period, calibrate crop yields to approximate a 1.5% per year increase in yields expected due to both crop technology and genetic advances (U.S.D.A., 1990); see further discussions below. To evaluate the impacts of alternative yield increase levels (e.g., 1.0% and 0.5%), this step is repeated for each level.

7. Weight the model results by the soil texture area distribution (i.e., fraction of cropland associated with each soil texture group) for each simulated scenario in each CD to get the final model projections.

5.2.1 Underlying Assumptions for Starting Conditions and Baseline Projections

Table 5.11 lists the underlying assumptions used to approximate the evolutionary changes in agricultural practices over the 120-year simulation period, including the past 80 years and the 40-year projection period, so that we could use CENTURY to attempt to estimate changes in soil carbon. Clearly, we did not have the resources nor the data to accurately track historical changes in agricultural practices for the 489-million-acre Study Region. Our goal was to develop a reasonable pattern of the timing and nature of changes in agriculture that have a direct effect on soil carbon, in order to arrive at a reasonable starting point for assessing future changes.

Climate -

The 41-year climate data base discussed in Section 4.0 was used in simulating the actual time period of data 1948-88, and both the prior and following time periods of 1907-47 and 1989-2030. Although CENTURY includes an option to stochastically generate monthly precipitation, testing showed that this produced much greater projected year-to-year variability in crop yields than observed. Also, since an analogous capability did not exist for monthly air temperature, use of the observed data was judged to be the best approach.

Tillage -

The type and number of tillage operations were shown in Table 5.6 for each of the simulation time periods. Conventional tillage was assumed through 1970, when a gradual shift to various types of conservation tillage began. Larson and Osborne (1982) cite statistics showing that conservation tillage was only 2.3% of harvested cropland nationwide in 1965, and this increased to 16% in 1979. Citing data from the Conservation Tillage Information Center (CTIC), Mannering et al. (1987) show that conservation tillage was increasing but was still less than 10 to 15 million acres nationwide in the late 1960s. The RAMS data showed conventional tillage to currently still be 70% of the study region harvested cropland, i.e., 1989-90. For the 1971-88 simulation period, we reduced the number of tillage operations to accommodate the trend toward less tillage, but maintained conventional tillage as the dominant practice.

Fertilizer and Irrigation -

Dramatic increases in fertilizer use in the 1940s and following WW II is cited as one of the reasons for significant yield increases for the major production crops (Tisdale et al., 1985). As shown in Table 5.11, we assumed the use of fertilizers began about 1936 with levels leading to 50% of maximum production for 1936-74, 80% of maximum production for 1948-70, and 100% of maximum production after 1970.

For irrigation applications, the Council for Agricultural Science and Technology (CAST) noted significant increases in irrigation water use in the Great Plains and the East starting in the mid-to-late 1940s (CAST, 1992). We assumed that irrigation began extensively in the time period beginning in 1948, and that irrigation water was applied when the moisture deficit reached 50% of available water holding capacity. The RAMS output identified the specific crops, rotations, and PAs where irrigation was practiced.

Harvest and Manure Applications -

The impacts of harvest operations on plant residues and the procedures for accommodating the C and N return from forage crops was discussed above in Section 5.1. In Table 5.11 we note that, for the initial time period of 1907-35, we assume that 50% of the plant residue is removed along with the grain at harvest time, and that, beginning in 1936, only the grain is harvested with all the plant residue remaining in the field. These assumptions were derived from Cole et al. (1989) for wheat-fallow cropping systems in the northern Great Plains to approximate the advent of harvesting combines and their greater selectivity of grain harvest. The validity of these assumptions for other crops and regions is unknown and should be further investigated.

Crop Varieties and Yields -

As noted above, the procedure we followed to estimate initial SOC levels involved calibrating crop yields to match historic levels during the simulation period. This led to lower yielding varieties (and associated crop parameters in CENTURY) for the 1907-47 time periods, increasing yields from 1948-70, and the highest historic yields in the latest period of 1971-88. The crop yield data (discussed in Section 4.0) clearly showed the sometimes dramatic trends of increasing crop yields; Flach et al. (1992) cite references supporting annual increases in crop yields averaging 1.8% per year during that past 40 years. For the projection period 1989-2030, a **1.5% per year increase was assumed** based on U.S.D.A. projections (U.S.D.A., 1990). Although the CAST report indicates that this level of yield increase may be obsolete (the projections were made in the early 1980s) and optimistic since increases in the 1980s were considerably less, it concluded that they were plausible (CAST, 1992).

This assumption of a 1.5% per year increase in crop yields is a critical factor in projecting soil carbon levels, and associated carbon sequestration, over the next 40

years. To assess the general sensitivity of the study conclusions to this assumption, additional model runs were performed on the entire Study Region assuming annual yield increases of 1.0% and 0.5% (see Section 6.4).

5.3 STATUS QUO/BASELINE CONDITIONS

The Status Quo, or Baseline, scenario represents the projection of changes in SOC from 1990 to 2030 under current cropping practices and current trends, the most critical of which is the assumed annual 1.5% increase in crop yields. As noted earlier, the output of the RAMS model included the acreages for each crop rotation practiced within each PA, along with the tillage practices and areas receiving supplemental irrigation. The other assumptions used in simulating each crop rotation under the Status Quo conditions with CENTURY were discussed above in terms of model parameter values selected. The baseline for the RAMS model is the 1991 growing season. Commodity program parameters for the 1991 programs were used. Input prices for 1990 were used. 1991 data were not available, but, crop inputs such as seed and fertilizer are often purchased in the previous year for tax purposes or because discounts are offered. Acreages and chemical usage were calibrated to 1990/91 data. Commodity prices were estimated as averages for the 1991 calendar year, using projected prices for the later months. crop yields, were estimated for 1991.

5.4 ALTERNATIVE POLICY SCENARIOS

Three policy scenarios were analyzed, including increased use of **Conservation Tillage**, increased use of **Cover Crops**, and **impacts of the Conservation Reserve Program (CRP)**. The first two of the three scenarios were represented in RAMS by (1) targeting adoption of no-till and reduced tillage practices to levels suggested by tightening the criteria for defining highly erodible land for conservation compliance purposes, and (2) targeting planting of winter cover crops following sorghum, silage and small grains. The third involved identifying 'likely' changes in the CRP over the 1990-2030 projection period. In the case of conservation compliance, targeting of the most erosive land offers a dual benefit of reducing erosion and increasing storage of carbon in agricultural soils. Therefore, we are exploiting mutually beneficial policy outcomes by selecting the appropriate instrument.

5.4.1 Constricting the Criteria for Defining Highly Erodible Land

Conservation compliance, initiated in the 1985 farm bill, ties receipt of a long list of financial benefits from the government to the development and implementation of plans to reduce erosion on tracts of land determined to be eroding excessively (i.e., highly erodible lands). The criteria for defining highly erodible lands, eventually rested with $EI > 8$, where EI is an "erodibility index" equal to RKLS/T for water erosion. R, K, L, and S are the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) coefficients and T is the theoretical amount of soil loss that if exceeded will lead to losses in productivity. Only water erosion is considered and is clearly the dominant form of erosion in the study region. $EI > 8$ is merely a guideline which individual counties followed while identifying highly erodible land.

Once a tract of land is labeled highly erodible, conservation practices must be outlined in a plan and approved by local SCS officials. A separate criteria was involved in deciding which practices were acceptable. The most restrictive criteria demands that erosion be reduced to T. Individual producers proving economic hardship were allowed to meet a less restrictive criteria. With the more restrictive criteria, the following relationships must hold on highly erodible land:

(1) $E \leq T$
(2) $E = RKLSCP$,

Therefore,

(3) $RKLSCP \leq T$ or
(4) $1/CP \geq RKLS/T$,

From above,

(5) $EI = RKSL/T$,

Therefore

(6) $1/CP \geq EI$,

where:

E	=	erosion measured in tons/acre
T	=	allowable soil loss for which productivity is maintained
RKLS	=	USLE coefficients for climate, soils, and topography
CP	=	USLE coefficients for specific production practices
EI	=	erodibility index

Modeling conservation compliance in RAMS involved estimation of EI values from the National Resource Inventory (NRI) and other sources for all land in the study area. Six "highly erodible land groups" (HELG) based on ranges of the estimated EI values are defined, as follows:

EI Range	HELG
0-8	not highly erodible
9-15	1
16-22	2
23-29	3
30-36	4
37-43	5
>43	6

The amount of land falling into each HELG is estimated from NRI and other data. CP values estimated for all production activities in RAMS are evaluated for each group of highly erodible

land. From equation (6), if $EI^* < 1/CP$, where EI^* is the minimum of the range for each HELG, the practice is considered to meet the conservation compliance requirements for that HELG.

For the present analysis, the amount of land falling into one of the six highly erodible land groups was used as the target for different levels of conservation tillage. This was modeled by constraining the sum of No-Till plus Reduced Tillage to be equal to the amount of highly erodible land. Naturally, as the minimum EI for land to be considered highly erodible was reduced from 8 to 5 to 2, the amount of land required to be in conservation tillage increased. Table 5.12 gives the amount of land considered highly erodible as a percentage of the total cropped acres for various levels of EI for the entire Study Region. Based on this analysis, the EI target values of 8, 5 and 2 were chosen to represent three alternative levels of conservation tillage implementation within the Study Region. The RAMS analysis then provided the specific changes in tillage practices for all the crop rotations practiced within each PA. Table 5.13 summarizes the tillage distribution for the Study Region for each of these three -- low, medium, high -- levels of conservation tillage implementation; Table 5.14 shows the same information by PA.

5.4.2 Winter Cover Crops

With guidance from CARD, Dr. Rick Cruse, Professor of Agronomy at Iowa State University, gathered data and developed agronomic practices for winter cover crops in the Study Region. While cover crops will likely improve the soil carbon content of the soil (all else equal), reduce soil erosion and fix nitrogen available to the subsequent crop in the case of hairy vetch, cover crops also cost money and, because of competition for moisture, reduce yields in the subsequent crop. Further, establishment of a reasonable stand of cover crop is not feasible with every crop sequence in every PA of the Study Region. Dr. Cruse defined the crop sequence, geographic area and application method combinations that are feasible candidates for establishing cover crops.

Figure 5.3 shows the PAs where cover crops were deemed to be feasible along with the '% of cropland' that includes rotations with cover crops, as determined by RAMS. Table 5.15 shows the cover crop acreages and '% of cropland' by PA and for the Study Region. Although only 12% of the Study Region includes rotations with cover crops, in some PAs the proportion reaches 40 to 50%, and it averages 23% for the PAs where cover crops are viable. Cover crops were considered feasible primarily in the southern half of the Study Region, with the greatest concentration in the southcentral area in the states of Missouri, Arkansas, southern Illinois, and western Tennessee. Note that the specific mix of rotations in PA 32 were not considered supportive of cover crops.

Following the identification exercise, the data needed in RAMS were collected. Because of the crop sequence and geographic specific nature of utilizing cover crops, the time needed to collect and process the large amount of data was greater than initially anticipated. Once the necessary data were collected and incorporated into RAMS, a new baseline with cover crops was run.

Table 5.12 Percentage of Acres Considered Highly Erodible for Alternative EI Criteria by PA and the Entire Study Region

	% Considered Highly Erodible						
PA	EI=8	EI=7	EI=6	EI=5	EI=4	EI=3	EI=2
22	6.91%	8.15%	9.53%	10.99%	17.92%	24.38%	37.29%
23	10.46%	13.10%	16.74%	21.40%	28.15%	39.27%	55.63%
24	17.01%	19.50%	23.51%	28.03%	33.66%	42.50%	57.04%
25	10.92%	13.09%	16.47%	20.35%	26.07%	33.83%	47.96%
26	1.80%	2.00%	2.63%	4.01%	6.15%	9.62%	15.35%
27	6.41%	7.60%	9.70%	13.48%	18.14%	23.46%	33.15%
28	24.66%	29.22%	35.29%	41.30%	48.94%	59.07%	73.12%
31	50.20%	53.73%	56.54%	60.73%	66.15%	73.70%	82.08%
32	22.36%	25.32%	30.23%	36.20%	43.90%	55.06%	69.21%
34	48.17%	51.54%	55.86%	60.86%	65.33%	72.30%	83.62%
35	13.94%	16.33%	19.72%	23.76%	30.12%	39.94%	56.21%
39	5.77%	6.93%	8.61%	11.12%	14.80%	20.75%	31.52%
40	32.32%	35.65%	39.01%	44.65%	50.95%	61.12%	73.50%
41	27.57%	30.18%	33.39%	37.20%	42.31%	50.76%	64.93%
42	18.13%	20.48%	23.15%	26.60%	32.58%	41.01%	57.20%
43	29.84%	33.20%	36.69%	42.08%	47.84%	57.65%	75.75%
44	20.86%	23.04%	25.24%	29.01%	35.62%	46.17%	68.68%
47	0.88%	1.23%	1.79%	2.31%	3.20%	5.05%	9.89%
53	6.40%	7.61%	9.38%	11.78%	15.83%	21.06%	33.02%
56	34.37%	38.31%	40.97%	44.99%	48.49%	54.13%	65.40%
57	45.29%	48.48%	51.85%	55.93%	60.29%	66.35%	75.78%
58	7.16%	9.20%	11.79%	16.24%	21.06%	30.03%	49.39%
59	24.21%	28.52%	33.00%	37.85%	45.22%	52.64%	69.08%
60	46.14%	50.69%	55.12%	61.19%	67.26%	73.15%	80.55%
61	23.92%	25.74%	28.36%	31.49%	37.87%	51.63%	79.77%
63	3.50%	4.73%	7.01%	10.44%	16.58%	25.59%	45.34%
64	17.18%	23.77%	32.40%	44.45%	60.88%	75.99%	89.04%
Study Region	18.04%	20.32%	23.16%	26.97%	32.18%	39.78%	53.39%

Table 5.13 Tillage Distributions for Policy Scenarios

Modeled Scenarios	Tillage Practice CTFP	CTSP	RT	NT
Status Quo/Baseline	23%	47%	27%	3%
Low Conservation	23%	43%	29%	5%
Medium Conservation	23%	41%	29%	8%
High Conservation	13%	31%	30%	26%
Cover Crops	22%	48%	27%	3%

Table 5.15 Cover Crop Land Distribution by PA

PA #	Cropland (acres)	Cover Crop (acres)	Cover Crop as Percent of Cropland
24	2,164,040	597,924	27.63%
27	6,356,361	1,472,307	23.16%
28	1,237,701	83,901	6.78%
31	2,701,337	442,785	16.39%
34	5,124,066	8,021	0.16%
35	13,904,872	2,815,670	20.25%
41	25,216,417	3,321,539	13.17%
42	13,576,737	2,508,280	18.47%
43	4,878,079	2,282,049	46.78%
44	8,982,813	4,456,571	49.61%
56	2,649,217	546,271	20.62%
57	10,156,826	1,471,673	14.49%
59	5,444,927	933,370	17.14%
60	8,975,078	3,728,537	41.54%
61	864,007	406,235	47.02%
64	4,144,596	1,236,308	29.83%
Total Area	116,377,074	26,311,441	22.61%

Percent under Cover Crop for the RAMS Study Area = 12.15%

Table 5.14 Tillage Practice Distribution by PA for Modeled Scenarios

	Status Quo (EI>8)			Low Conservation (EI≤8)			Medium Conservation (EI≤5)			High Conservation (EI≤2)		
	CNT	RT	NT	CNT	RT	NT	CNT	RT	NT	CNT	RT	NT
22	99.4	0.0	0.6	62.8	34.3	2.9	62.8	34.3	2.9	62.7	34.3	3.0
23	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	44.4	34.3	21.3
24	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	43.0	34.3	22.7
25	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	52.0	34.3	13.6
26	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9
27	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9
28	71.9	22.4	5.7	71.9	22.4	5.7	58.7	22.4	18.9	26.9	22.4	50.7
31	72.6	21.1	6.3	49.8	21.1	29.2	39.3	21.1	39.7	17.9	21.1	61.0
32	91.6	4.1	4.3	61.4	34.3	4.3	61.4	34.3	4.3	30.8	34.3	34.9
34	72.6	17.7	9.8	51.8	21.2	26.9	39.1	21.2	39.6	16.4	21.2	62.4
35	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	43.8	34.3	21.9
39	63.4	33.7	2.8	63.4	33.7	2.8	63.4	33.7	2.8	63.4	33.7	2.8
40	62.8	34.3	2.9	62.8	34.3	2.9	55.4	36.6	8.0	26.5	37.0	36.5
41	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	35.1	34.3	30.6
42	62.8	34.3	2.9	62.8	34.3	2.9	62.8	34.3	2.9	42.8	34.3	22.9
43	62.8	34.3	2.9	62.8	34.3	2.9	57.9	34.3	7.8	24.3	34.3	41.4
44	77.7	18.7	3.7	77.7	18.7	3.7	71.0	18.7	10.3	31.3	18.7	50.0
47	71.4	26.9	1.8	71.4	26.9	1.8	71.4	26.9	1.8	71.4	26.9	1.8
53	73.4	25.0	1.5	73.4	25.0	1.5	73.4	25.0	1.5	67.0	25.0	8.0
56	74.9	23.8	1.3	65.6	23.8	10.6	55.0	23.8	21.2	34.6	23.8	41.6
57	66.4	31.1	2.4	54.7	31.1	14.2	44.1	31.1	24.8	24.2	31.1	44.7
58	74.1	24.8	1.2	74.1	24.8	1.2	74.1	24.8	1.2	50.6	24.8	24.6
59	74.9	23.8	1.3	74.9	23.8	1.3	62.1	23.8	14.1	30.9	23.8	45.3
60	64.7	32.6	2.7	53.9	32.6	13.5	38.8	32.6	28.6	19.4	32.6	47.9
61	98.0	0.0	2.0	72.2	25.8	2.0	68.5	25.8	5.7	20.2	25.8	53.9
63	86.7	12.2	1.1	77.7	21.2	1.1	77.7	21.2	1.1	54.7	22.6	22.7
64	75.8	22.8	1.4	75.8	22.8	1.4	55.6	22.8	21.6	11.0	22.8	66.2
Total RAMS Area	70.0	27.4	2.6	66.3	29.3	4.4	63.2	29.4	7.4	44.2	29.5	26.3

Abbrevations: CNT - Conventional Till, RT - Reduced Till, NT - No-Till

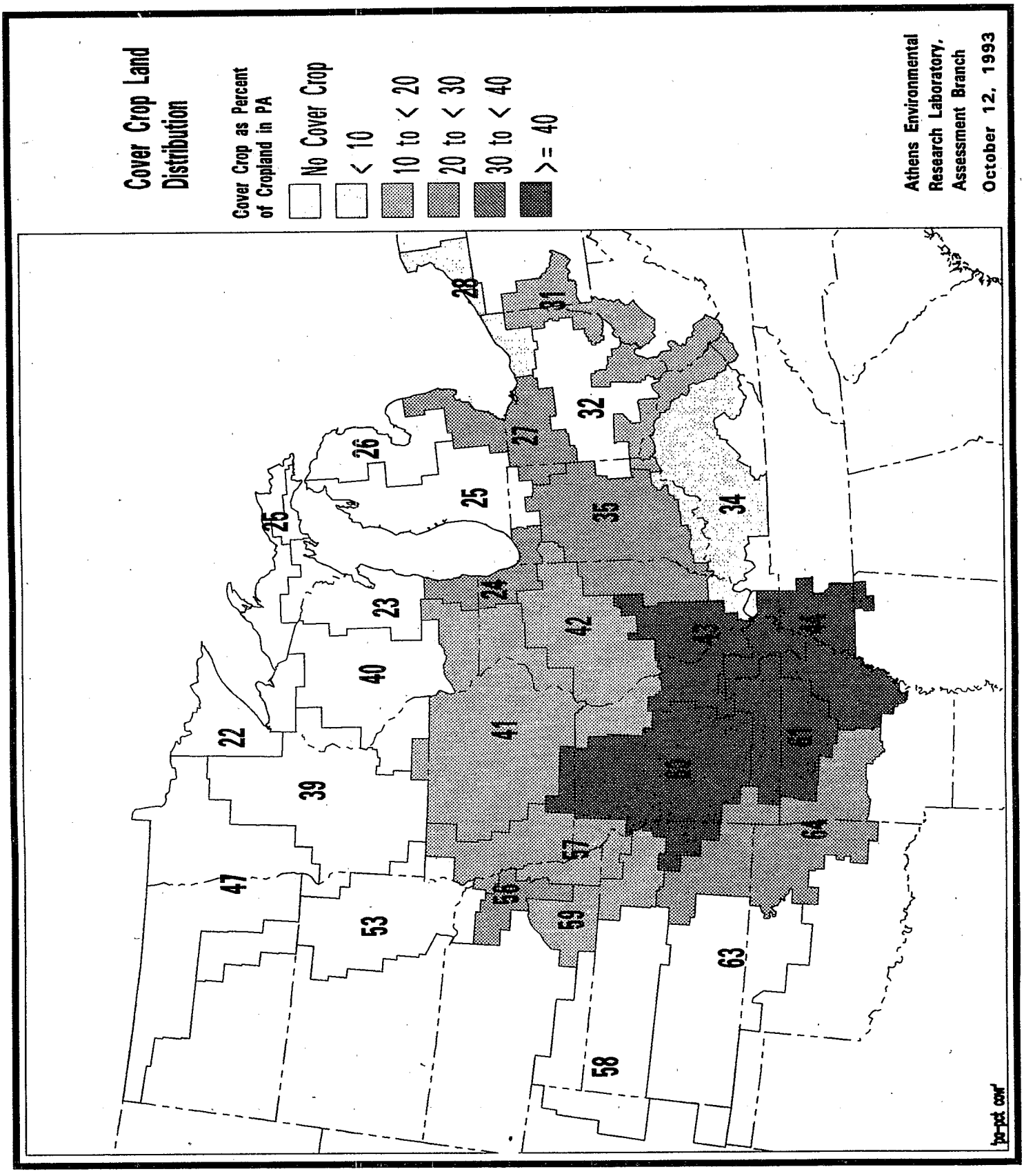


Figure 5.3 Cover crop land distribution within the study region

Including rotations with cover crops increased the number of activities in RAMS by 10 to 30 percent and increased the time required to find the optimal solution for each run.

Targeting cover crops to be grown following sorghum, silage and small grain is accomplished by including a constraint in RAMS to force activities meeting this criterion into the model. The level of the target is specified as the sum of the sorghum, silage and small grain acreage grown under the baseline. While production activities with cover crops for any of the crop sequences modeled are allowed, only those with cover crops grown after one of these crops will count toward satisfying the constraint. One important outcome of this approach is the value of the shadow price on the cover crop constraint. The interpretation of the shadow price is the dollars per acres subsidy needed, at the margin, to get producers to willingly plant the target level of winter cover crops. That is, if a single per-acre incentive payment was offered in the PA, the shadow price is what this incentive payment would need to be to achieve the target level of cover crops.

For the PAs (and CDs), crop rotations, and crop sequences identified by CARD as viable for cover crops, the CENTURY model input was modified to add **legume hay** as a cover crop following harvest of the previous crop, with the entire crop returned to the soil prior to planting of the subsequent crop in the rotation. Legume hay was chosen to represent cover crops to avoid the need to define fertilizer applications, and initial testing showed that legume hay would be consistent with the biomass produced by the rye or hairy vetch cover crop species recommended by CARD. In the spring following the winter cover crop period, the normal tillage practices were followed, i.e., moldboard plow for CT, chisel plow for RT, and herbicides for NT. Note that Table 5.13 shows a slight decrease in CTFP and a slight increase in CTSP for the Study Region as a whole as a result of cover crops requiring spring plowing in place of fall plowing.

5.4.3 Conservation Reserve Program (CRP)

In order to assess the potential impacts of CRP land on SOC, two alternative scenarios were developed and simulated with CENTURY. Below we discuss the two scenarios -- CRP1 and CRP2 -- in terms of their nationwide significance and interpretation, followed by a discussion of how the scenarios would be implemented within the Study Region and are represented by the CENTURY model.

CRP1

Through discussions with several researchers familiar with the policy process at USDA, researchers at CARD determined a "likely" outcome of the CRP program, as current contracts expire (see Table 5.16). It is assumed that the current program reaches 40 million acres nationwide by 1995. This scenario would then maintain CRP coverage on 15 to 20 million acres to include (a) 2.7 million acres of trees, (b) 8.3 million acres of environmentally sensitive grassland, and (c) 4 to 9 million acres of additional grassland. This yields an average of 17.5

Table 5.16 Nationwide CRP Cumulative Enrollment by Crop Under CRP1, 1996-2005 (Thousand Acres).

	Wheat	Corn	Sorghum	Barley	Oats	Cotton	Rice	Soybean	Other	Annual Total
1995	11677	4914	2669	3088	1509	1482	17	4972	9672	40000
1996	11339	4829	2539	3010	1466	1453	17	4804	9418	38875
1997	9330	3616	1979	2473	1220	1097	16	3791	7638	31161
1998	7682	3324	1628	2034	1023	907	15	3337	6286	26236
1999	6720	3020	1458	1766	890	800	12	2998	5560	23224
2000	5896	2788	1342	1551	782	748	10	2727	5075	20919
2001	5832	2731	1327	1534	768	732	10	2678	4988	20601
2002	5679	2613	1301	1503	740	706	10	2576	4842	19971
2003	5489	2459	1256	1453	713	687	9	2443	4638	19147
2004	5299	2304	1212	1402	687	668	8	2311	4433	18324
2005	5109	2150	1168	1351	660	648	8	2175	4232	17500

million acres to remain in the CRP program through the end of the study period, and 22.5 million acres of CRP land to return to production as contracts from the current program expire.

As contracts expire, beginning in 1996, a portion of the total CRP enrollment in 1986 returns to crop production. The land remaining in CRP from 1986 contracts is determined as $ACRP1_{1996} = 17.5 * (ACRP_{1986} / 40)$ where $ACRP_{1986}$ is the total CRP enrollment during 1986. Acreage remaining in the new CRP from contracts expiring in later years is determined similarly. The amount of land returning to crop production as each contract expires is then equal to $ACRP1_{t+10} - ACRP_t$.

Table 5.16 details the distribution of land in the baseline CRP among its alternative uses as existing contracts expire, old contracts are renewed, and some new land is brought into the program. This distribution reflects the use of CRP land before it entered the original 40 million acre CRP. The land returning to crop production is assigned to production of each of the seven program crops (corn, wheat, sorghum, barley, oats, rice, and cotton) and to soybeans according to the proportion of that crop's acreage reduction attributable to CRP in the crop year it entered the original CRP. These reductions are outlined in the FAPRI 1992 Outlook (Johnson et al., 1992) and are based on estimates provided by USDA.

CRP2

CRP2 is simply a continuation of the current program, assuming that the goal of 40 million acres is reached by 1995; all contracts are renewed. No additions or reductions were made to the BLS projections for this scenario, except as provided for by the FAPRI projections in the "fine

tuning" process. Table 5.17 gives the breakdown of the current CRP by area reductions attributed to particular crops. Only the seven program crops and soybeans were explicitly accounted for in the BLS during this analysis. Acreages of other crops were judged to be too small to have significant impacts in the model, and were thus considered in the "other" total. For the analysis, the CRP structure projected through the final sign-up was maintained in every simulation year after 1995.

Table 5.17. Nationwide CRP Current and Projected Annual Enrollment Under CRP2, 1986 - 1995 (Thousand Acres).

	Wheat	Corn	Sorghum	Barley	Oats	Cotton	Rice	Soybean	Other	Annual Total
1986	600	151	231	139	76	50	1	300	452	2000
1987	3571	2156	995	954	437	633	2	1800	3165	13713
1988	2930	520	624	780	351	339	2	807	2403	8756
1989	1710	540	303	477	236	190	4	604	1291	5355
1990	1465	413	206	382	192	92	4	482	862	4098
1991	114	101	27	30	25	28	0	86	154	565
1992	272	209	46	55	50	46	1	182	260	1121
1993	338	275	79	90	47	35	1	236	363	1464
1994	338	275	79	90	47	35	1	235	364	1464
1995	338	275	79	90	47	35	1	242	357	1464
Crop Total	1677	4914	2669	3088	1509	1482	17	4972	9672	40000

Source: Johnson, et al., FAPRI 1992 U.S. Agricultural Outlook.

RAMS provides the current CRP acres in each PA. Table 5.18 lists these CRP acres and '% of cropland' for each PA and for the Study Region, totaling 15 million acres. Figure 5.4 shows the distribution of these acres throughout the Study Region, as the '% of cropland' listed in Table 5.18 **even though the CRP acres are not included in the Study Region cropland total of 216 million acres.** CRP ranges from less than 1% to almost 15% of cropland in the PAs, and totals almost 7% of the cropland in the Study Region.

CRP Simulation with CENTURY

For each PA, CENTURY CRP simulations were performed for two conditions to represent the CRP scenarios discussed above. CRP1 is represented by a conversion to CRP in 1986 and a return to crop production in 2006, while CRP2 is represented by the land remaining in CRP

Table 5.18 CRP Acres by PA Within the Study Region

PA #	CRP (acres)	Cropland (acres)	CRP Acres as Percent of Cropland
22	705	468,736	0.15%
23	62,475	2,850,672	2.19%
24	61,805	2,164,038	2.86%
25	168,216	4,293,392	3.92%
26	42,950	2,475,260	1.74%
27	110,951	6,356,362	1.75%
28	17,550	1,237,701	1.42%
31	33,601	2,701,336	1.24%
32	188,731	6,156,615	3.07%
34	277,762	5,124,067	5.42%
35	325,903	13,904,865	2.34%
39	761,558	12,206,423	6.33%
40	438,578	6,072,917	7.22%
41	1,623,548	25,216,406	6.44%
42	464,764	13,576,758	3.42%
43	234,917	4,878,077	4.82%
44	511,144	8,982,813	5.69%
47	2,139,753	19,937,310	10.73%
53	1,469,394	14,409,609	10.20%
56	167,275	2,649,214	6.31%
57	747,068	10,156,825	7.36%
58	1,347,404	13,760,145	9.79%
59	234,926	5,444,932	4.31%
60	1,317,292	8,975,086	14.68%
61	12,122	864,009	1.40%
63	2,048,974	17,472,893	11.73%
64	262,849	4,144,601	6.34%
Total Area	15,072,216	216,481,104	6.96%

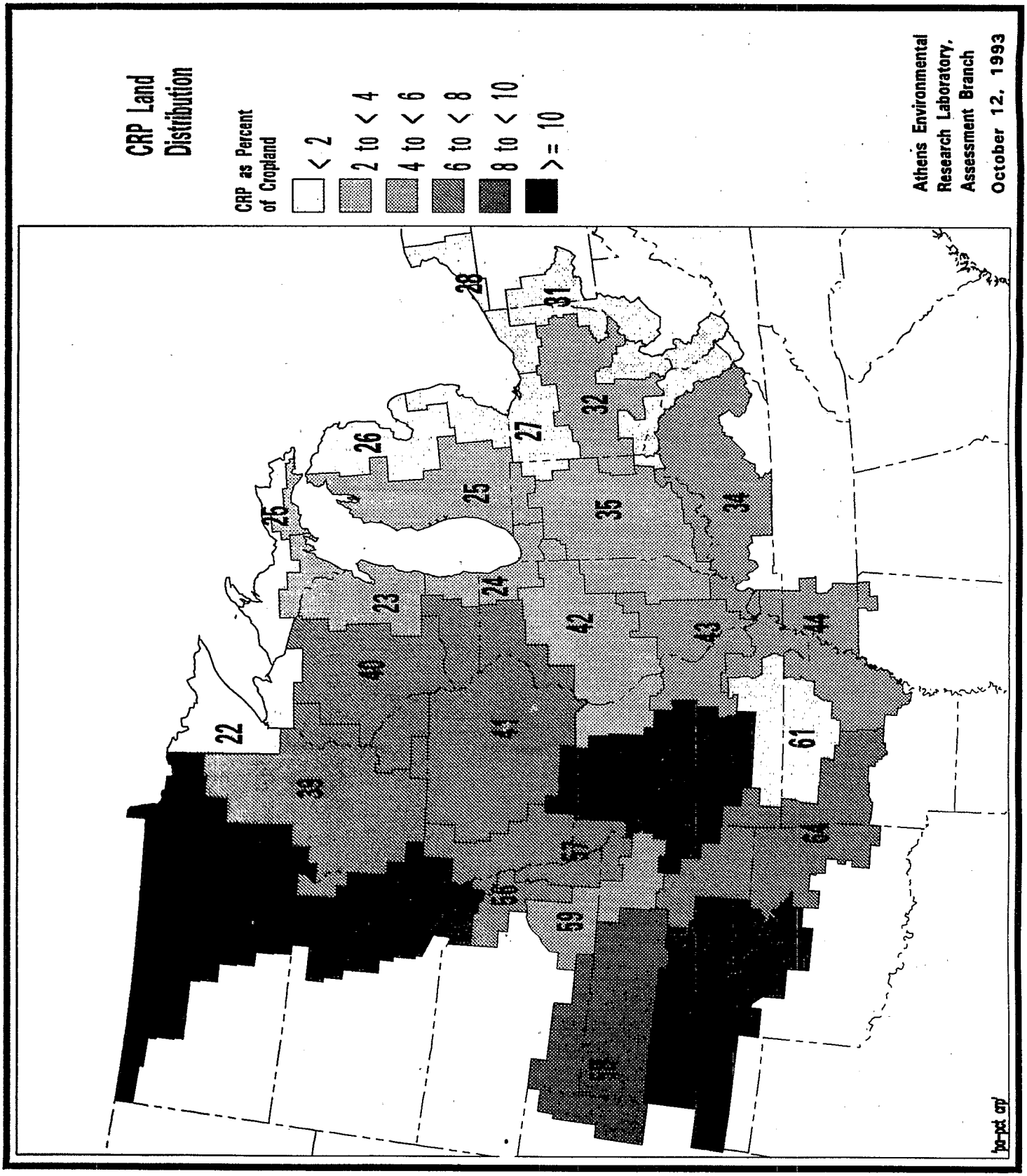


Figure 5.4 CRP distribution within the study region

from 1986 through 2030. The primary assumptions in representing CRP land in CENTURY are as follows:

Native grass grown (50% warm and 50% cold weather grass species)
No annual tillage
No harvest or cutting of grass
No fertilizer application
Atmospheric N deposition is included
Crop senescence in the month of November

For CRP simulations, the initial SOC conditions were determined as described in Section 5.2. The dominant crop rotation was simulated from 1907 through 1985 when conversion to CRP was assumed. Under CRP1 when crop production resumes in 2006, the simulation returns to the dominant crop rotation in each PA. Under CRP2, the converted land remains in CRP through 2030. The only exceptions to these procedures were for PAs where the dominant rotation is continuous hay; all the other PAs had dominant rotations with a minimum of 40% cash crop, i.e. at least 2 out of 5 years in corn, soybeans, wheat, etc. (see Table 5.10). For the PAs with dominant hay rotations, we chose the next most common rotation that included at least 40% of the years in a cash crop; we refer to this as the **dominant cash crop rotation.** The impacted PAs and dominant cash crop rotations are listed below:

PA	DOMINANT CASH CROP ROTATION		TILLAGE
PA28	CR144	CRN,CRN,WWT,HLH,HLH	CTSP
PA31	CR145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP
PA58	CR100	CRN	CTSP
PA60	CR201	CRN,SOY,WWT	CTSP
PA61	CR186	CRN,SOY	CTFP
PA63	CR218	CRN,WWT	CTFP

For the above PAs, the starting 1986 conditions for the CRP scenarios were estimated by running the dominant rotation for the 1907-1970 time period and then converting to the dominant cash crop rotation for the 1971 to 1985 period. This approach provided consistency with the assumptions on historical practices for all the PAs and allowed a 15-year period for the cash crop rotation prior to CRP conversion.

In summary the CRP scenarios are as follows:

CRP1 Dominant rotation, or dominant cash crop rotation, is converted to CRP in 1986. In 2006, after 20 years under CRP, 56% of 15 million enrolled acres in the Study Region (i.e., 8.4 million acres) are converted back to the dominant rotation (or cash crop rotation), with the remaining 44% (6.6 million acres) staying in CRP through 2030.

CRP2 Land remains in CRP from 1986 through 2030 at the 15 million acre level.

5.5 OPERATIONAL PROCEDURES FOR GENERATING SOC LEVELS

As discussed in the Section 3.5, the Project Methodology involved matching of historical and projected crop yield data with CENTURY yield predictions, under assumed crop residue and management practices, as key elements in estimating soil carbon levels for the historical, current, and projection time periods. The basic premise was that adjusting CENTURY model parameters to accurately portray historical crop yield data, and using reasonable assumptions for historical (and future) tillage and management practices, would result in accurate estimates of carbon inputs into the soil environment, and would thus provide a sound basis for estimating soil carbon.

Since the Study Region is divided into 80 climatic divisions (CDs), each CD with at least four crop/rotation/tillage combinations, and calibrations were required for each crop throughout the 120-year simulation period, a large number of CENTURY simulations were performed. Consequently, an automated calibration procedure was developed to calibrate the CENTURY crop yield model to predict both historical and projected future crop yield levels. The following section discusses the operational steps that were followed for the CENTURY crop yield calibrations and the overall simulations of historical practices and alternative policy scenarios.

5.5.1 Operational Procedure for CENTURY Simulations

Eight steps were executed in order to perform the CENTURY model yield calibrations and simulations to estimate soil organic carbon levels in each CD for every crop/rotation/tillage combination in the Study Region.

STEP 1. The first step consisted of creating weather files for the 80 CDs, as defined by the meteorologic data analyses discussed in Section 4.1. Using the procedure discussed in Section 4.1, weather files consisting of 41 years of monthly precipitation (cm/month), maximum temperature (°C), and minimum temperature (°C) were created for each CD.

STEP 2. The crop and agricultural management inputs to the CENTURY model are provided by a 'scheduling' file. The following information is contained in each scheduling file:

a. Sequence and crops grown in crop rotation.
b. Crop variety grown (e.g., high yield or low yield).
c. Planting and harvesting dates for each crop in a rotation.
d. Time and type of tillage practice.
e. Amount of fertilizer application (calculated by CENTURY).

f. Amount of irrigation application (calculated by CENTURY).
g. Starting and ending year of simulation.

A scheduling file was created for each crop/rotation/tillage combination. The CENTURY model allows the user to simulate different crop rotations during different time periods of the simulation, e.g., a crop rotation can be simulated from year 1 to year 4, and then the conditions at the end of year 4 are the starting conditions for simulations starting in year 5. The crop rotation starting in year 5 can be different from the crop rotation simulated from years 1 to 4. This option in the CENTURY model is called the EXTEND option.

As discussed in the Project Methodology (Section 3.5), scheduling files were created for the dominant crop rotation in each CD beginning in 1907 and ending in 1988, this file was named the EXTEND scheduling file. For all the other crop rotations in the CD, including the dominant crop rotation, new scheduling files were created, with the simulation start year of 1989 and ending in 2030. As an example, if four crop rotations were practiced in a particular CD, then we prepared five scheduling files: one EXTEND scheduling file for the dominant crop rotation for the period 1907 to 1988 and four scheduling files for all crop rotations for the period 1989 to 2030.

The crop rotations practiced in each CD are listed in Table D.1 in Appendix D; these rotations are identified by a **crop rotation # (CR)** which is defined in Table 5.3. The crop varieties (i.e., as a function of yield level) along with the historical and current management practices are listed in Tables 5.6 and 5.11.

STEP 3. The 'site-specific' file for CENTURY contains information about site latitude, longitude, weather statistics, and soil physical properties, all of which were estimated for each CD. This information is used by CENTURY to calculate initial soil C and N conditions when the IVAUTO option is selected (see Section 5.2). The weather statistics required in the site specific files were calculated using the FILE100.EXE program. The input to this program is the CD weather file and the output from the program is the weather statistics consisting of the 41 year average of monthly precipitation (cm/month), maximum temperature (°C), and minimum temperature (°C), along with the monthly standard deviation and skewness for precipitation. The weather statistics information is output in the CD###.100 file, where ### refers to the CD number, which is the site specific file for the CD. The FILE100 program was executed for all the CDs. The latitude and longitude of the centroid of each CD, which is used to estimate evapotransporation, was estimated and input to each CD file.

The following soil physical properties are contained in this file, and were estimated for each of the soil texture groups found in each CD, as discussed in Section 4:

a. Percent Sand
b. Percent Silt
c. Percent Clay
d. Bulk density
e. Field capacity moisture content
f. Wilting point moisture content

STEP 4. In Section 5, Table 5.11 lists the crop yield varieties that were assumed to be grown in the various time periods during both the historical and projection period simulation. The information about crop variety and its associated crop parameters is contained in the CROP.100 file. Two crop parameters -- namely, PRDX (potential above ground monthly production) and HIMAX (harvest index maximum - fraction of above ground live carbon in grain) -- differentiate between the low, medium, and high yielding crop varieties. The yearly crop biomass production is controlled by the PRDX parameter; low yielding crop varieties have a lower PRDX and vice versa. The HIMAX parameter controls the amount of carbon that goes into grain production. These two parameters control the amount of crop yield and were used in the calibration of CENTURY simulated crop yields to observed (i.e., historical) crop yields in each CD. For the projection period, only PRDX was increased while HIMAX was maintained at the values for the 1971-88 period.

For the dominant crop rotation (CR) in each CD, five crop yield varieties were created in the CROP.100 file; however, for the crop rotations other than the dominant crop rotation only two crop varieties during the period 1989 to 2030 were created. The relative crop yield varieties simulated during these various time periods are listed below:

Period 1907-47	-	Low Yield
Period 1948-70	-	Medium Yield
Period 1971-88	-	High Yield
Period 1989-2010	-	Higher Yield
Period 2011-2030	-	Highest Yield

The limits on the HIMAX parameter used for yield calibration are:

Corn - 0.35 to 0.60
Soybean - 0.22 to 0.50
Wheat - 0.22 to 0.48 (includes oats, barley, and small grains)

These limits on HIMAX values for the major crops were obtained from various literature sources (Russell, 1991; Jones, 1983) and discussions with NREL staff (A. Metherell, NREL, personal communication, 1992). No limit was set on the PRDX value as this was the only CENTURY parameter which controlled biomass production. The recommended procedure was to increase or decrease the PRDX and HIMAX values, within the above limits, to match observed crop yields (C.V. Cole, personal communication, 1993). For projected yields, only PRDX was increased. This is discussed below in greater detail.

STEP 5. After the completion of steps 1 through 4, the CENTURY model crop yield calibrations were performed. The calibration procedure is discussed below.

Historical Period (1907-88)

Only crops in the dominant crop rotation were calibrated for this historical time period, and only for the dominant soil type in the CD. However, if the dominant soil type in the CD was loamy sand/sand, then the calibration was also performed for a silt or clay loam textured soil, since these loam soils were generally dominant throughout the Study Region. The calibration procedure consisted of comparing the mean simulated crop yield for each crop grown in the crop rotation for the time periods listed in Step 4, with the mean observed (or projected) crop yield value of the respective time period. If the mean value of the simulated crop production was within $\pm$ 1 percent of the observed mean value, then the calibration was assumed to be complete.

While calibrating for crop production if the simulated yields were lower than observed yields, then the PRDX and HIMAX values in the CROP.100 file were increased simultaneously, while insuring that the limits of HIMAX were not violated. Once the maximum value of HIMAX was reached, then only the PRDX parameter was increased. The above procedure was followed in the reverse order if simulated yields were higherthan the observed crop yields. The calibrated PRDX and HIMAX values for the dominant soil type were then used without further calibration for the remaining soil types in the CD.

Once the dominant crop rotation was calibrated for the historical period, the remaining crop rotations along with the dominant rotation in the CD were then simulated and calibrated for the projection period.

Projection Period (1989-2030)

As noted earlier, a 1.5% annual increase in crop yield was assumed, initially; the procedures were than repeated with 1.0% and 0.5% yield increases. Based on the projected increase, yield targets for the projection period were calculated for each crop in each crop rotation and CD. The calibration

procedures for both the historical and projection periods were implemented by an automated iteration procedure using UNIX optimization script commands. These commands changed the PRDX and HIMAX simultaneously for the historical period, as discussed above, and then re-ran the model; for the projection period, HIMAX was maintained constant at the values calibrated for the 1971-88 period, and only PRDX was adjusted in the caibration. The iteration was continued until the calibration tolerance of $\pm$ 1% was attained.

The projection period crop rotations were simulated using the EXTEND option of the CENTURY model, which allowed us to initialize the 1989 year with the 1988 year-ending values. The dominant crop rotation was simulated for the historical period through 1988 for each soil type in the CD, and then EXTENDED into the projection period for each of the remaining crop rotations in the CD. This extension was performed separately for each soil texture group in the CD. The CENTURY output for each CD was then area-weighted by multiplying the output from each soil type by the fraction of area they occupied in the CD, and then summing the results to obtain the weighted results for each crop rotation.

The mean simulated weighted yields for each time period were again compared with the observed (and projected) yields, and if the simulated yields were within about $\pm$ 5 percent of the observed yields then the yields were assumed to be calibrated. Otherwise, the CENTURY model was re-calibrated for the time periods where the differences in observed and simulated yields were greater than this tolerance.

STEP 6. The CENTURY output variables printed for each model run, along with a brief definition, are:

CENTURY Output Variable	Definition
TOTC	Total Soil Organic Carbon (includes carbon stored in soil, surface and root litter)
SOMTC	Soil Organic Carbon (includes carbon stored in soil and root litter)
SOMSC	Soil Organic Carbon (includes carbon stored in soil only)
CGRAIN	Economic Yield of Carbon in Grain, used to calculate Grain Yields: YIELD (grains) kg/ha = CGRAIN*28.75

SHREMA	Annual accumulator of Carbon removed from shoots during grazing
SDREMA	Annual accumulator of Carbon removed from standing dead during grazing, used to calculate Hay and Silage Yields,

YIELD (Hay) kg/ha = (SHREMA+SDREMA)*30
YIELD (Silage) kg/ha = (SHREMA+SDREMA)*35

CPRODA	Net Primary Production
CINPUTS	Total Soil Carbon Inputs

For Hay and Silage Crops -
CINPUT = CPRODA + CRETA * (SHREMA*SDREMA)
- (SHREMA + SDREMA)
For Grain Crops -
CINPUT = CPRODA - (CGRAIN+CRMVST)

VOLEXA	Accumulator for nitrogen volatilization as a function of nitrogen remaining after uptake by plants
VOLGMA	Accumulator for nitrogen volatilized as a function of gross mineralization

Used to calculate total N emissions from soils,
TOTAL N Volatilized = (VOLEXA+VOLGMA)

CRMVST	Amount of Carbon removed through straw during harvest
FERTOT(1)	Accumulator of Nitrogen applied during the year

STEP 7. The calibration procedure in Step 5 was used for simulating all the status quo C/R/T combinations in all the 80 CDs. Once the status quo simulations were completed, the three policy alternatives, i.e, increased conservation tillage, use of cover crops, and CRP alternatives were simulated. The policies are described in detail in Section 5.4., and their impacts were simulated only for the projection period.

Increased Conservation Tillage

In this policy alternative, combinations of C/R/T reflecting the selected targets for conservation tillage were estimated by RAMS. The C/R/T combinations were essentially identical to those in the status quo simulations except for the a few rotations where tillage practices were changed. The necessary scheduling files with changes in tillage practice were created and then using the EXTEND option, the results obtained for the dominant crop rotation simulations

performed in the Status Quo scenario were extended into the projection period for each of these combinations with changed tillage practices. The projection period calibration procedure as stated above was performed again for crops included in the new C/R/T combinations. As noted in Section 5.4, three policies consisting of low, medium, and high levels of conversation tillage were simulated.

Cover Crop

The identification of C/R/T combinations reflecting the targets on cover crops was provided by CARD. As noted earlier, we used **legume hay** as the cover crop and developed revised scheduling files for the projection period for the C/R/T combinations with cover crops added. The EXTEND option of the CENTURY model was used again for extending the results of the dominant crop rotation into the appropriate C/R/T combinations with cover crops. There was no calibration needed for the cover crop simulations as the C/R/T combinations which now supported cover crops were already simulated and calibrated without cover crops in the Status Quo scenario.

CRP Acres

The RAMS study area includes 15 million acres which are enrolled under the CRP program, this area was not included in the 216 million acres of cropland simulated in the Status Quo scenario. Since the CRP program was started in 1986, we simulated the dominant crop (or cash crop) rotation from 1907 to 1985, and then used the EXTEND option of the CENTURY model to simulate two CRP scenarios as discussed in Section 5.4. The CRP land was simulated using grass as the native crop. No calibration was necessary as the dominant crop rotation was already calibrated in the Status Quo scenario.

STEP 8. The final step involved processing and analyzing the CENTURY output. CENTURY output for every policy scenario, for all of the C/R/T's, weighted by soil type, comprised approximately 1500 files and occupied 15 million bytes of disk space. Each C/R/T storage or emission factor was multiplied by its area in the CD, which varied according to the policy scenario that was being run. After multiplication by the area, weighted storages and emissions totals were computed by multiplying the output by the area of the C/R/T combination in the CD. The post-processing was performed using two programs TABLES.BAS and FACTORS.BAS written in Quick BASIC. The program extracted from each datafile (one datafile per C/R/T) the result values for the years 1980, 1990, 2000, 2010, 2020, and 2030. The extracted results were multiplied by the area of the specific C/R/T in the CD.

SECTION 6.0

MODEL SIMULATIONS AND ASSESSMENT RESULTS

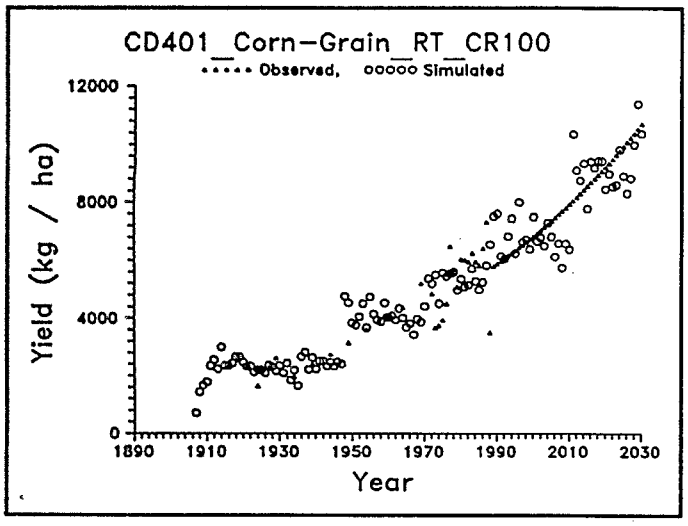
This section presents the simulation results for both the Baseline/Status Quo conditions and the alternative scenarios described in Section 5.0. Considering the extent of the Study Region, the number of CDs, and the alternative combinations of crops, rotations, and tillage practices, the vast quantity of output generated by the models could be analyzed in a variety of ways. For this initial assessment we have focussed primarily on soil carbon (SOC) values, and changes in SOC as impacted by the agricultural production systems and the variation in soils and climate conditions throughout the Study Region. We have analyzed these impacts in two ways: (1) unit area impacts, in terms of gC/m^2, to assess local impacts of the practices, and (2) aggregated impacts, in terms of total grams C, to evaluate the net change in C (i.e., sequestration potential) due to both practice and land use changes. These results are presented in Sections 6.1 and 6.2, respectively. Since the area in the Conservation Reserve Program (CRP) is separate from the cropland acres in our Study Region, the CRP alternatives are discussed separately in Section 6.3. Whereas, the results in Sections 6.1 through 6.3 are based on the 1.5%/year yield increase, Section 6.4 provides summary results for the whole Study Region for alternative yield increase levels.

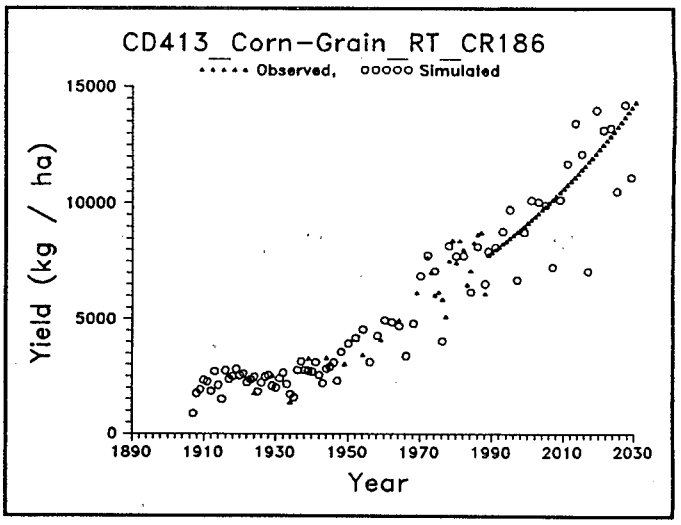
6.1 IMPACTS OF AGRICULTURAL PRODUCTION SYSTEMS ON SOIL CARBON

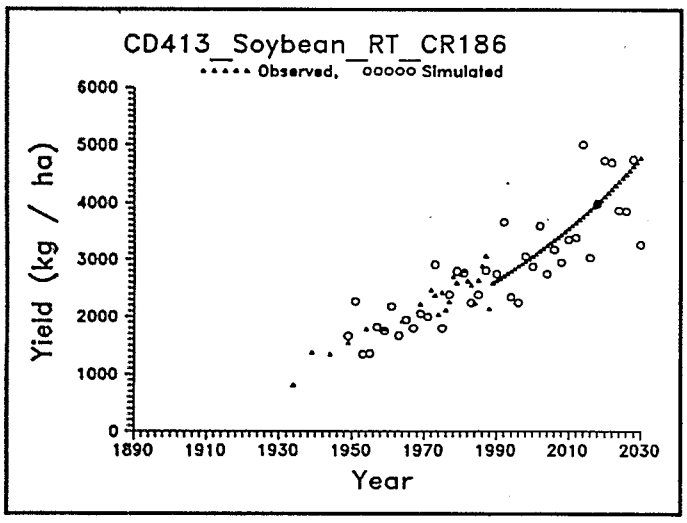
Lacking long-term soil carbon databases to confirm the CENTURY model predictions, we included two 'consistency' checks as part of the modeling effort to insure that the model results are reasonable and consistent with the general literature, observations, and impressions of carbon dynamics within the Study Region. These two checks included comparisons of simulated and observed crop yields, and simulated soil carbon levels in selected CDs compared to mapped estimates developed by Kern and Johnson (1991) in a recent study.

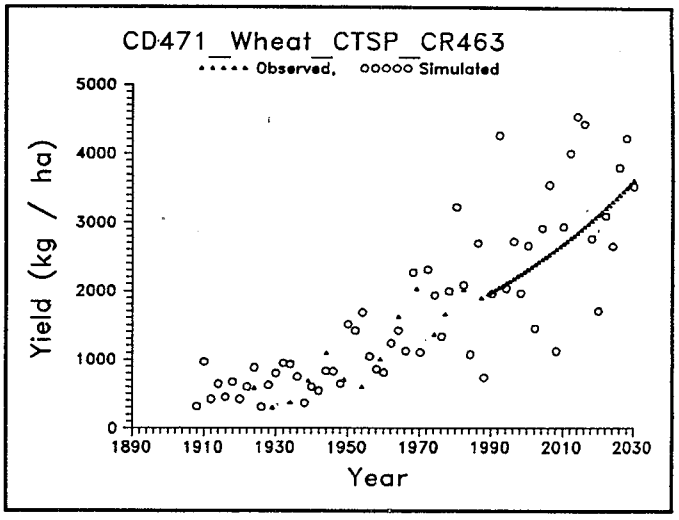
Figures 6.1 and 6.2 show comparisons of simulated and both observed (1924-88) and projected (1989-2030) crop yields for selected CDs and C/R/T combinations throughout the Study Region; more than 3000 of these types of comparisons were made for each crop within each CD and C/R/T combination. Complete results for all CDs and C/R/T combinations are available from the EPA Athens Laboratory.

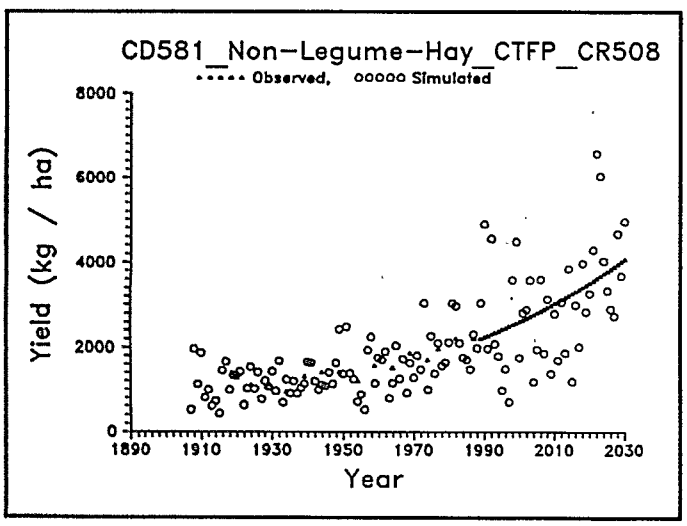
Although these are calibrated results within a relatively tight tolerance of $\pm$ 5%, the model shows good agreement and year-to-year variability compared to observations during the historic period of 1924-1988. Since carbon inputs to the soil are a direct function of crop yields (and residue management practices), accurate yield simulation provides a sound basis for accurately











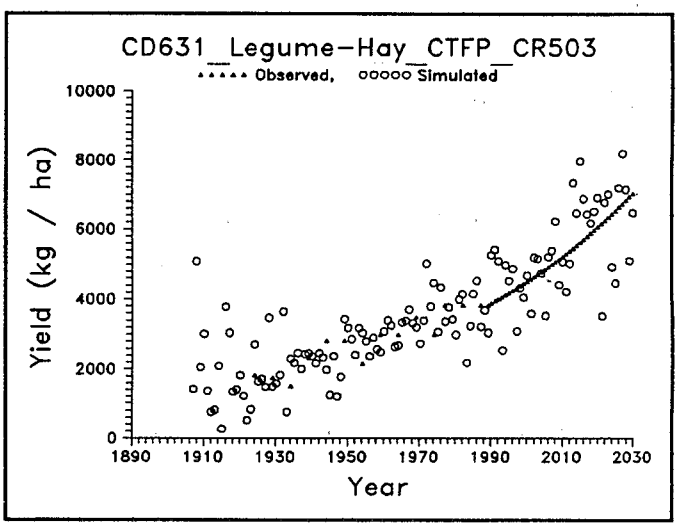
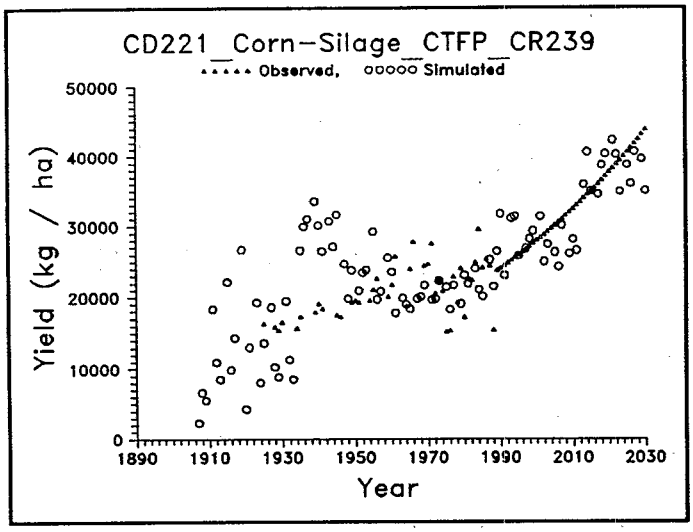
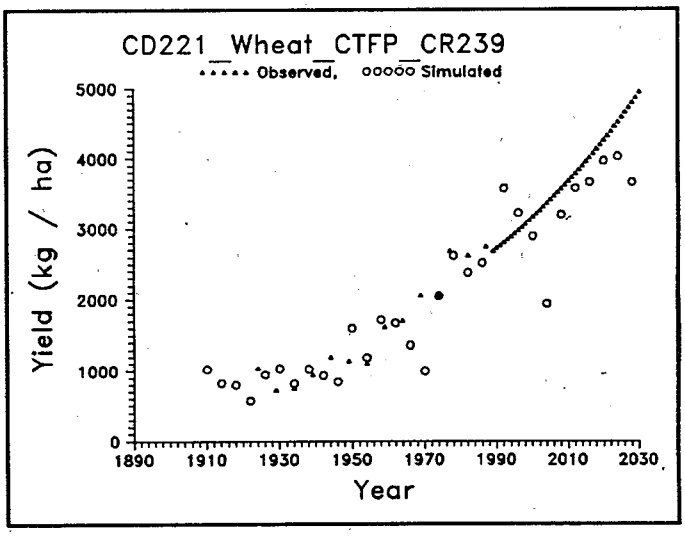
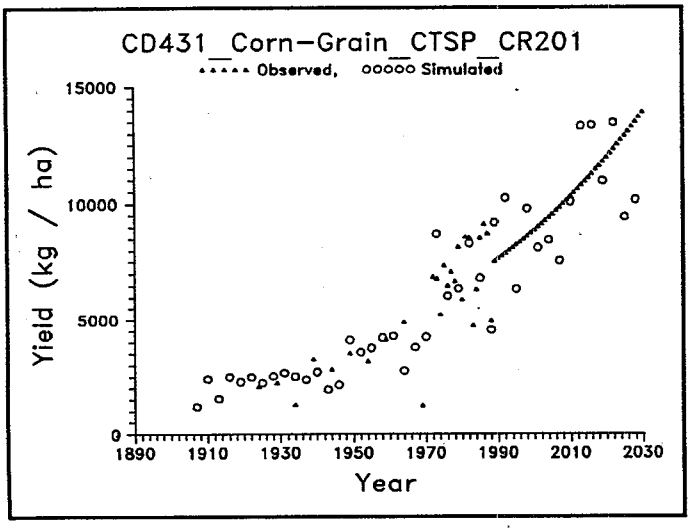
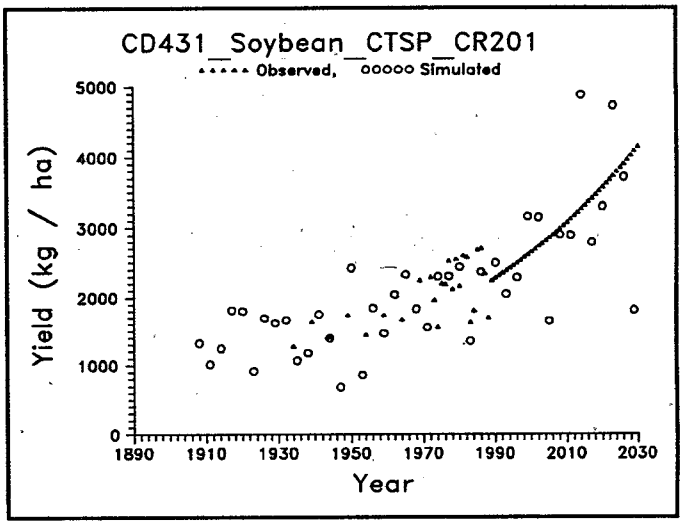


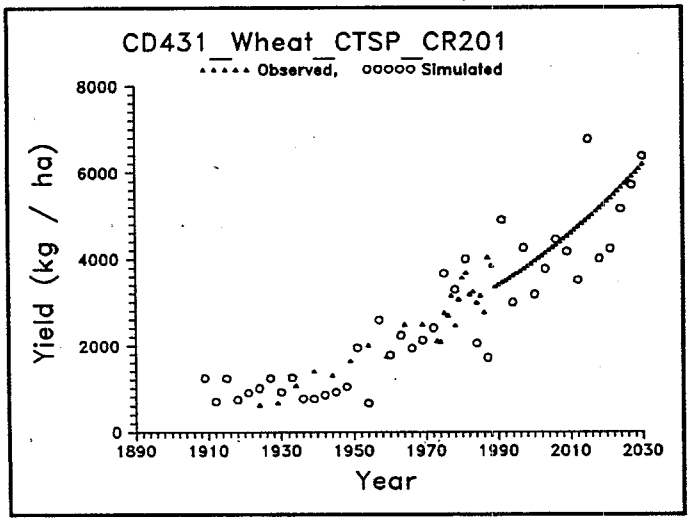
Figure 6.1 Simulated vs. actual and projected crop yields for selected CDs and C/R/T Combinations











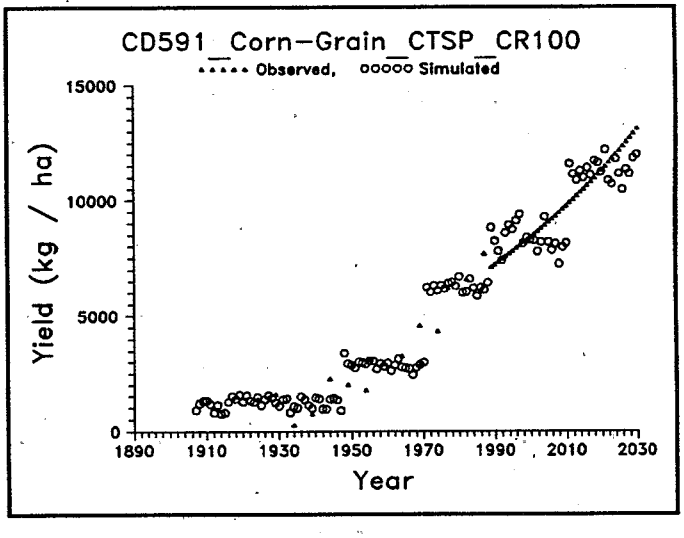


Figure 6.2 Simulated vs. actual and projected crop yields for selected CDs and C/R/T Combinations

simulating SOC. Note that during the projection period of 1989-2030, the year-to-year variability is generally greater than during the historic period. During this period, the model was calibrated to the annual yields resulting from the assumed 1.5% annual increase; the greater variability indicates greater sensitivity to actual annual variations in climatic conditions at these higher levels of potential crop production. Thus, at high potential crop production levels, climate variations may lead to greater fluctuations in actual crop yields.

Table 6.1 shows a comparison of soil carbon levels for selected test CDs with corresponding values estimated by Kern and Johnson (1991), who developed a national map of agricultural soil carbon from the 1982 and 1987 NRI database (Goebel and Dorsch, 1982; Goebel, 1987), the 1982 SCS Soil Interpretation Records, and the SCS Pedon Database. The Kern and Johnson values shown in Table 6.1 were estimated from their published maps and adjusted to a 20-cm depth to be consistent with the CENTURY model predictions. The CENTURY values shown in the table are a range for all C/R/T combinations in the test CD for the 1980 to 1990 time period. Except for two test CDs (CD473 and CD643), the CENTURY estimates are **consistently in or near the low end** of the estimated range from Kern and Johnson. The general spatial pattern of SOC from both estimates is similar, with the highest values in the central and northern portions of the Study Region and the lowest values in the western, southern, and eastern periphery (see Figure 6.10 for spatial display of 1990 SOC values). For the two CDs where the CENTURY values are about 40% too low, it is interesting to note that the neighboring CDs produced SOC values within the Kern and Johnson range; differences in soil texture and climate used in the two methods are possible reasons for this spatial shift and differences in SOC.

Table 6.1 Comparison of CENTURY (1980-1990) SOC with Values Estimated From Kern and Johnson Report

		SOC, gC/m^2	
CD	**Location**	**Kern/Johnson**	**CENTURY, 1980-90**
272	N.E. OH	4000-5000	4160-4450
341	N.E. KY	3000-4000	3080-3280
413	Central IA	5000-7000	4500-4800
473	No. MN	6000-8000	3800-3920
603	Central MO	3000-5000	3050-3130
632	S.W. KS	3000-4000	3000-3030
643	N.W. AR	3000-4000	1820-1970

Note: CENTURY values in this table are for soil carbon without root or crop residues included.

In sum, both of the consistency checks indicated reasonable model behavior when compared to selected observed data points for crop yields and soil carbon. Although further validation is needed and highly recommended (see Section 7.0), these consistency checks were deemed sufficient to justify use of the modeling procedures and methodology for this preliminary assessment.

6.1.1 Impacts of Crops, Rotations, and Tillage Practices

Table 6.2 shows model predictions of SOC for rotations and tillage combinations for selected CDs distributed throughout the Study Region; the locations of these CDs are shown in Figure 6.3. The values in Table 6.2 are year-end conditions at ten-year intervals from 1980 to 2030, and the percent change is calculated for each ten-year period starting in 1990 and for the entire 40-year projection period, 1990-2030. As noted in Section 3.2, the SOC values are the Total Soil Carbon in the **top 20 cm of the soil profile, including both root and surface residues,** and are presented as unit area impacts in gC/m^2. Table C.1 in Appendix C includes results for all CDs within the Study Region.

Figures 6.4, 6.5, and 6.6 are examples of the CENTURY model predictions for SOC for the entire simulation period of 1907-2030 for CDs 413, 473, and 632, respectively. These are presented to demonstrate the historical and future trends in SOC predicted by CENTURY under the model application assumptions discussed in Section 5.0.

From the model results shown in these figures, Table 6.2, and Appendix C, the following observations are provided:

1. Values in Table 6.2 are generally representative of those for all CDs and C/R/T combinations; the percent change for the 40-year projection period is typically about **30% to 80%**. For all CDs and C/R/T combinations, the **average increase was 55%**, with an **average minimum of 25%** and an **average maximum of 87%** (from Table C.2). However, selected C/R/T combinations have much larger and smaller changes, including a few (primarily wheat-fallow rotations) with negative changes i.e., loss of SOC during the projection period.

   The greatest percent changes, ranging up to 150% to 200%, usually occur when a dominant hay or grain rotation, simulated during the historic period (i.e. 1907-88) is followed by a corn or corn-silage based rotation during the 40-year projection period. This is due to the large biomass production of corn, and the resulting high level of carbon inputs to the soil for these rotations. Conversely, the smallest increases, and some decreases, in SOC are for the reverse situation.

Table 6.2 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for Selected Climatic Divisions

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
				1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
262	100	CRN (Dryland)	CTSPD	3193	3460	3703	3816	4346	4695	7.02%	3.05%	13.88%	8.03%	35.69%
262	100	CRN (Irrigated)	CTSPI	3193	3370	3635	3727	4251	4577	7.86%	2.53%	14.05%	7.66%	35.81%
262	100	CRN (Dryland)	RTD	3193	3465	3811	3958	4566	4958	9.98%	3.85%	15.36%	8.58%	43.08%
262	100	CRN (Irrigated)	RTI	3193	3382	3773	3923	4542	4923	11.56%	3.97%	15.77%	8.38%	45.56%
262	100	CRN (Dryland)	NTD	3193	3498	4182	4525	5318	5832	19.55%	8.20%	17.52%	9.66%	66.72%
262	100	CRN (Irrigated)	NTI	3193	3409	4166	4516	5317	5790	22.20%	8.40%	17.73%	8.89%	69.84%
262	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	3193	3466	3805	4114	4336	4819	9.78%	8.12%	5.39%	11.13%	39.03%
262	215	CRN,SWT,SWT	RT	3193	3473	4273	4623	5480	6290	23.03%	8.19%	18.53%	14.78%	81.11%
262	280	CSL,SWT	RT	3193	3485	4585	5150	6298	7223	31.56%	12.32%	22.29%	14.68%	107.25%
262	366	OTS,NLH,NLH,NLH	CTSP	3193	3482	3777	3838	4268	4657	8.47%	1.61%	11.20%	9.11%	33.74%
272	100	CRN	NT	4289	4607	6043	6964	8364	9402	31.16%	15.24%	20.10%	12.41%	104.08%
272	138	CRN,CRN,SOY,WWT,HLH	CTSP	4289	4560	5056	5474	6300	6761	10.87%	8.26%	15.08%	7.31%	48.26%
272	186	CRN,SOY	CTSP	4289	4559	5029	5395	6076	6613	10.30%	7.27%	12.62%	8.83%	45.05%
272	186	CRN,SOY	RT	4289	4569	5109	5520	6256	6834	11.81%	8.04%	13.33%	9.23%	49.57%
272	186	CRN,SOY	NT	4289	4606	5364	5924	6769	7412	16.45%	10.43%	14.26%	9.49%	60.92%
272	201	CRN,SOY,WWT	RT	4289	4570	5231	5689	6180	6994	14.46%	8.75%	8.63%	13.17%	53.04%
272	243	CSL,CSL,OTS,HLH,HLH	CTSP	4289	4581	5546	6210	7194	7861	21.06%	11.97%	15.84%	9.27%	71.60%
272	366	OTS,NLH,NLH,NLH	CTSP	4289	4592	5132	5435	6088	6653	11.75%	5.90%	12.01%	9.28%	44.88%
341	144	CRN,CRN,WWT,HLH,HLH	CTSP	3294	3478	3620	3842	4316	4611	4.08%	6.13%	12.33%	6.83%	32.57%
341	144	CRN,CRN,WWT,HLH,HLH	RT	3294	3456	3667	3922	4447	4787	6.10%	6.95%	13.38%	7.64%	38.51%
341	144	CRN,CRN,WWT,HLH,HLH	NT	3294	3498	3795	4116	4683	5068	8.49%	8.45%	13.77%	8.22%	44.88%
341	186	CRN,SOY	CTFP	3294	3442	3528	3682	4077	4354	2.49%	4.36%	10.72%	6.79%	26.49%
341	186	CRN,SOY	NT	3294	3495	3911	4263	4824	5281	11.90%	9.00%	13.15%	9.47%	51.10%
341	232	CRN,NLH,NLH,NLH	CTSP	3294	3443	3514	3614	3992	4255	2.06%	2.84%	10.45%	6.58%	23.58%
341	232	CRN,NLH,NLH,NLH	RT	3294	3457	3531	3647	4011	4271	2.14%	3.28%	9.98%	6.48%	23.54%
413	100	CRN	CTSP	4677	4967	5933	6559	7510	8442	19.44%	10.55%	14.49%	12.41%	69.96%
413	100	CRN	RT	4677	4979	6098	6804	7913	9012	22.47%	11.57%	16.29%	13.88%	81.00%
413	115	CRN,CRN,CRN,HLH,HLH,HLH	CTSP	4677	4969	5693	6244	6740	7590	14.57%	9.67%	7.94%	12.61%	52.74%
413	138	CRN,CRN,SOY,WWT,HLH	CTSP	4677	4968	5355	5658	6333	6741	7.78%	5.65%	11.93%	6.44%	35.68%
413	138	CRN,CRN,SOY,WWT,HLH	RT	4677	4979	5413	5768	6513	6958	8.71%	6.55%	12.91%	6.83%	39.74%
413	186	CRN,SOY	CTFP	4677	4966	5123	5286	5493	5790	3.16%	3.18%	3.91%	5.40%	16.59%
413	186	CRN,SOY	CTSP	4677	4965	5193	5390	5634	5980	4.59%	3.79%	4.52%	6.14%	20.44%
413	186	CRN,SOY	RT	4677	4976	5257	5491	5758	6133	5.64%	4.45%	4.86%	6.51%	23.25%
413	186	CRN,SOY	NT	4677	5018	5553	5958	6356	6815	10.66%	7.29%	6.68%	7.22%	35.81%
413	243	CSL,CSL,OTS,HLH,HLH	CTSP	4677	4988	5981	6588	7606	8592	19.90%	10.14%	15.45%	12.96%	72.25%
413	503	HLH,HLH,HLH,HLH	CTSP	4677	5041	5216	5733	6341	7134	3.47%	9.91%	10.60%	12.50%	41.51%
413	508	NLH,NLH,NLH,NLH	CTFP	4677	5054	5230	5746	6233	7114	3.48%	9.86%	8.47%	14.13%	40.75%

Table 6.2 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
473	2	BAR,BAR,SOY	CTSP	3895	3971	5046	5594	6327	7277	27.07%	10.86%	13.10%	15.01%	83.25%
473	2	BAR,BAR,SOY	RT	3895	3977	5117	5713	6470	7508	28.66%	11.64%	13.25%	16.04%	88.78%
473	100	CRN	NT	3895	3976	5435	6156	7504	8698	36.69%	13.26%	21.89%	15.91%	118.76%
473	125	CRN,CRN,OTS,NLH,NLH	CTSP	3895	3958	4921	5555	6397	7265	24.33%	12.88%	15.15%	13.56%	83.55%
473	145	CRN,CRN,WWT,HLH,HLH,HLH	CTFP	3895	3965	4918	5618	6258	7215	24.03%	14.23%	11.39%	15.29%	81.96%
473	215	CRN,SWT,SWT	CTSP	3895	3956	5157	5868	6859	7948	30.35%	13.78%	16.88%	15.87%	100.91%
473	215	CRN,SWT,SWT	RT	3895	3967	5232	5993	7091	8317	31.88%	14.54%	18.32%	17.28%	109.65%
473	215	CRN,SWT,SWT	NT	3895	3975	5428	6311	7524	9106	36.55%	16.26%	19.22%	21.02%	129.08%
473	262	CSL,OTS,HLH,HLH,HLH	CTFP	3895	3975	5020	5630	6625	7597	26.28%	12.15%	17.67%	14.67%	91.11%
473	463	SMF,SWT	CTSP	3895	3917	4128	4133	4345	4511	5.38%	0.12%	5.12%	3.82%	15.16%
473	463	SMF,SWT	RT	3895	3917	4479	4649	5219	5758	14.34%	3.79%	12.26%	10.32%	47.00%
473	508	NLH,NLH,NLH,NLH	CTFP	3895	3977	4700	5289	5674	7133	18.17%	12.53%	7.27%	25.71%	79.35%
603	131	CRN,CRN,SOY	CTSP	3268	3266	4002	4331	4796	5394	22.53%	8.22%	10.73%	12.46%	65.15%
603	131	CRN,CRN,SOY	NT	3268	3276	4132	4571	5107	5728	26.12%	10.62%	11.72%	12.15%	74.84%
603	186	CRN,SOY	CTSP	3268	3277	3810	4205	4839	5369	16.26%	10.36%	15.07%	10.95%	63.83%
603	186	CRN,SOY	RT	3268	3279	3847	4276	4944	5532	17.32%	11.15%	15.62%	11.89%	68.70%
603	186	CRN,SOY	NT	3268	3280	3975	4483	5205	5848	21.18%	12.77%	16.10%	12.35%	78.29%
603	201	CRN,SOY,WWT	CTSP	3268	3277	3865	4224	4719	5342	17.94%	9.28%	11.71%	13.20%	63.01%
603	201	CRN,SOY,WWT	RT	3268	3280	3901	4273	4821	5489	18.93%	9.53%	12.82%	13.85%	67.34%
603	201	CRN,SOY,WWT	NT	3268	3280	3977	4420	4970	5625	21.25%	11.13%	12.44%	13.17%	71.49%
603	503	HLH,HLH,HLH,HLH	CTSP	3268	3280	3340	3516	3924	4213	1.82%	5.26%	11.60%	7.36%	28.44%
603	508	NLH,NLH,NLH,NLH	CTFP	3268	3280	3334	3559	3823	4209	1.64%	6.74%	7.41%	10.09%	28.32%
603	508	NLH,NLH,NLH,NLH	RT	3268	3279	3338	3486	3825	4049	1.79%	4.43%	9.72%	5.85%	23.48%
632	186	CRN,SOY	CTSP	3275	3204	4139	4581	5343	5898	29.18%	10.67%	16.63%	10.38%	84.08%
632	186	CRN,SOY	RT	3275	3205	4163	4644	5418	6040	29.89%	11.55%	16.66%	11.48%	88.45%
632	186	CRN,SOY	NT	3275	3206	4219	4789	5610	6213	31.59%	13.51%	17.14%	10.74%	93.79%
632	218	CRN,WWT	CTFP	3275	3204	4143	4709	5523	6203	29.30%	13.66%	17.28%	12.31%	93.60%
632	218	CRN,WWT	CTSP	3275	3204	4188	4804	5657	6380	30.71%	14.70%	17.75%	12.78%	99.12%
632	218	CRN,WWT	RT	3275	3205	4261	4870	5775	6513	32.94%	14.29%	18.58%	12.77%	103.21%
632	218	CRN,WWT	NT	3275	3206	4256	4816	5701	6520	32.75%	13.15%	18.37%	14.36%	103.36%
632	490	WWT	RT	3275	3146	3684	3876	4439	5017	17.10%	5.21%	14.52%	13.02%	59.47%
632	490	WWT	NT	3275	3146	3819	4062	4627	5188	21.39%	6.36%	13.90%	12.12%	64.90%
632	503	HLH,HLH,HLH,HLH	CTFP	3275	3206	3270	3606	3853	4238	1.99%	10.27%	6.84%	9.99%	32.18%
632	503	HLH,HLH,HLH,HLH	RT	3275	3205	3278	3630	3897	4313	2.27%	10.73%	7.35%	10.67%	34.57%
632	508	NLH,NLH,NLH,NLH	CTSP	3275	3208	4094	4274	4778	5831	27.61%	4.39%	11.79%	22.03%	81.76%
632	508	NLH,NLH,NLH,NLH	RT	3275	3208	4177	4378	4886	5952	30.20%	4.81%	11.60%	21.81%	85.53%
632	508	NLH,NLH,NLH,NLH	NT	3275	3208	4214	4450	4970	6038	31.35%	5.60%	11.68%	21.48%	88.21%

Table 6.2 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
643	100	CRN	NT	1787	1953	2898	3387	4097	4533	48.38%	16.87%	20.96%	10.64%	132.10%
643	131	CRN,CRN,SOY	CTSP	1787	1928	2414	2630	2885	3275	25.20%	8.94%	9.69%	13.51%	69.86%
643	131	CRN,CRN,SOY	RT	1787	1934	2476	2712	2987	3446	28.02%	9.53%	10.14%	15.36%	78.17%
643	131	CRN,CRN,SOY	NT	1787	1953	2630	2979	3341	3811	34.66%	13.26%	12.15%	14.06%	95.13%
643	218	CRN,WWT	CTFP	1787	1929	2419	2692	3105	3480	25.40%	11.28%	15.34%	12.07%	80.40%
643	218	CRN,WWT	RT	1787	1935	2571	2935	3460	3919	32.86%	14.15%	17.88%	13.26%	102.53%
643	366	OTS,NLH,NLH,NLH	CTSP	1787	1968	2290	2420	2968	3261	16.36%	5.67%	22.64%	9.87%	65.70%
643	490	WWT	RT	1787	1894	2350	2582	3060	3448	24.07%	9.87%	18.51%	12.67%	82.04%
643	503	HLH,HLH,HLH,HLH	CTSP	1787	1953	2044	2173	2509	2771	4.65%	6.31%	15.46%	10.44%	41.88%

Note: Abbrevations Used in the Table

CD	-	Climate Division	CR	-	Crop Rotation
CTFP	-	Conventional Till Fall Plow	CTSP	-	Conventional Till Spring Plow
RT	-	Reduced Till	NT	-	No Till
BAR	-	Barley	OTS	-	Oats
CRN	-	Corn	SMF	-	Summer Month Fallow
CSL	-	Corn Silage	SOY	-	Soybean
HLH	-	Legume Hay	SWT	-	Spring Wheat
NLH	-	Non Legume Hay	WWT	-	Winter Wheat

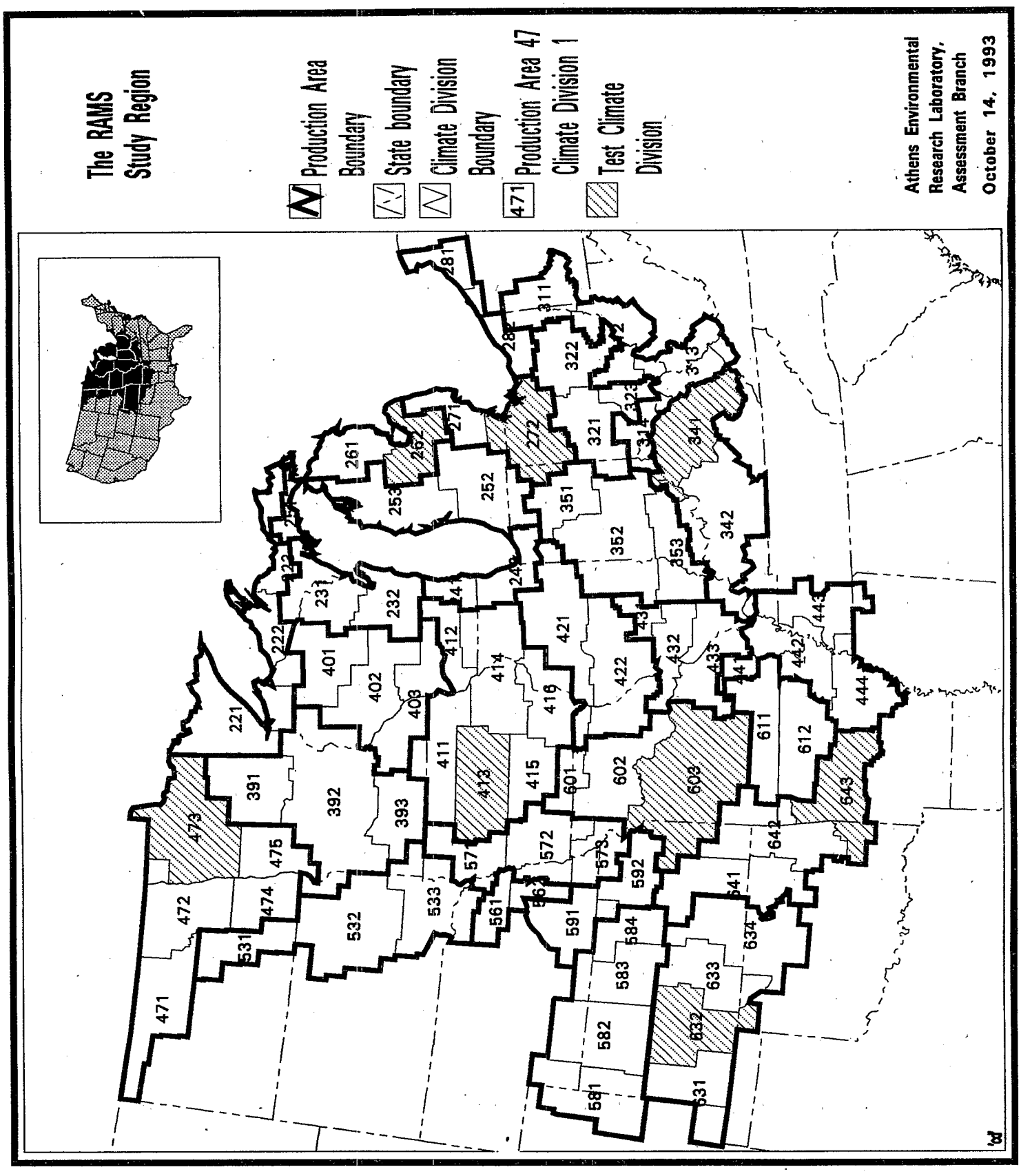


Figure 6.3 Locations of climate divisions (CDs) listed in Table 6.2

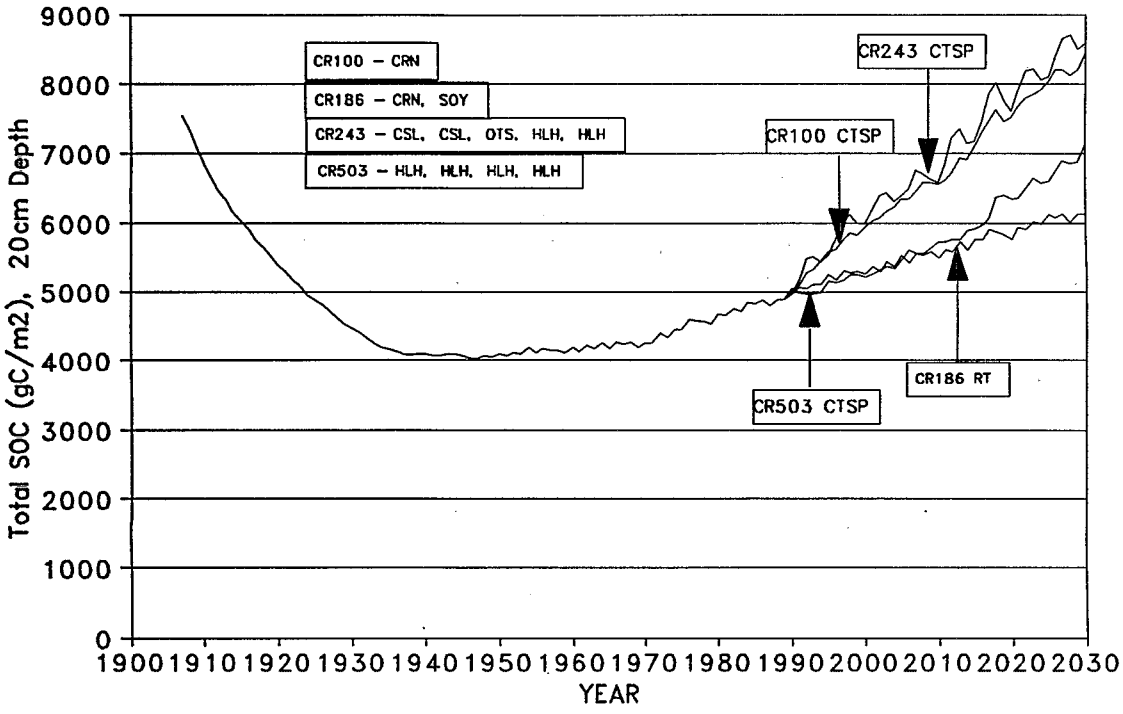


Figure 6.4. Changes and Impacts of Agricultural Production Systems On Total SOC in CD413, 1907–2030

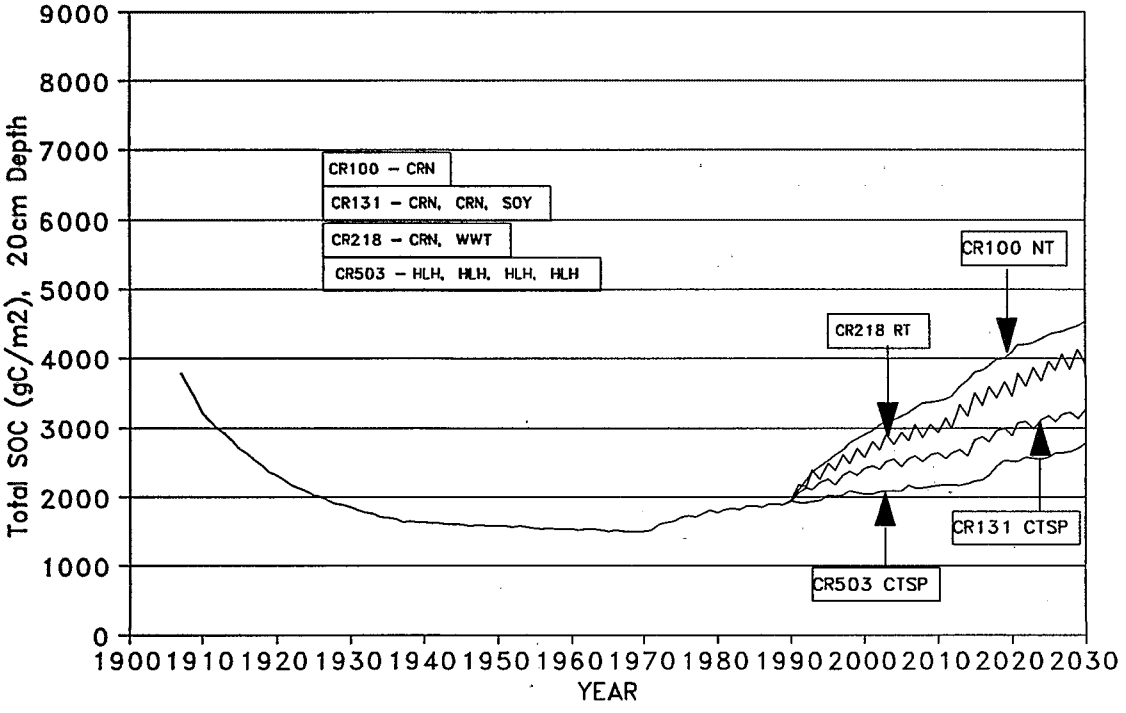


Figure 6.5. Changes and Impacts of Agricultural Production Systems On Total SOC in CD643, 1907–2030

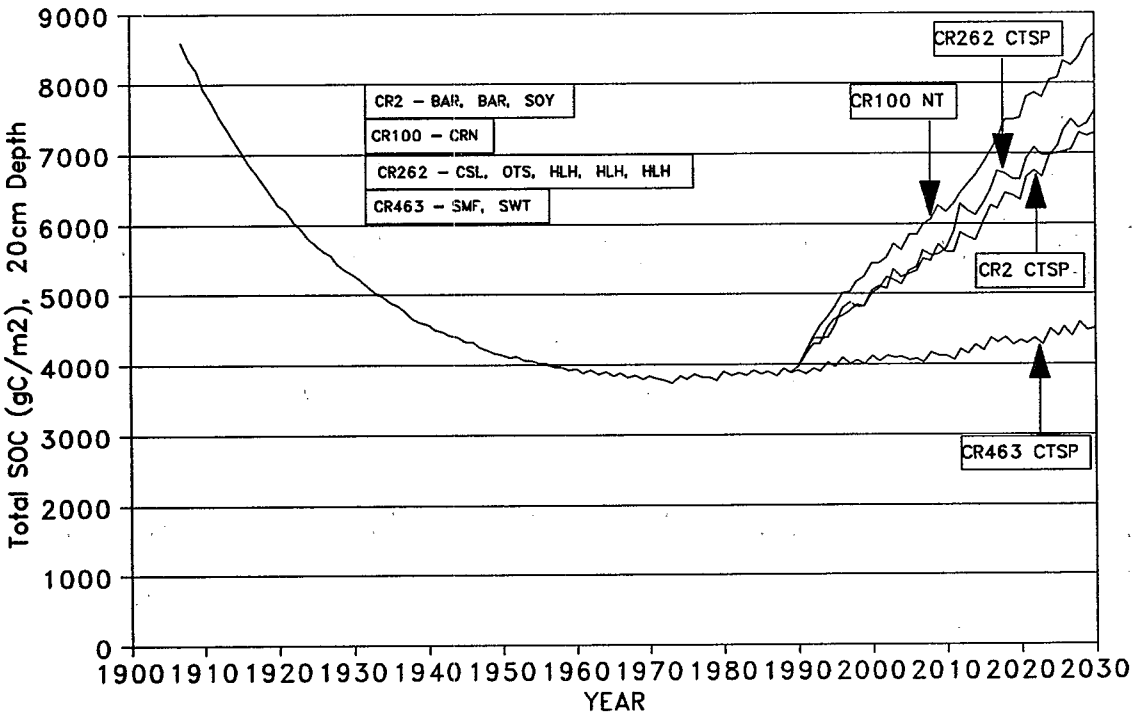


Figure 6.6. Changes and Impacts of Agricultural Production Systems on Total SOC in CD473, 1907–2030

2. Historical practices, as represented by the model assumptions used in this study, have led to decreases in SOC until about the 1940's and 1950's. Since then the model predictions of SOC are increasing for most crop production systems that leave significant amounts of crop residue on the field. At this time, these predicted trends appear to be reasonable and consistent with the application assumptions and the available literature. A variety of studies have noted the typical steep decrease in SOC when forest and grasslands are converted to agricultural production (Mann, 1986; Schlesinger, 1984; Odell et al, 1984), but increases in SOC have also been documented when soils are initially low in carbon (Mann, 1986) or under intensive fertilization (Odell et al, 1984). Houghton et al (1983) have shown idealized curves of SOC following conversion of native lands to agriculture that are similar to the pattern in Figures 6.4 - 6.6. Paustian (1992), and others, have noted increases in SOC with increased carbon inputs due to amendments and residue management that retain most of the crop residue on the field.

Thus, the pattern of decreasing SOC following conversion of native land to agriculture, and subsequent increases with more intensive fertilization and increased carbon inputs is generally consistent with the literature; however, we have no direct confirmation of these CENTURY model predictions at the scale of the Study Region at this time. Hopefully, the ongoing data consolidation effort by CSU-NREL and MSU will help to validate these conclusions when it is available.

3. The model results show **consistent and significant increases in SOC** throughout the projection period, except for a few hay or grain-based rotations in CDs located in the southern and western portions of the Study Region. The increases are due primarily to the assumption of a 1.5% annual increase in crop yields and subsequent increases in carbon inputs, as noted in Section 5.2.1. The sensitivity of the Study Region results to alternative annual yield increase levels is discussed in Section 6.4.

4. The impacts of the **tillage** practices -- Conventional Till, Reduced Till, No-Till -- are significant and highly variable across the Study Region. The degree of the impact is a function of the complex interactions of specific crops and rotations, climate and soil characteristics. We generally see significant increases in SOC as one moves from CT to RT to NT. In many cases, the increase in SOC due to RT may be 10% to 15% higher, and for NT up to 50 % higher, than for CT; however, in other C/R/T and CD combinations the changes are much less, and often less than generally assumed by conventional wisdom. For example, the changes in SOC for selected CDs for a corn-soybean rotation (CR186) are shown below for selected CDs where all three tillage alternatives are practiced:

Percent Change in SOC, 1990-2030 for Corn-Soybean Rotations and Tillage Practices

	CD272	CD413	CD321	CD392	CD603
CTSP	45%	20%	53%	37%	64%
RT	50%	23%	58%	40%	69%
NT	61%	36%	68%	52%	78%

In some CDs, the percent change does not adequately describe the real impact; for example, in CD392 the percent change for RT is only 3% more than for CTSP, but the absolute difference in SOC from 1990 to 2030 is about 190 gC/m^2. Differences of a few percent among practices are probably not significant within the context of this study.

These results on the impacts of tillage should be considered preliminary for a number of reasons: (1) we simply do not quantitatively understand all the impacts of tillage alternatives as a function of soils and climate on crop yields, residue decomposition, and organic matter dynamics; (2) the parameter changes in current models, like CENTURY, to distinguish RT and NT are uncertain and require further investigation; and (3) some mechanisms for movement and disposition of surface residues under alternative tillage practices (e.g., earthworm activity, new tillage implements, etc.) are not well represented by the model. In fact, some members of the Study Team questioned whether we knew enough about the differences in processes and parameter changes to warrant modeling both RT and NT as separate, distinct alternatives. This area warrants further investigation before our conclusions on the impacts of alternative tillage practices can be confirmed (see Section 7.0).

6. The impact of irrigation was primarily on maintenance of crop yields; information from RAMS identified the CDs and rotations where irrigation was practiced. For many of the southern CDs (e.g., 632, 643 in Table 6.2) essentially all the cropland was irrigated. However, for some of the northern and eastern CDs, the RAMS output identified rotation acres both with and without irrigation; this occurred in CD 262, as shown by 'dryland' and 'irrigated' conditions in Table 6.2 following the tillage type designation. For CD 262, the irrigated condition produced slightly lower SOC levels (although the percent difference was higher) due to higher CO_2 emissions and SOC decomposition under the higher soil moisture levels of the irrigated land.

7. Differences in the 1980 SOC conditions (Table C.1 in Appendix C) within a PA, i.e., among CDs with the same first two digits (e.g., 411, 412, 413), are due entirely to soil and climate differences, and historical crop yield levels, since the historical management practices and dominant rotations are the same within the PA.

6.1.2 Impacts of Cover Crops

Implementation of cover crops in appropriate CDs and C/R/T combinations identified by the CARD analysis resulted in dramatic increases in SOC in many cases. Table 6.3 shows the SOC and percent change for selected CDs and for C/R/T combinations both with and without cover crops; Table C.3 in Appendix C includes complete results for all CDs and rotations with cover crops, while Table C.4 shows the average, minimum, and maximum percent change for each CD with cover crops. Figures 6.7 and 6.8 graphically show the SOC changes for two selected rotations in CDs 413 and 603, respectively.

As noted in Section 5.4, only 45 CDs out of the total number of 80 were considered conducive to cover crops due to climate, crops, and length of the growing season. These CDs were located in the central and southern portions of the Study Region (Figure 5.2).

Table 6.3 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for Crop Rotations with and without Cover Crops for Selected Climate Divisions

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
241	201	CRN,SOY,WWT	RT	5591	6072	6444	6586	7079	7862	6.12%	2.20%	7.48%	11.06%	29.47%
241	201	CRN,SOY,WWT	RT-C	5591	6075	6755	7040	7602	8423	11.19%	4.21%	7.98%	10.79%	38.65%
241	262	CSL,OTS,HLH,HLH,HLH	CTSP	5591	6079	6453	6631	7359	7778	6.15%	2.75%	10.97%	5.69%	27.94%
241	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	5591	6079	6546	6760	7498	7910	7.68%	3.26%	10.91%	5.49%	30.12%
272	201	CRN,SOY,WWT	RT	4289	4570	5231	5689	6180	6994	14.46%	8.75%	8.63%	13.17%	53.04%
272	201	CRN,SOY,WWT	RT-C	4289	4571	5514	6076	6756	7519	20.63%	10.19%	11.19%	11.29%	64.49%
272	243	CSL,CSL,OTS,HLH,HLH	CTSP	4289	4581	5546	6210	7194	7861	21.06%	11.97%	15.84%	9.27%	71.60%
272	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4289	4581	5614	6337	7370	8118	22.54%	12.87%	16.30%	10.14%	77.21%
312	250	CSL,CSL,SOY	NT	3543	3634	5721	7233	8809	10400	57.42%	26.42%	21.78%	18.06%	186.18%
312	250	CSL,CSL,SOY	NT-C	3543	3634	6712	8680	10626	12963	84.70%	29.32%	22.41%	21.99%	256.71%
341	186	CRN,SOY	NT	3294	3495	3911	4263	4824	5281	11.90%	9.00%	13.15%	9.47%	51.10%
341	186	CRN,SOY	NT-C	3294	3495	4005	4433	5088	5600	14.59%	10.68%	14.77%	10.06%	60.22%
413	186	CRN,SOY	CTFP	4677	4966	5123	5286	5493	5790	3.16%	3.18%	3.91%	5.40%	16.59%
413	186	CRN,SOY	CTFP-C	4677	4968	5340	5650	6154	6763	7.48%	5.80%	8.92%	9.89%	36.13%
413	243	CSL,CSL,OTS,HLH,HLH	CTSP	4677	4988	5981	6588	7606	8592	19.90%	10.14%	15.45%	12.96%	72.25%
413	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4677	4991	5893	6499	7584	8557	18.07%	10.28%	16.69%	12.82%	71.44%
442	416	SRG,SOY,SOY	CTFP	2761	2986	3235	3281	3641	4051	8.33%	1.42%	10.97%	11.26%	35.66%
442	416	SRG,SOY,SOY	CTFP-C	2761	2985	4640	5393	6131	7077	55.44%	16.22%	13.68%	15.42%	137.08%
442	458	SOY,WWT,SOY	CTFP	2761	2935	2888	2886	3067	3263	-1.60%	-0.06%	6.27%	6.39%	11.17%
442	458	SOY,WWT,SOY	CTFP-C	2761	2934	3989	4818	5499	5952	35.95%	20.78%	14.13%	8.23%	102.86%
442	459	SOY,WWT,WWT,WWT	RT	2761	2942	3304	3401	3762	4163	12.30%	2.93%	10.61%	10.65%	41.50%
442	459	SOY,WWT,WWT,WWT	RT-C	2761	2939	3593	3993	4420	5042	22.25%	11.13%	10.69%	14.07%	71.55%
603	131	CRN,CRN,SOY	NT	3268	3276	4132	4571	5107	5728	26.12%	10.62%	11.72%	12.15%	74.84%
603	131	CRN,CRN,SOY	NT-C	3268	3277	4953	5963	6828	7593	51.14%	20.39%	14.50%	11.20%	131.70%
603	186	CRN,SOY	CTSP	3268	3277	3810	4205	4839	5369	16.26%	10.36%	15.07%	10.95%	63.83%
603	186	CRN,SOY	CTSP-C	3268	3277	4381	5276	6172	6864	33.68%	20.42%	16.98%	11.21%	109.45%
603	201	CRN,SOY,WWT	CTSP	3268	3277	3865	4224	4719	5342	17.94%	9.28%	11.71%	13.20%	63.01%
603	201	CRN,SOY,WWT	CTSP-C	3268	3277	4496	5283	6169	7052	37.19%	17.50%	16.77%	14.31%	115.19%
603	201	CRN,SOY,WWT	RT	3268	3280	3901	4273	4821	5489	18.93%	9.53%	12.82%	13.85%	67.34%
603	201	CRN,SOY,WWT	RT-C	3268	3280	4490	5267	6191	7079	36.89%	17.30%	17.54%	14.34%	115.82%
612	186	CRN,SOY	NT	2033	2005	2536	2949	3516	3858	26.48%	16.28%	19.22%	9.72%	92.41%
612	186	CRN,SOY	NT-C	2033	2005	3516	4511	5510	6280	75.36%	28.29%	22.14%	13.97%	213.21%
612	458	SOY,WWT,SOY	CTFP	2033	2005	2157	2273	2480	2678	7.58%	5.37%	9.10%	7.98%	33.56%
612	458	SOY,WWT,SOY	CTFP-C	2033	2004	3277	4286	5102	5622	63.52%	30.79%	19.03%	10.19%	180.53%

Table 6.3 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
643	218	CRN,WWT	RT	1787	1935	2571	2935	3460	3919	32.86%	14.15%	17.88%	13.26%	102.53%
643	218	CRN,WWT	RT-C	1787	1935	3151	3850	4594	5125	62.84%	22.18%	19.32%	11.55%	164.85%

Abbrevations Used in Table:

CD	-	Climate Division	CR	-	Crop Rotation
CTFP	-	Conventional Till Fall Plow	CTSP	-	Conventional Till Spring Plow
RT	-	Reduced Till	NT	-	No Till
CRN	-	Corn	CSL	-	Corn Silage
OTS	-	Oats	SOY	-	Soybean
WWT	-	Winter Wheat			

Note: "-C" in the TILL Column represents crop rotations with Cover Crops.

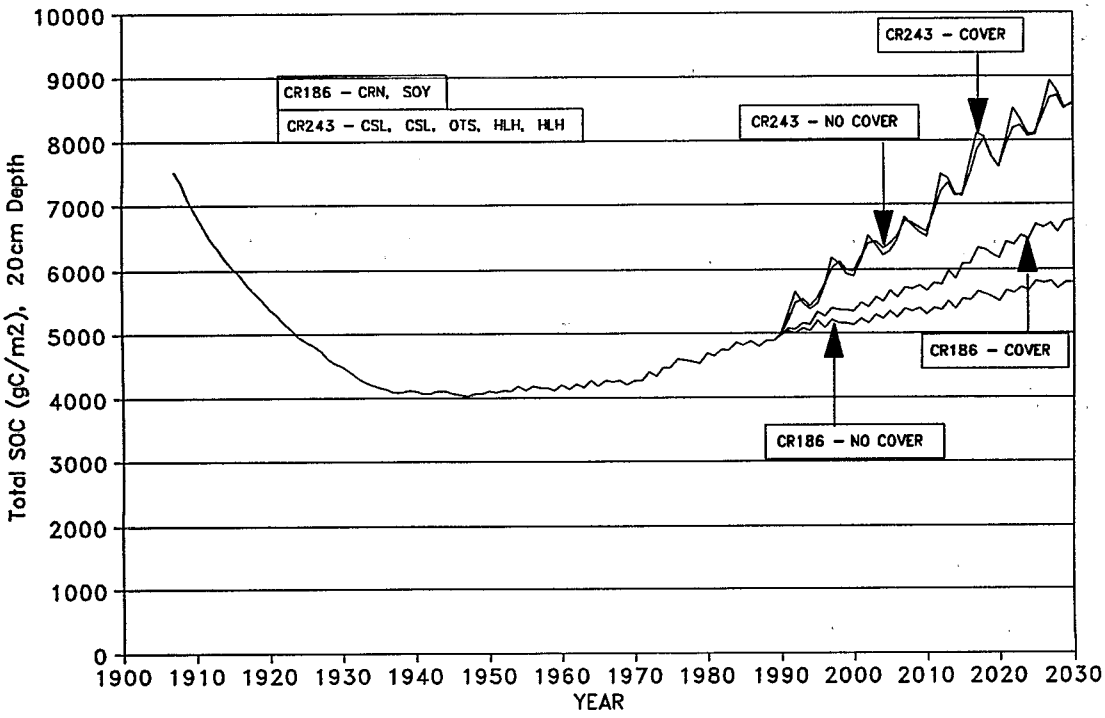


Figure 6.7. Changes and Impacts of Cover Crops on Total SOC in CD413 1907–2030

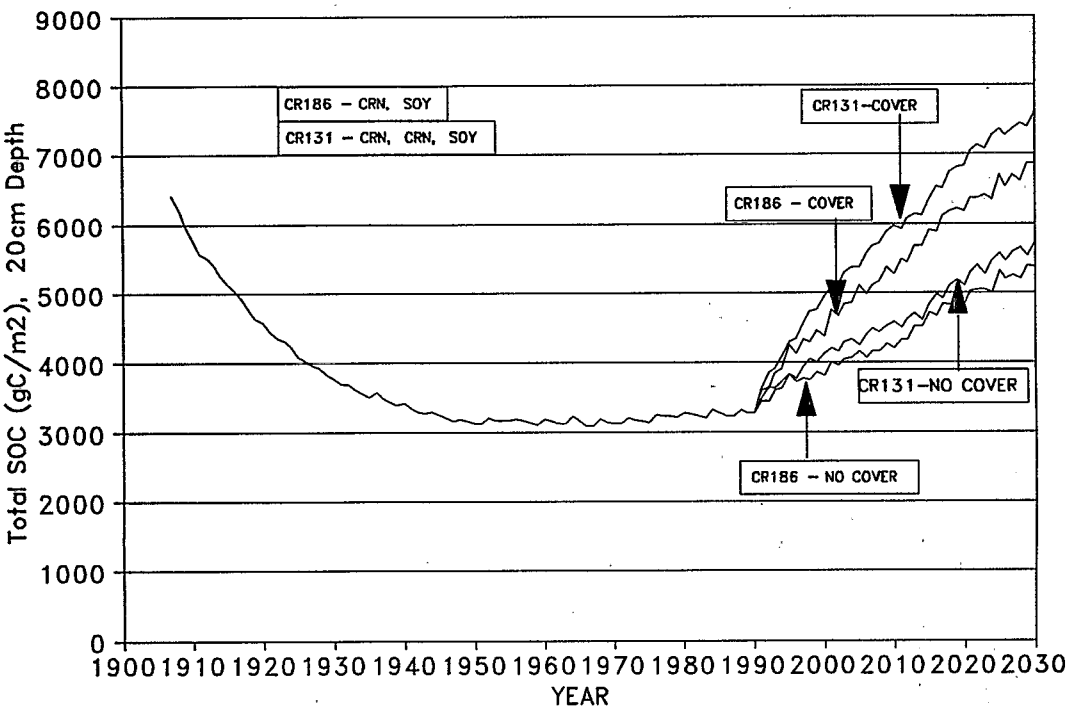


Figure 6.8. Changes and Impacts of Cover Crops on Total SOC in CD603, 1907–2030

A review of these results provides the following observations:

1. Use of cover crops can significantly increase SOC for many C/R/T combinations, especially for CDs located in the southern portions of the Study Region. For example, in CDs 603 and 612 the largest increases during the 40-year projection period are on the order of 100% to 150% greater with cover crops. For all CDs and C/R/T combinations with cover crops, the **average increase was 63%**, with an **average minimum of 29%** and an **average maximum of 117%**. For some CDs and C/R/T combinations, the increase is two to three times greater with cover crops. However, many of these situations are for corn-silage and hay rotations where the 'manure-return' assumption, combined with cover crops, leads to the large increase.

2. For the CDs located in the central portion of the Study Region (which corresponds to the northern tier of cover crop CDs), the SOC increase is much less than in the other crop cover regions. These points are evident in the values in Table 6.3 and the curves in Figure 6.7. CDs 241, 272, 341, and 413 show smaller differences for cover crops than the other CDs.

   As noted above, crop rotation 186 in CD 413 shows a relatively small increase in SOC when a cover crop is implemented. This is partly due to yield reductions in the crops following the cover crop, as shown in Figure 6.9. CARD had noted that the northern tier of cover crop CDs were considered areas where the economic benefits of cover crops might be 'marginal' at best, and subsequent yield reductions are expected.

3. Even if climate conditions are favorable for cover crops, the extent of the impact on SOC depends on the specific crop rotation sequence. Thus, as discussed in Section 5.4, crop rotation 350 (CSL,CSL,SOY) can support cover crops in each winter (inter-crop) period, whereas rotation 186 (CRN,SOY) includes a cover crop only after the soybean crop, i.e., only 50% of the time. Clearly, the more often a cover crop is grown, the greater the potential impact on SOC. Longer rotations, such as CR 262 (CSL,OTS,HLH,HLH,HLH), show the least impact because they often have fewer opportunities for cover crop growth; for CR 262 a cover crop is only grown after CSL, so only one out of five years (i.e., 20% of the time) includes a cover crop.

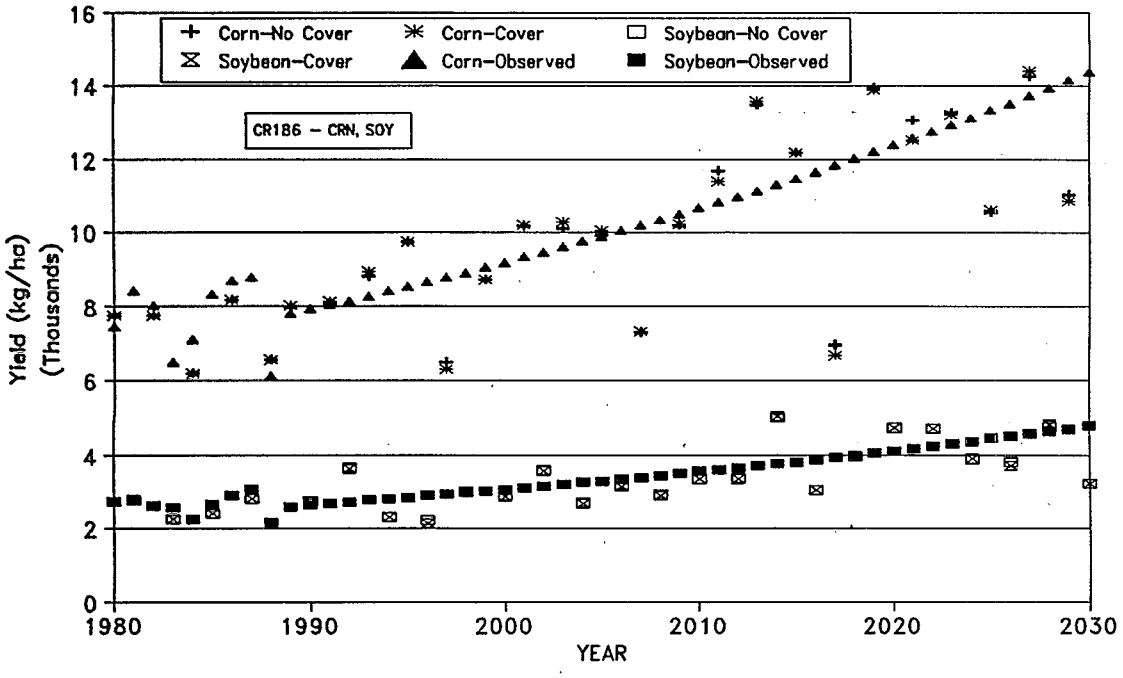


Figure 6.9. Impact of Cover Crops on Corn and Soybean Yields in CD413

6.2 CLIMATE DIVISION AND STUDY REGION IMPACTS OF MODELED SCENARIOS

6.2.1 Total SOC Impacts for CDs and the Study Region

To evaluate the aggregate impact on SOC within each CD and the entire Study Region, the unit SOC soil storage values discussed above were converted to total SOC, i.e., gC, by multiplying unit values times the appropriate areas associated with each C/R/T combination for each modeled scenario. The result of this conversion is included in Table 6.4, which shows both the **absolute** and **percent change** in SOC for the Status Quo conditions and each modeled scenario (except CRP which is discussed in Section 6.3, below). The absolute values represent the difference in total SOC storage between 1990 and 2030 in each CD for each modeled scenario, while the percent change relates the difference to the 1990 Status Quo values.

The end of Table 6.4 includes summary statistics for each column; below we have listed some of the key numbers from those statistics.

	Gain in Total SOC, 1990-2030	
	Gigatonnes C	Percent of 1990 Value
Status Quo/Baseline	1.795	49.1%
Low Conservation	1.808	49.4%
Medium Conservation	1.825	49.9%
High Conservation	1.904	52.0%
Cover Crops	1.944	53.1%

In Table 6.5 we've calculated the absolute and percent difference in SOC relative to Status Quo conditions in 2030 for each CD for each modeled scenario. These numbers indicate how much different 2030 SOC would be for each alternative, compared to the Status Quo.

From these results the following observations are provided:

1. Under the Status Quo or Baseline scenario, **1.8 Gt C** will be retained or sequestered within the Study Region from 1990 to 2030 under the Status Quo assumptions described earlier. This represents a **49% increase** over the current 1990 level of SOC of **3.66 Gt C in the Study Region** based on the model calculations.

2. The range in increase in SOC among the CDs goes from a minimum of 22% to a maximum of 101% during the 40-year projection period, under the Status Quo scenario.

3. The three conservation compliance (tillage) alternatives had a small, but **significant**, impact on SOC or carbon sequestration in the Study Region as a whole. The differences shown above, especially for the High Conservation alternative, although small are considered significant because of the consistency of the increase and the relatively modest level of conservation tillage represented by the scenario. For the High Conservation scenario, the SOC change relative to the Status Quo ranges from +36% to -13%, with an average increase of 8% (Table 6.5); thus the impacts vary among the CDs. However, the CDs with negative changes showed consistent shifts away from corn-based rotations to grain and soybean based rotations; thus the SOC decreases were due more to crop changes than to tillage impacts.

Table 6.4 Absolute and Percent Change in Total Soil Carbon from 1990 to 2030 in the Study Region for Status Quo and Alternative Scenarios

CD #	Status Quo		Low Cons.		Med. Cons.		High Cons.		Cover Crop	
	Absolute [MtC]	Percent [%]	Absolute [MtC]	Percent [%]	Absolute [MtC]	Percent [%]	Absolute [MtC]	Percent [%]	Absolute [MtC]	Percent [%]
CD221	2.23	26.02%	2.47	28.62%	2.47	28.62%	2.47	28.62%	2.23	26.02%
CD222	0.61	26.18%	0.68	28.81%	0.68	28.81%	0.68	28.81%	0.61	26.18%
CD223	0.64	26.45%	0.71	28.98%	0.71	28.98%	0.71	28.98%	0.64	26.45%
CD231	4.80	46.15%	4.80	46.15%	4.80	46.15%	5.10	49.04%	4.80	46.15%
CD232	33.00	61.57%	33.00	61.57%	33.00	61.57%	34.40	64.06%	33.00	61.57%
CD241	5.10	29.65%	5.10	29.65%	5.10	29.65%	5.50	31.98%	5.40	31.40%
CD242	9.00	34.22%	9.00	34.22%	9.00	34.22%	10.10	38.26%	9.80	37.26%
CD251	0.10	28.65%	0.10	28.65%	0.10	28.65%	0.11	30.37%	0.10	28.65%
CD252	24.50	45.71%	24.50	45.71%	24.50	45.71%	25.50	47.49%	24.50	45.71%
CD253	4.60	31.08%	4.60	31.08%	4.60	31.08%	5.00	33.78%	4.60	31.08%
CD261	2.27	40.18%	2.27	40.18%	2.27	40.18%	2.27	40.18%	2.27	40.18%
CD262	15.80	53.56%	15.80	53.56%	15.80	53.56%	15.80	53.56%	15.80	53.56%
CD271	7.60	41.99%	7.60	41.99%	7.60	41.99%	7.60	41.99%	7.80	43.09%
CD272	49.80	50.20%	49.80	50.20%	49.80	50.20%	49.80	50.20%	52.70	53.07%
CD281	4.20	35.29%	4.20	35.29%	4.40	36.97%	4.90	41.18%	4.30	36.13%
CD282	5.40	41.86%	5.40	41.86%	5.50	42.64%	5.20	40.31%	5.40	41.86%
CD311	9.20	58.97%	9.70	62.18%	9.60	61.54%	8.70	55.77%	9.80	62.82%
CD312	7.80	73.58%	8.30	78.30%	8.10	76.42%	7.30	68.87%	9.10	85.85%
CD313	1.91	63.67%	2.01	67.00%	1.98	65.78%	1.75	58.14%	2.40	80.00%
CD314	9.70	69.29%	10.10	71.63%	10.10	71.63%	9.10	64.54%	10.80	77.14%
CD321	32.90	50.77%	34.00	52.39%	34.00	52.39%	35.90	55.15%	32.90	50.77%
CD322	17.00	49.28%	17.40	50.43%	17.40	50.43%	18.30	52.89%	17.00	49.28%
CD323	6.40	52.03%	6.60	53.66%	6.60	53.66%	7.00	56.91%	6.40	52.03%
CD341	8.60	33.33%	9.60	37.07%	10.00	38.61%	10.80	41.70%	8.60	33.33%
CD342	18.40	37.63%	20.20	41.22%	20.90	42.65%	22.10	45.01%	18.40	37.63%
CD351	26.70	49.54%	26.70	49.54%	26.70	49.54%	28.60	52.96%	28.20	52.32%
CD352	80.00	50.00%	80.00	50.00%	80.00	50.00%	83.00	51.88%	85.00	53.13%
CD353	23.80	44.32%	23.80	44.32%	23.80	44.32%	24.90	46.20%	26.30	48.88%
CD391	3.02	32.54%	3.02	32.54%	3.02	32.54%	3.02	32.54%	3.02	32.54%
CD392	65.00	39.39%	65.00	39.39%	65.00	39.39%	65.00	39.39%	65.00	39.39%
CD393	35.60	47.21%	35.60	47.21%	35.60	47.21%	35.60	47.21%	35.60	47.21%
CD401	5.80	31.87%	5.80	31.87%	5.90	32.42%	6.40	34.97%	5.80	31.87%
CD402	22.20	35.35%	22.20	35.35%	22.80	36.25%	24.80	39.30%	22.20	35.35%
CD403	30.40	40.75%	30.40	40.75%	31.40	42.09%	34.20	45.72%	30.40	40.75%
CD411	46.00	44.66%	46.00	44.66%	46.00	44.66%	52.00	50.49%	51.00	49.51%
CD412	13.50	42.06%	13.50	42.06%	13.50	42.06%	14.70	45.65%	14.80	46.11%
CD413	42.00	35.00%	42.00	35.00%	42.00	35.00%	48.00	39.67%	48.00	40.00%
CD414	60.00	44.78%	60.00	44.78%	60.00	44.78%	67.00	50.00%	66.00	49.25%
CD415	24.90	46.63%	24.90	46.63%	24.90	46.63%	28.20	52.71%	27.60	51.69%
CD416	34.90	46.47%	34.90	46.47%	34.90	46.47%	38.70	51.39%	39.00	52.00%
CD421	66.00	46.15%	66.00	46.15%	66.00	46.15%	71.00	49.65%	72.00	50.35%
CD422	64.00	52.89%	64.00	52.89%	64.00	52.89%	68.00	56.20%	66.00	54.55%
CD431	9.40	46.08%	9.40	46.08%	9.60	47.06%	10.10	49.27%	11.80	57.84%
CD432	16.10	50.16%	16.10	50.16%	16.30	50.78%	17.30	53.56%	22.30	69.47%
CD433	13.40	46.85%	13.40	46.85%	13.60	47.55%	14.50	50.35%	16.00	55.56%
CD441	0.34	22.37%	0.34	22.37%	0.35	23.03%	0.43	28.10%	0.79	51.97%
CD442	16.20	34.91%	16.20	34.91%	16.50	35.56%	20.90	44.75%	32.80	70.69%
CD443	8.00	36.20%	8.00	36.20%	8.20	37.10%	10.40	46.85%	17.50	79.55%
CD444	14.80	47.44%	14.80	47.44%	15.00	47.92%	18.50	58.92%	30.40	97.44%
CD471	53.10	67.30%	53.10	67.30%	53.10	67.30%	53.10	67.30%	53.10	67.30%
CD472	80.00	77.67%	80.00	77.67%	80.00	77.67%	80.00	77.67%	80.00	77.67%
CD473	36.20	66.18%	36.20	66.18%	36.20	66.18%	36.20	66.18%	36.20	66.18%
CD474	42.00	101.45%	42.00	101.45%	42.00	101.45%	42.00	101.45%	42.00	101.45%
CD475	23.20	67.25%	23.20	67.25%	23.20	67.25%	23.20	67.25%	23.20	67.25%
CD531	18.70	46.52%	18.70	46.52%	18.70	46.52%	19.00	47.26%	18.70	46.52%
CD532	39.00	52.70%	39.00	52.70%	39.00	52.70%	39.00	52.70%	39.00	52.70%
CD533	37.80	57.10%	37.80	57.10%	37.80	57.10%	37.80	57.10%	37.80	57.10%
CD561	13.60	56.20%	13.70	56.38%	14.40	59.26%	15.70	64.61%	15.60	64.20%
CD562	10.70	59.12%	10.70	59.12%	11.10	61.33%	11.60	63.74%	11.50	63.54%
CD571	28.20	48.62%	28.90	49.74%	30.40	52.23%	32.60	55.92%	28.80	49.66%
CD572	39.10	52.20%	41.00	54.67%	41.90	55.79%	45.70	60.69%	42.00	56.00%
CD573	16.80	51.06%	17.30	52.42%	18.30	55.45%	19.80	59.82%	17.70	53.80%
CD581	12.60	33.60%	12.60	33.60%	12.60	33.60%	11.40	30.48%	12.60	33.60%
CD582	56.80	60.94%	56.80	60.94%	56.80	60.94%	52.20	56.25%	56.80	60.94%
CD583	31.60	49.14%	31.60	49.14%	31.60	49.14%	27.40	42.75%	32.40	52.26%
CD584	20.10	53.60%	20.10	53.60%	20.10	53.60%	18.40	49.07%	20.10	53.60%

Table 6.4 (contd.)

CD #	Status Quo Absolute [MtC]	Status Quo Percent [%]	Low Cons. Absolute [MtC]	Low Cons. Percent [%]	Med. Cons. Absolute [MtC]	Med. Cons. Percent [%]	High Cons. Absolute [MtC]	High Cons. Percent [%]	Cover Crop Absolute [MtC]	Cover Crop Percent [%]
CD591	39.40	49.50%	39.40	49.50%	40.30	50.56%	44.90	56.05%	44.50	55.97%
CD592	13.40	49.26%	13.40	49.26%	14.00	51.28%	15.30	55.84%	15.30	56.25%
CD601	6.90	42.33%	7.10	43.56%	7.40	45.12%	7.70	46.95%	7.40	45.40%
CD602	23.60	52.80%	24.00	53.69%	25.20	56.38%	25.50	56.92%	30.20	67.71%
CD603	33.80	51.06%	34.80	52.57%	36.80	55.59%	36.80	55.59%	47.80	72.21%
CD611	1.84	36.36%	1.95	38.54%	1.99	39.25%	2.25	44.47%	2.36	46.64%
CD612	1.29	35.44%	1.40	38.46%	1.44	39.56%	1.75	48.08%	2.77	76.10%
CD631	16.90	51.52%	17.10	52.13%	17.10	52.13%	18.60	56.71%	16.90	51.52%
CD632	27.50	44.28%	27.90	44.93%	27.90	44.93%	29.20	47.02%	27.50	44.28%
CD633	17.50	40.51%	17.80	41.11%	17.80	41.11%	18.90	43.65%	17.50	40.51%
CD634	24.40	39.74%	24.60	40.07%	24.60	40.07%	26.20	42.60%	24.40	39.74%
CD641	7.80	42.39%	7.80	42.39%	9.10	49.46%	9.30	50.27%	10.50	57.07%
CD642	12.90	54.66%	12.90	54.66%	14.30	60.34%	15.00	63.29%	16.10	68.22%
CD643	4.67	73.78%	4.67	73.78%	5.35	84.25%	5.82	91.22%	6.36	100.32%
Average	22.44	47.32%	22.59	47.93%	22.81	48.64%	23.80	50.56%	24.30	53.25%
Maximum	80.00	101.45%	80.00	101.45%	80.00	101.45%	83.00	101.45%	85.00	101.45%
Minimum	0.10	22.37%	0.10	22.37%	0.10	23.03%	0.11	28.10%	0.10	26.02%
Total Study Region Change from 1990	1795.02	49.08%	1807.52	49.41%	1824.56	49.86%	1903.66	51.96%	1943.95	53.13%

Table 6.5 Absolute and Percent Difference in Total Soil Carbon Relative to Status Quo in 2030

CD #	Relative Change Low Cons. Absolute [MtC]	Low Cons. Percent [%]	Relative Change Med. Cons. Absolute [MtC]	Med. Cons. Percent [%]	Relative Change High Cons. Absolute [MtC]	High Cons. Percent [%]	Relative Change Cover Crop Absolute [MtC]	Cover Crop Percent [%]
CD221	0.24	10.76%	0.24	10.76%	0.24	10.76%	--	--
CD222	0.07	11.48%	0.07	11.48%	0.07	11.48%	--	--
CD223	0.07	10.94%	0.07	10.94%	0.07	10.94%	--	--
CD231	0.00	0.00%	0.00	0.00%	0.30	6.25%	--	--
CD232	0.00	0.00%	0.00	0.00%	1.40	4.24%	--	--
CD241	0.00	0.00%	0.00	0.00%	0.40	7.84%	0.30	5.88%
CD242	0.00	0.00%	0.00	0.00%	1.10	12.22%	0.80	8.89%
CD251	0.00	0.00%	0.00	0.00%	0.01	6.00%	--	--
CD252	0.00	0.00%	0.00	0.00%	1.00	4.08%	--	--
CD253	0.00	0.00%	0.00	0.00%	0.40	8.70%	--	--
CD261	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD262	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD271	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.20	2.63%
CD272	0.00	0.00%	0.00	0.00%	0.00	0.00%	2.90	5.82%
CD281	0.00	0.00%	0.20	4.76%	0.70	16.67%	0.10	2.38%
CD282	0.00	0.00%	0.10	1.85%	-0.20	-3.70%	0.00	0.00%
CD311	0.50	5.43%	0.40	4.35%	-0.50	-5.43%	0.60	6.52%
CD312	0.50	6.41%	0.30	3.85%	-0.50	-6.41%	1.30	16.67%
CD313	0.10	5.24%	0.07	3.66%	-0.16	-8.38%	0.49	25.65%
CD314	0.40	4.12%	0.40	4.12%	-0.60	-6.19%	1.10	11.34%
CD321	1.10	3.34%	1.10	3.34%	3.00	9.12%	--	--
CD322	0.40	2.35%	0.40	2.35%	1.30	7.65%	--	--
CD323	0.20	3.12%	0.20	3.12%	0.60	9.37%	--	--
CD341	1.00	11.63%	1.40	16.28%	2.20	25.58%	0.00	0.00%
CD342	1.80	9.78%	2.50	13.59%	3.70	20.11%	0.00	0.00%
CD351	0.00	0.00%	0.00	0.00%	1.90	7.12%	1.50	5.62%
CD352	0.00	0.00%	0.00	0.00%	3.00	3.75%	5.00	6.25%
CD353	0.00	0.00%	0.00	0.00%	1.10	4.62%	2.50	10.50%
CD391	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD392	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD393	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD401	0.00	0.00%	0.10	1.72%	0.60	10.34%	--	--
CD402	0.00	0.00%	0.60	2.70%	2.60	11.71%	--	--
CD403	0.00	0.00%	1.00	3.29%	3.80	12.50%	--	--
CD411	0.00	0.00%	0.00	0.00%	6.00	13.04%	5.00	10.87%
CD412	0.00	0.00%	0.00	0.00%	1.20	8.89%	1.30	9.63%
CD413	0.00	0.00%	0.00	0.00%	6.00	14.29%	6.00	14.29%
CD414	0.00	0.00%	0.00	0.00%	7.00	11.67%	6.00	10.00%
CD415	0.00	0.00%	0.00	0.00%	3.30	13.25%	2.70	10.84%
CD416	0.00	0.00%	0.00	0.00%	3.80	10.89%	4.10	11.75%
CD421	0.00	0.00%	0.00	0.00%	5.00	7.58%	6.00	9.09%
CD422	0.00	0.00%	0.00	0.00%	4.00	6.25%	2.00	3.13%
CD431	0.00	0.00%	0.20	2.13%	0.70	7.45%	2.40	25.53%
CD432	0.00	0.00%	0.20	1.24%	1.20	7.45%	6.20	38.51%
CD433	0.00	0.00%	0.20	1.49%	1.10	8.21%	2.60	19.40%
CD441	0.00	0.00%	0.01	2.94%	0.09	26.47%	0.45	132.35%
CD442	0.00	0.00%	0.30	1.85%	4.70	29.01%	16.60	102.47%
CD443	0.00	0.00%	0.20	2.50%	2.40	30.00%	9.50	118.75%
CD444	0.00	0.00%	0.20	1.35%	3.70	25.00%	15.60	105.41%
CD471	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD472	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD473	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD474	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD475	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD531	0.00	0.00%	0.00	0.00%	0.30	1.60%	--	--
CD532	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD533	0.00	0.00%	0.00	0.00%	0.00	0.00%	--	--
CD561	0.10	0.74%	0.80	5.88%	2.10	15.44%	2.00	14.71%
CD562	0.00	0.00%	0.40	3.74%	0.90	8.41%	0.80	7.48%
CD571	0.70	2.48%	2.20	7.80%	4.40	15.60%	0.60	2.13%
CD572	1.90	4.86%	2.80	7.16%	6.60	16.88%	2.90	7.42%
CD573	0.50	2.98%	1.50	8.93%	3.00	17.86%	0.90	5.36%
CD581	0.00	0.00%	0.00	0.00%	-1.20	-9.52%	--	--
CD582	0.00	0.00%	0.00	0.00%	-4.60	-8.10%	--	--
CD583	0.00	0.00%	0.00	0.00%	-4.20	-13.29%	--	--
CD584	0.00	0.00%	0.00	0.00%	-1.70	-8.46%	--	--

Table 6.5 (contd.)

CD #	Relative Change Low Cons. Absolute [MtC]	Low Cons. Percent [%]	Relative Change Med. Cons. Absolute [MtC]	Med. Cons. Percent [%]	Relative Change High Cons. Absolute [MtC]	High Cons. Percent [%]	Relative Change Cover Crop Absolute [MtC]	Cover Crop Percent [%]
CD591	0.00	0.00%	0.90	2.28%	5.50	13.96%	5.10	12.94%
CD592	0.00	0.00%	0.60	4.48%	1.90	14.18%	1.90	14.18%
CD601	0.20	2.90%	0.50	7.25%	0.80	11.59%	0.50	7.25%
CD602	0.40	1.69%	1.60	6.78%	1.90	8.05%	6.60	27.97%
CD603	1.00	2.96%	3.00	8.88%	3.00	8.88%	14.00	41.42%
CD611	0.11	5.98%	0.15	8.15%	0.41	22.28%	0.52	28.26%
CD612	0.11	8.53%	0.15	11.63%	0.46	35.66%	1.48	114.73%
CD631	0.20	1.18%	0.20	1.18%	1.70	10.06%	--	--
CD632	0.40	1.45%	0.40	1.45%	1.70	6.18%	--	--
CD633	0.30	1.71%	0.30	1.71%	1.40	8.00%	--	--
CD634	0.20	0.82%	0.20	0.82%	1.80	7.38%	--	--
CD641	0.00	0.00%	1.30	16.67%	1.50	19.23%	2.70	34.62%
CD642	0.00	0.00%	1.40	10.85%	2.10	16.28%	3.20	24.81%
CD643	0.00	0.00%	0.68	14.56%	1.15	24.63%	1.69	36.19%
Average	0.16	1.54%	0.37	3.07%	1.36	8.16%	1.85	13.87%
Maximum	1.90	11.63%	3.00	16.67%	7.00	35.66%	16.60	132.35%
Minimum	0.00	0.00%	0.00	0.00%	-4.60	-13.29%	0.00	0.00%

Moreover, as shown in Table 5.13, the High Conservation Scenario was based on a 26% level for NT, while the Medium Conservation scenario assumed only an 8% NT level; the corresponding levels of conservation tillage (i.e. combined RT and NT) were 37% and 56%, respectively for Medium and High scenarios. Data for 1992 from CTIC indicate that NT was practiced on 19% of cropland within the Cornbelt, and combined conservation tillage was 43%; also, dramatic increases in both practices are expected for 1993 (Dan McCain, CTIC, personal communication, 1993). Thus, the levels of RT and NT derived from the RAMS simulations are modest when compared to more recent data. Increased levels of RT and NT practices would show a greater increase in the Study Region SOC than indicated by the three scenarios evaluated. Although these results of tillage impacts are encouraging, further study is needed before we can confirm these conclusions (See Section 7.0). In addition, conservation tillage has other benefits (e.g., water quality improvement) not considered in this study.

4. **Cover crops have a significant impact on SOC** in the Study Region leading to a 53% increase from 1990, compared to 49% for Status Quo, and an **additional 0.14 Gt C sequestered** in the Study Region. Although these numbers are not large, they are the result of cover crops being **implemented on only 12%** of the cropland in the Study Region. Among the CDs with cover crops, the average SOC increase over the Status Quo was 14% with a range from 0% to 132% (Table 6.5).

6.2.2 Spatial Assessment of Study Region SOC Impacts

To assess and analyze spatial variations in the simulation results, the GIS capabilities of the Environmental Research Laboratory in Athens, GA were employed to display the results discussed above for all CDs within the Study Region. The accompanying figures generated by the Athens GIS staff are as follows:

Figure 6.10 Simulated 1990 Soil Carbon (gC/m^2) Distribution Within the Study Region
Figure 6.11 Simulated 1990 Soil Carbon (gC/m^2) Distribution Within the Study Region Weighted by Cropland Distribution
Figure 6.12 Simulated 2030 Soil Carbon (gC/m^2) Distribution Within the Study Region
Figure 6.13 Simulated 2030 Soil Carbon (gC/m^2) Distribution Within the Study Region Weighted by Cropland Distribution
Figure 6.14 Increase in Soil Carbon (gC/m^2) Within the Study Region From 1990 to 2030 under the Status Quo Scenario
Figure 6.15 Increase in Soil Carbon (gC/m^2) Within the Study Region From 1990 to 2030 under the Status Quo Scenario Weighted by Cropland Distribution
Figure 6.16 Percent Change in Soil Carbon Within the Study Region From 1990 to 2030 under the Status Quo Scenario

Figure 6.17 Percent Difference in Soil Carbon Within the Study Region For 2030 For **High Conservation** Relative to the Status Quo Scenario

Figure 6.18 Percent Difference in Soil Carbon Within the Study Region For 2030 For **Cover Crops** Relative to the Status Quo Scenario

Appendix D includes a complete set of the model results maps, plus additional maps, (e.g., cropland and CRP distribution, additional tillage and cover crop scenario maps), that help the reader to interpret the GIS-displayed model results.

As noted above, Figures 6.10 through 6.13 show the 1990 SOC, 2030 SOC, and the difference or gain in SOC during the 40-year projection period, respectively, under the Status Quo scenario. The units are gC/m^2, as opposed to the units of MtC in Tables 6.4 and 6.5, in order to eliminate the impact of the amount of cropland area. The spatial patterns in these figures are quite complex and difficult to analyze quantitatively. However, some trends and observations are evident, as follows:

1. The pattern of higher values of SOC (dark shades) in the central and northern portions of the Study Region, and lower values (light shades) in the eastern, southern, and western peripheries, is consistent with other soil carbon mapping efforts (e.g., Kern and Johnson, 1991).

2. The 1990 (Figure 6.10) and 2030 (Figure 6.12) maps of SOC show the same general spatial pattern, although with significantly higher values for 2030. This is indicated by the increase in CDs with the darker shades in Figures 6.12 and 6.13.

3. The regions with the greatest **absolute** change (Figure 6.14) and **percent change** (Figure 6.15) appear to be those CDs with dominant corn-based rotations and/or those located in the central and northern portions of the Study Region. The smallest absolute increases are generally in the south.

4. Figures 6.11, 6.13, and 6.15, respectively, show the 1990 and 2030 SOC values, and the increase from 1990 to 2030, **weighted by cropland area** in order to account for the relative distribution of cropland within the Study Region; these figures were generated by multiplying the SOC values in Figures 6.10, 6.12, and 6.14 by the **fraction of area representing cropland** (shown in Figure 5.1). These figures are a more accurate spatial representation of SOC distribution within the Study Region since they show the net impact of both unit area changes and cropland distribution. Thus, comparing Figure 6.10 and 6.11 shows the greatest concentration of SOC in the central area i.e., the Cornbelt and Plains portions of Study Region; northern areas, such as PA 22, have large unit area values but comprise a small portion of the total SOC because of the small area of cropland. Figure 6.15 shows the largest increases generally in the central portion of the Study Region, with the exception of CDs 473 and 474. In PA 47,

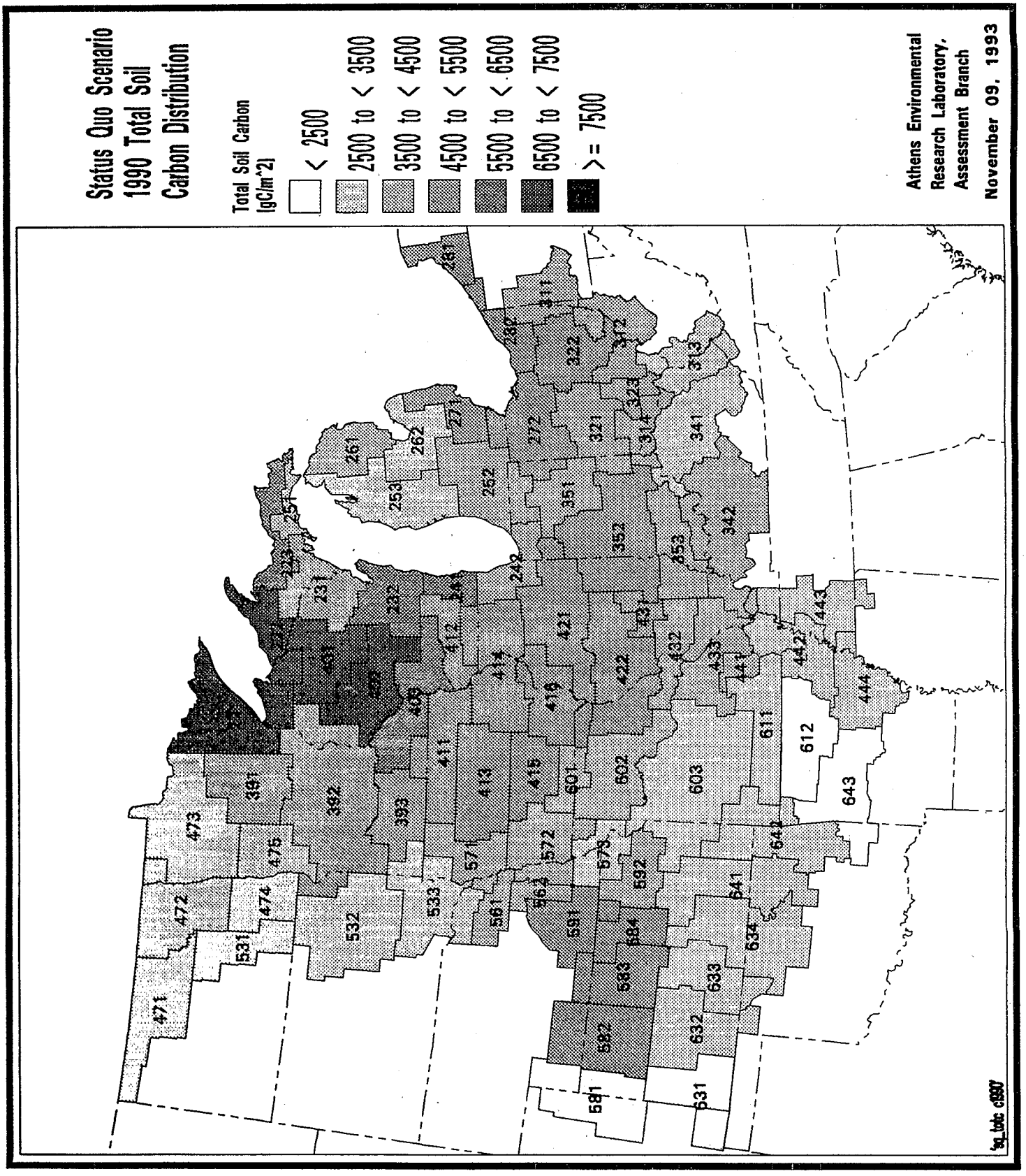


Figure 6.10 Simulated 1990 Soil Carbon (gC/m2) distribution within the study region

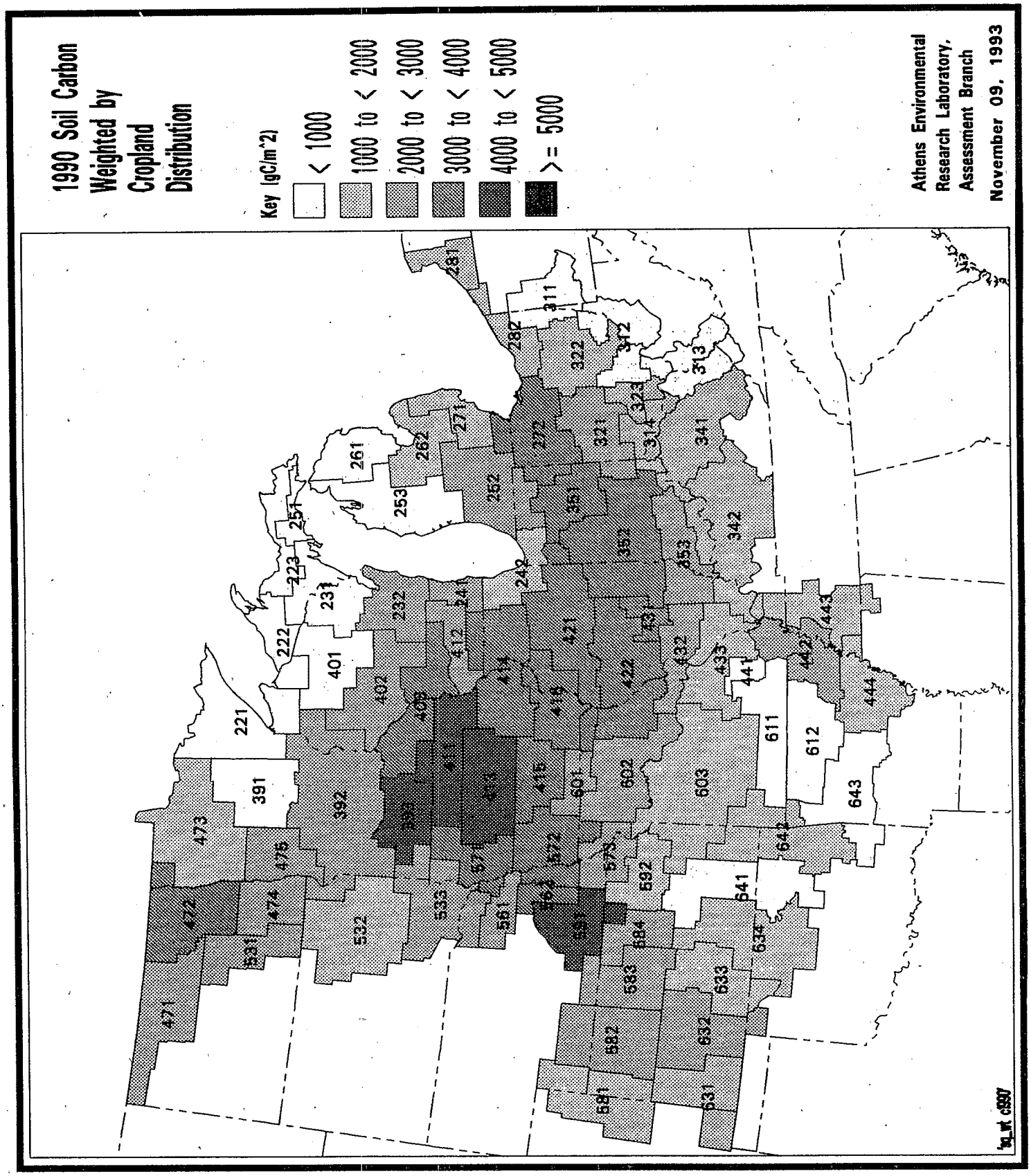


Figure 6.11 Simulated 1990 Soil Carbon (gC/m2) distribution within the study region weighted by cropland distribution

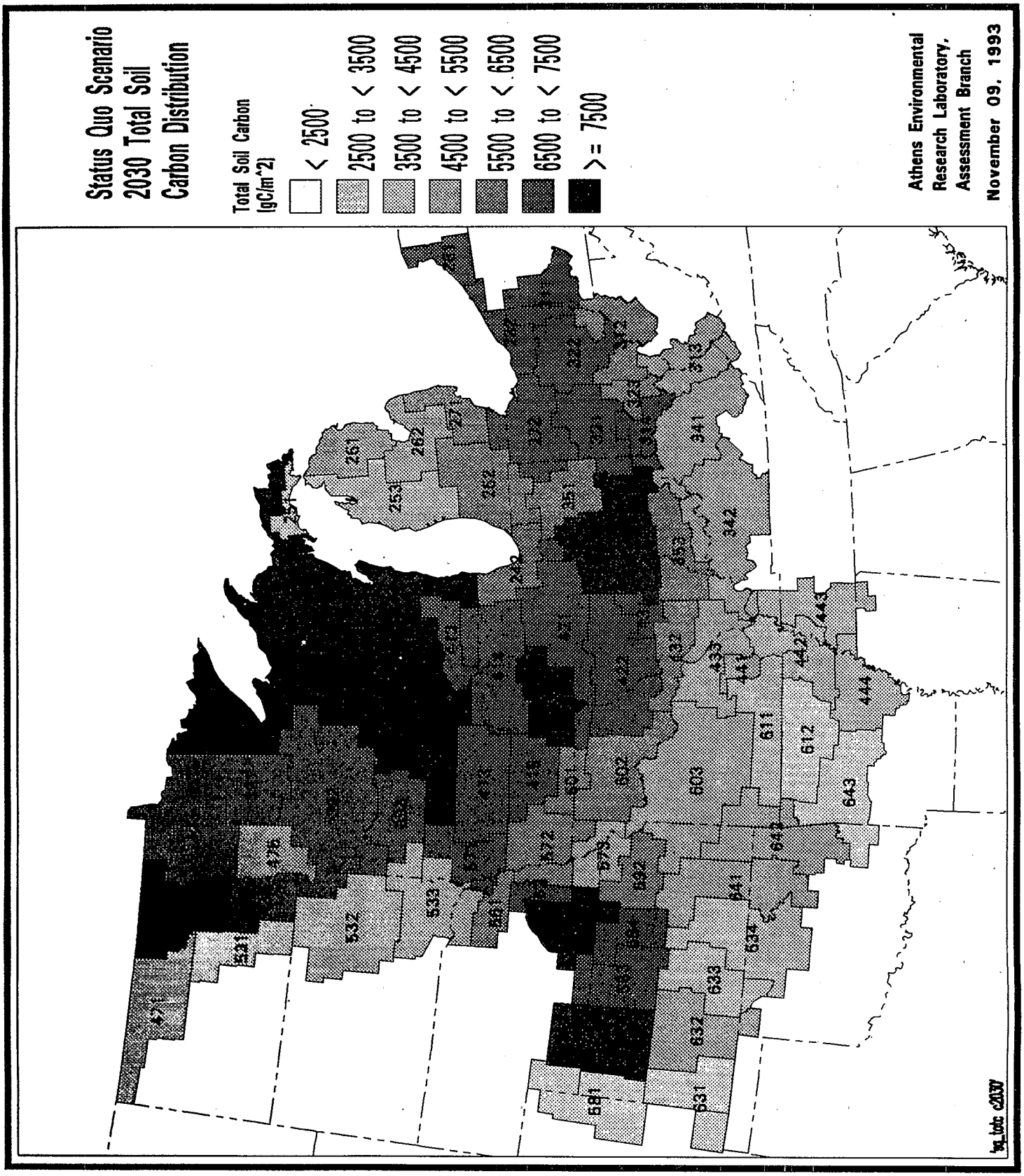


Figure 6.12 Simulated 2030 Soil Carbon (gC/m2) distribution within the study region

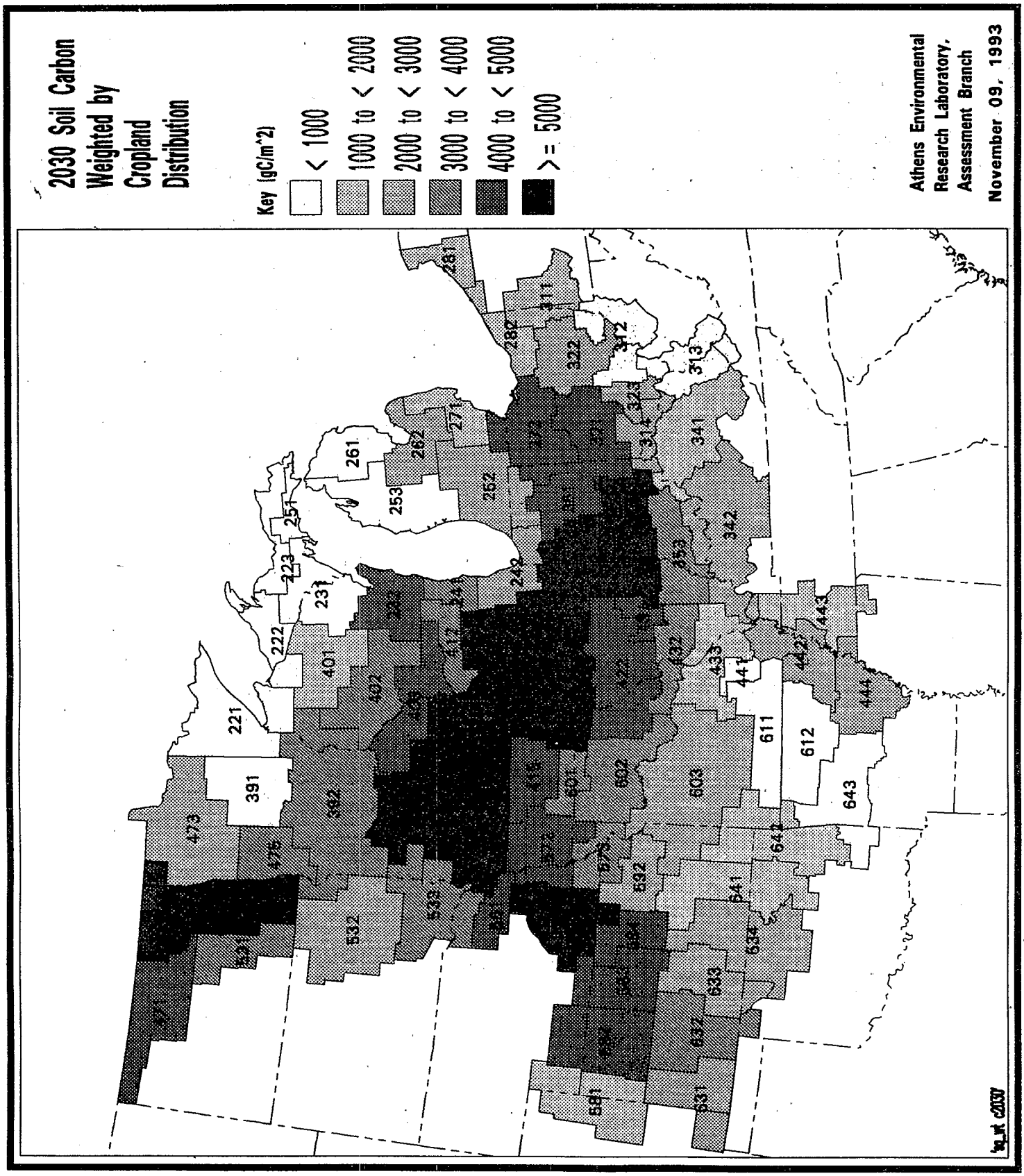


Figure 6.13 Simulated 2030 Soil Carbon (gC/m2) distribution within the study region weighted by cropland distribution

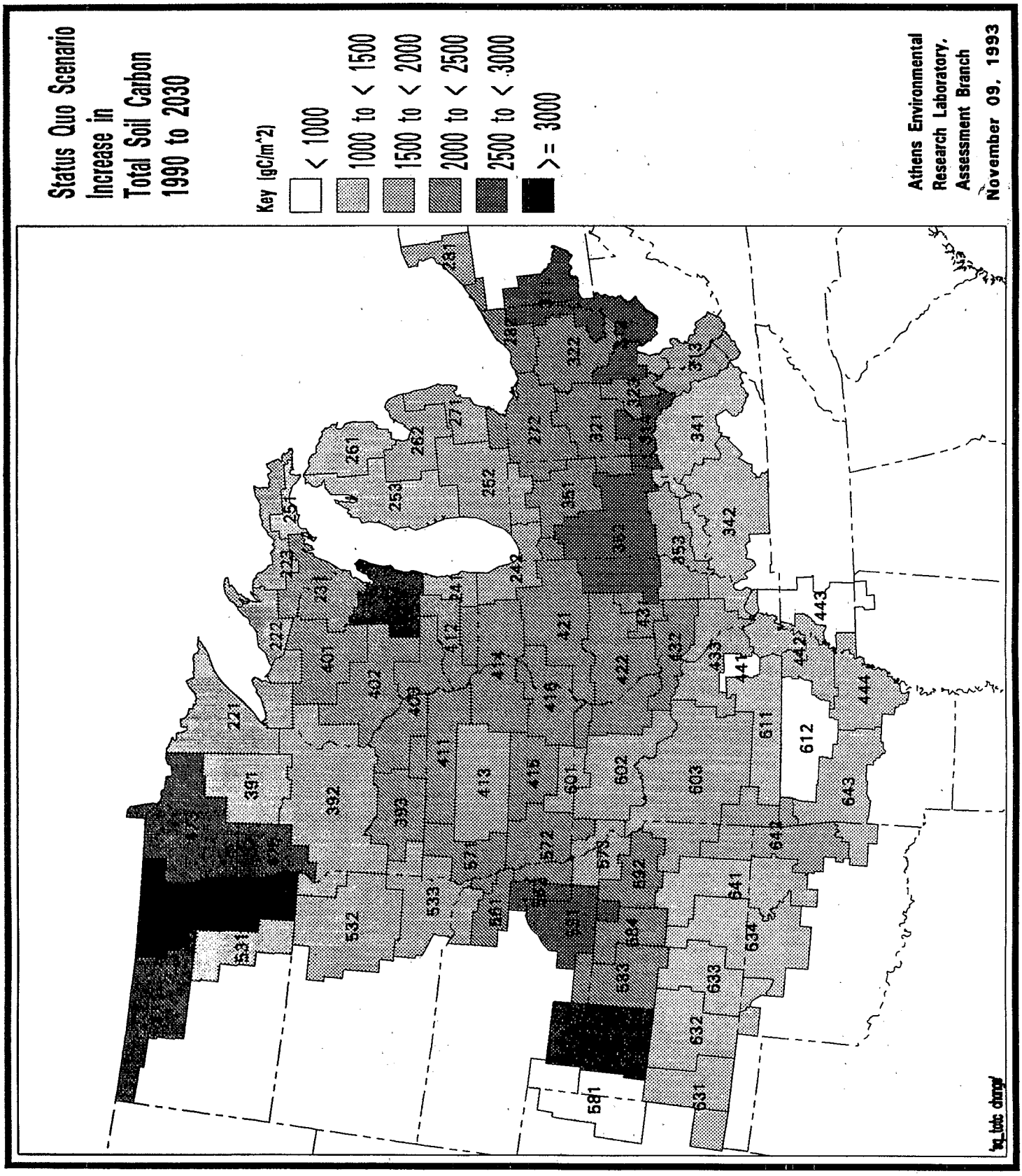


Figure 6.14 Increase in Soil Carbon (gC/m2) within the study region from 1990 to 2030 under the Status Quo Scenario

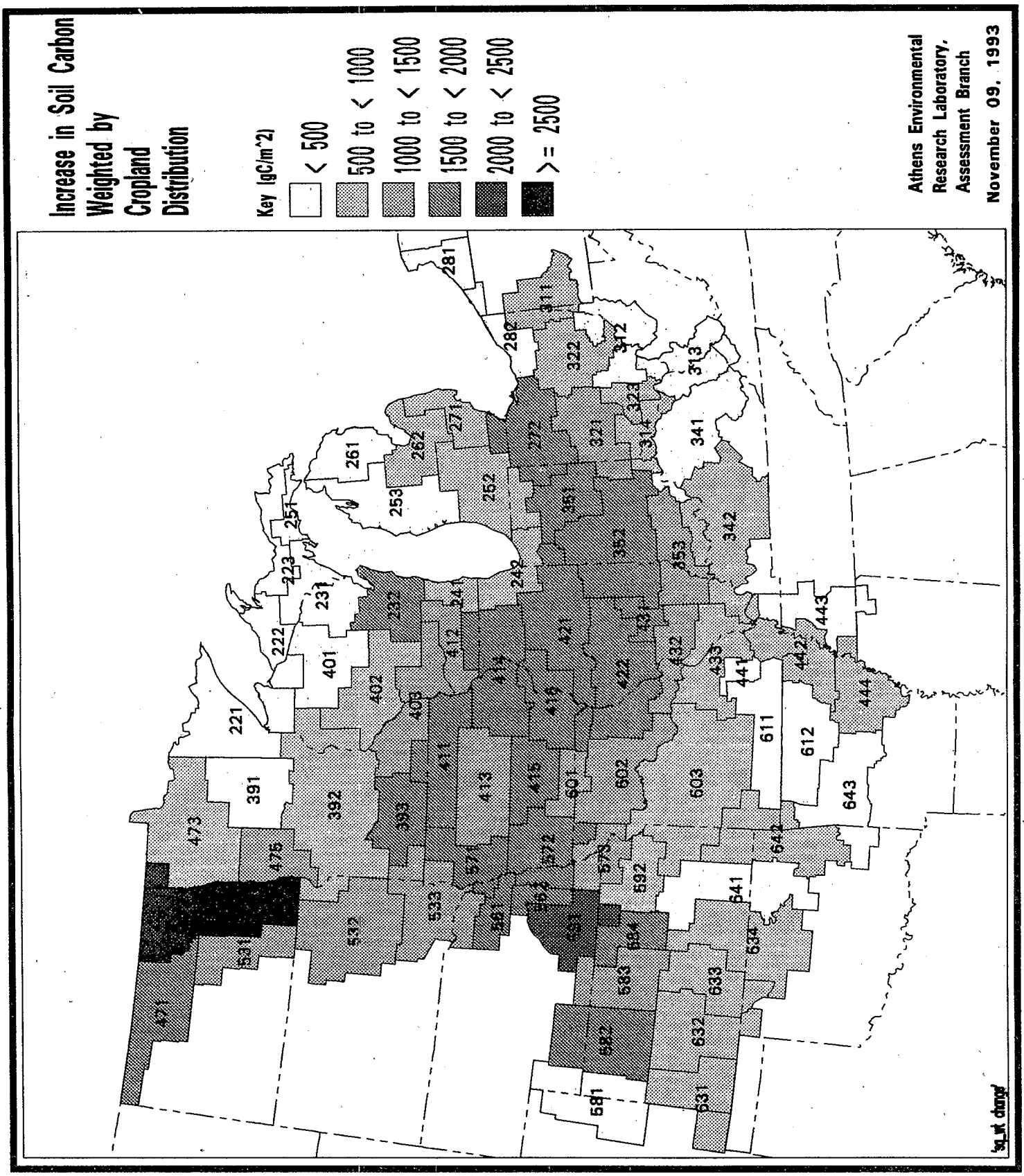


Figure 6.15 Increase in Soil Carbon (gC/m2) within the study region from 1990 to 2030 under the Status Quo Scenario weighted by cropland distribution

the dominant rotation is wheat-fallow, but 60% of the PA area is in corn, barley, or soybean-based rotations. The large simulated increase results from this change in rotations between the historical and projection periods. Figure 6.16 shows the increase weighted by the cropland distribution.

5. Under the Status Quo scenario, the **absolute increase in SOC** was generally in the range of 1500 to 2500 gC/m^2, as shown by the prevalence of the medium range of dark shades in Figure 6.14; Figure 6.15 shows smaller values in the range of 1000 to 2000 gC/m^2 due to the weighting by the cropland area. This range of values corresponds to a 50% to 70% increase in SOC (in the top 20 cm of the soil) as shown by the medium dark shaded areas in Figure 6.16. Some of the largest increases, such as in the CDs in PA 31, PA 47, and PA 53, are due to dominant rotations of wheat-fallow or hay, followed by corn-based rotations that lead to significant SOC increases during the projection period, as noted above.

6. Figure 6.17 shows the percent difference in SOC in 2030 for the High Conservation scenario compared to the Status Quo scenario. Except for a few CDs with negative differences (shown by the cross-hatched areas), the High Conservation scenario produced increased higher SOC throughout the Study Region with differences mostly in the range of 5% to 25%. The largest differences are generally in the southern and central portions of the Study Region. Most of the CDs show differences of 10% to 20%, with some of the southern and areas showing differences of more than 25% to 35%. As noted above, these differences are based on rather modest increases in RT and NT areas compared to more recent data on increasing usage of conservation tillage practices.

   The few PAs that show negative differences, as compared to the Status Quo scenario, are regions where the predicted changes in crop rotations (by the RAMS model) lead to significant increases in wheat-fallow rotations (i.e. PA 58) or increases in longer rotations with fewer years of corn and corn-silage (i.e. PA 31) (See Table E.1 in Appendix E). Independent confirmation of the likelihood of these types of rotational changes is needed in order to validate tillage scenario impacts in these regions.

7. The percent difference in SOC in 2030 due to cover crops is shown in Figure 6.18. Cover crops uniformly increased SOC throughout the Study Region (in areas where cover crops were included), with the differences ranging from 0% to more than 130%. In most of the central area, the differences are less than 15%, but increase to 30% and more for the southern CDs. These patterns indicate an increase in the gain in SOC due to climatic conditions from the central to the southern areas. Most of the PAs with small increases include crop rotations that provide little opportunity for cover crops, and/or are located where winter climate restricts cover crop growth.

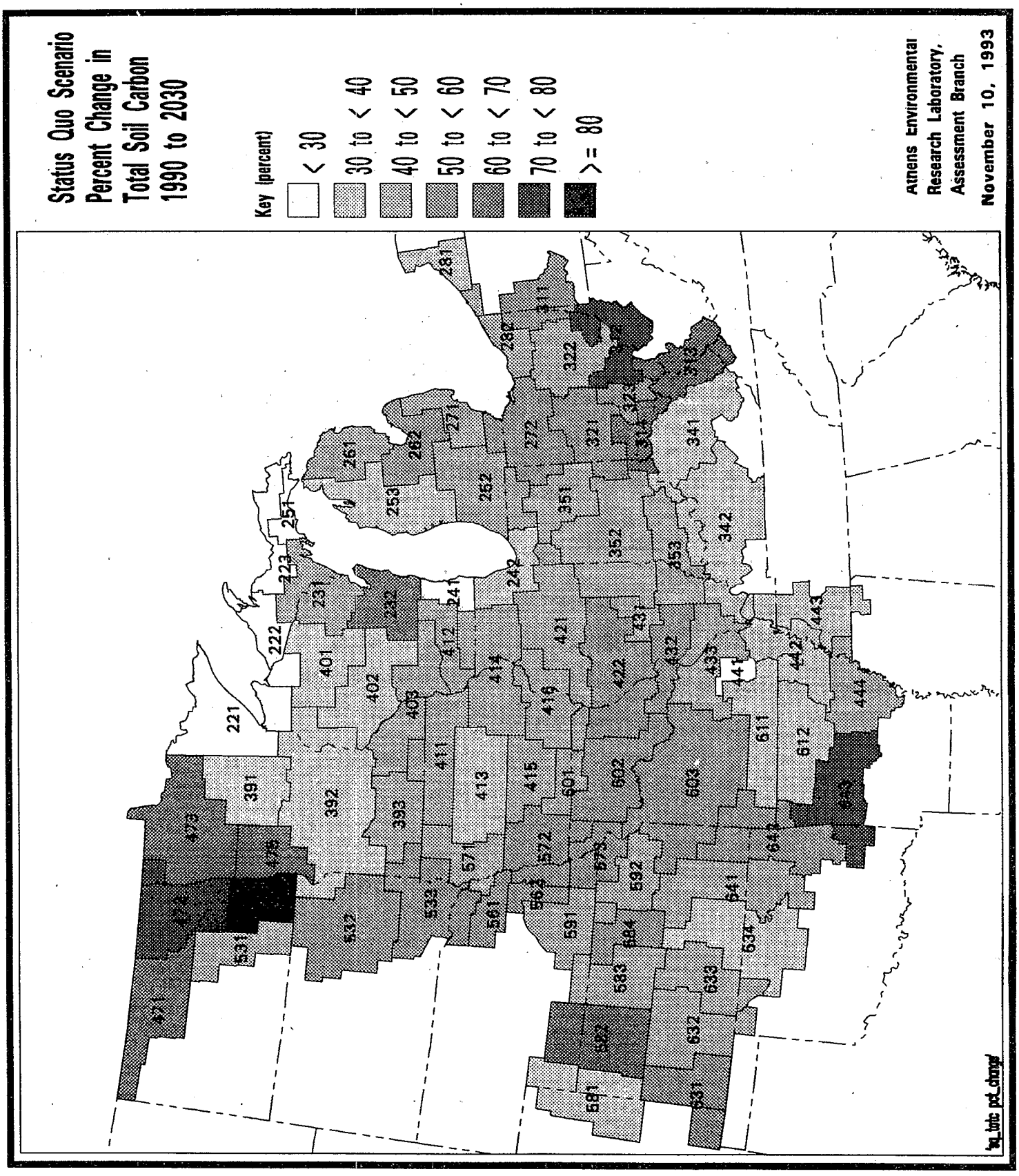


Figure 6.16 Percent change in Soil Carbon within the study region from 1990 to 2030 under the Status Quo Scenario

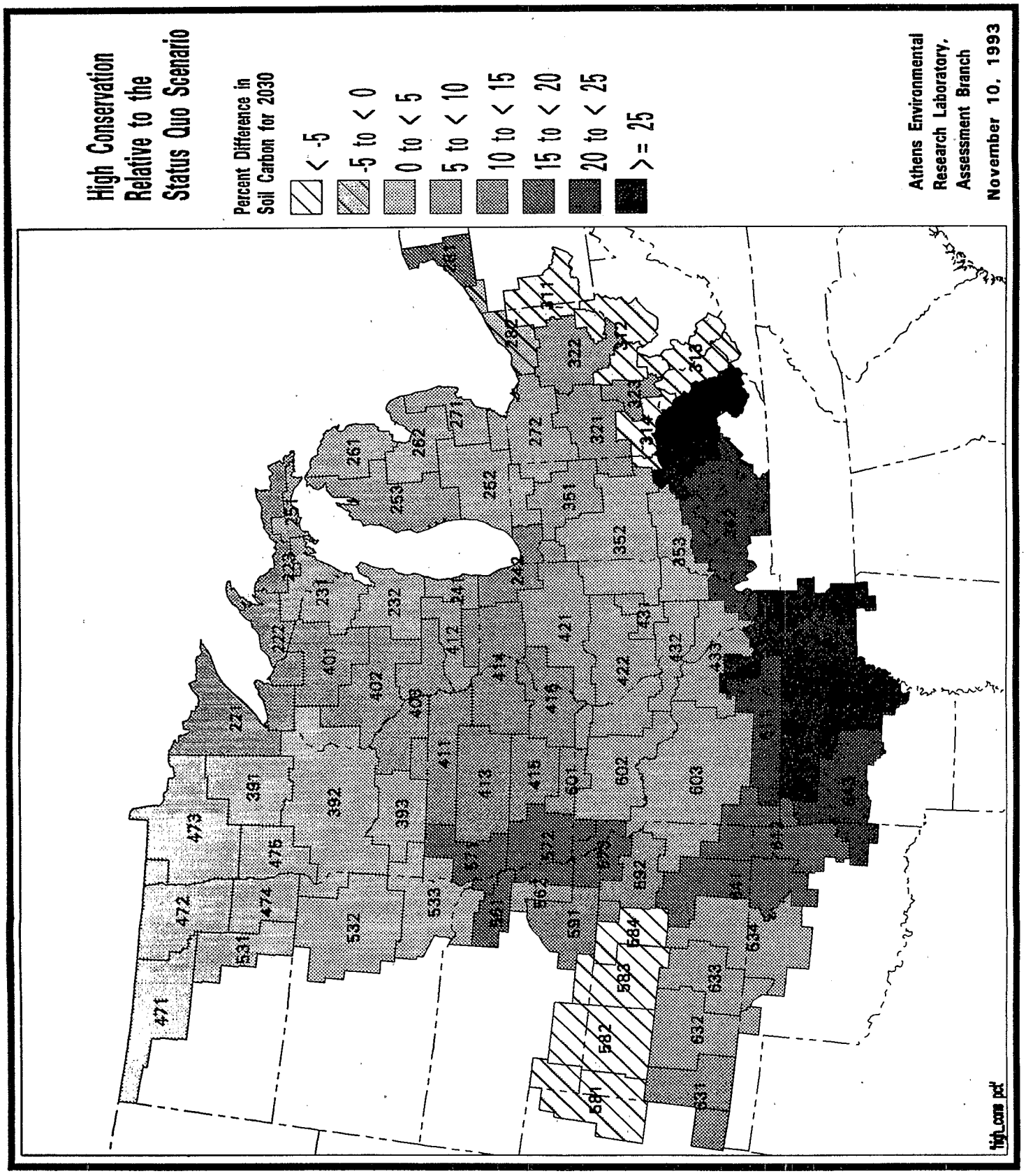


Figure 6.17 Percent difference in Soil Carbon within the study region for 2030 for **High Conservation** relative to the Status Quo Scenario

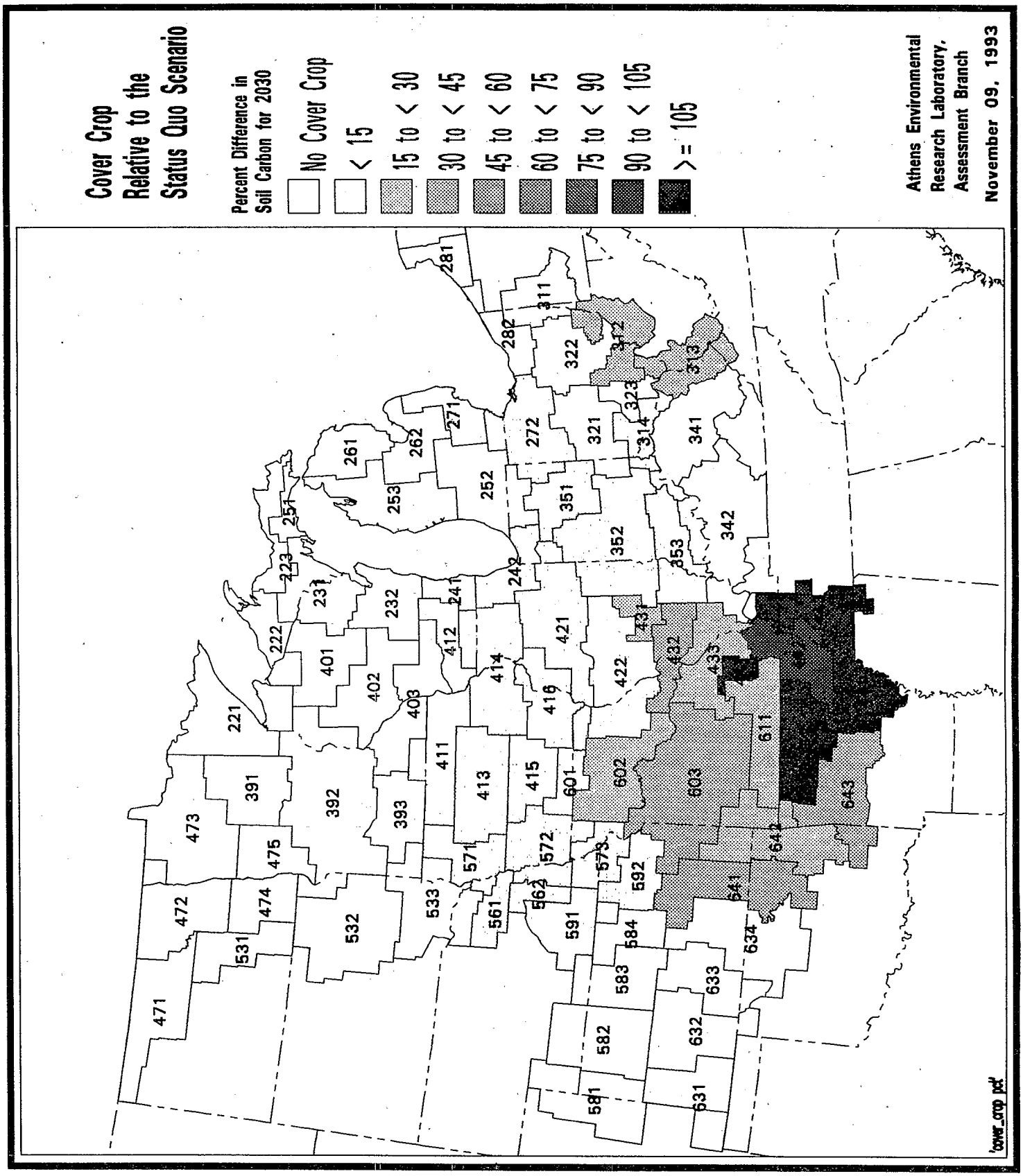


Figure 6.18 Percent difference in Soil Carbon within the study region for 2030 for Cover Crops relative to the Status Quo Scenario

6.3 PRELIMINARY ASSESSMENT OF CONSERVATION RESERVE PROGRAM (CRP) LAND

The procedures and assumptions for modeling SOC on CRP lands were described in Section 5.4. This section presents the results of modeling two CRP scenarios, CRP1 and CRP2, and compares the results to SOC conditions under the **dominant rotation, or dominant cash crop rotation,** for each CD in the Study Region. As noted in Section 5.4, CRP1 assumes a 20-year CRP enrollment of approximately 15 million acres within the Study Region starting in 1986, with 56% converted back to the dominant rotation in 2007, and the remaining 44% staying in CRP through 2030. CRP2 assumes that the 15 million acres remains in CRP throughout the projection period, i.e., through 2030.

Initially, a third CRP scenario was to be evaluated to represent a 25% increase in CRP enrollment to 18.75 million acres. However, in order to do the assessment we needed to know where the additional 3.75 million acres would come from, i.e., which C/R/T combinations are taken out of production (from the 216 million acres), and how do the remaining C/R/T acres change in each PA. This information was not available for this study.

6.3.1 Unit Area Impacts of CRP Land Conversion on SOC

Table 6.6 summarizes the changes in SOC on a unit area basis, i.e., in terms of gC/m^2, for the dominant rotation, CRP1 simulation, and CRP2 simulation for eight selected CDs (whose locations are shown in Figure 6.1). Table C.5 in Appendix C includes results for all CDs. Figures 6.19 and 6.20 graphically show the pattern of SOC changes during the projection period for four of these CDs. We've included the **dominant rotation** in the tables and figures as a baseline to which the CRP changes can be compared; obviously, the actual change would depend on which crops (and their rotations) are taken out of production.

From these preliminary results, the following observations are provided:

1. The results of the CRP simulations are mixed. In many cases, CRP1 leads to SOC values higher than the dominant rotation by the year 2030, and usually higher than CRP2. In other CDs, the dominant rotation maintains the highest SOC throughout the projection period. The key factor is likely the relative carbon inputs of the dominant rotation as compared to the CRP simulations. When the dominant rotation is a corn-based rotation, its 2030 SOC is usually the highest (e.g. CDs 262, 272, 632, and 643 in Table 6.6). However, this is not always true, especially if only one year of corn is in the rotation (e.g. CD 413, 603). The percent difference for the CRP simulations can range from a few percentage points to up to 20% or higher.

Table 6.6 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for CRP and Dominant Crop Rotations for Selected Climate Divisons

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
262	145	CRN,CRN,WWT,HLH,HLH,HLH	3193	3466	3805	4114	4336	4819	9.78%	8.12%	5.39%	11.13%	39.03%
262	145	CRP1	3193	3815	4020	4274	4397	4723	5.37%	6.33%	2.87%	7.43%	23.82%
262	999	CRP2	3193	3823	4028	4148	4338	4505	5.36%	2.97%	4.58%	3.84%	17.83%
272	186	CRN,SOY	4289	4559	5029	5395	6076	6613	10.30%	7.27%	12.62%	8.83%	45.05%
272	186	CRP1	4289	4758	5027	5322	5788	6205	5.65%	5.87%	8.74%	7.22%	30.41%
272	999	CRP2	4289	4770	5040	5273	5502	5732	5.66%	4.62%	4.34%	4.18%	20.16%
341	144	CRN,CRN,WWT,HLH,HLH	3294	3478	3620	3842	4316	4611	4.08%	6.13%	12.33%	6.83%	32.57%
341	144	CRP1	3294	3688	3998	4455	4742	5129	8.41%	11.45%	6.43%	8.17%	39.09%
341	999	CRP2	3294	3706	4014	4317	4549	4895	8.31%	7.54%	5.37%	7.60%	32.08%
413	186	CRN,SOY	4677	4966	5123	5286	5493	5790	3.16%	3.18%	3.91%	5.40%	16.59%
413	186	CRP1	4677	5155	5428	5655	5993	6452	5.31%	4.18%	5.97%	7.66%	25.17%
413	999	CRP2	4677	5159	5435	5586	5745	5970	5.34%	2.77%	2.84%	3.91%	15.72%
473	463	SMF,SWT	3895	3917	4128	4133	4345	4511	5.38%	0.12%	5.12%	3.82%	15.16%
473	463	CRP1	3895	4064	4359	4531	4584	4663	7.26%	3.95%	1.17%	1.72%	14.73%
473	999	CRP2	3895	4064	4359	4498	4658	4810	7.25%	3.18%	3.55%	3.26%	18.35%
603	201	CRN,SOY,WWT	3550	3688	3960	4136	4442	4762	7.37%	4.44%	7.39%	7.20%	29.12%
603	548	CRP1	3550	3899	4185	4545	4858	5282	7.34%	8.60%	6.90%	8.73%	35.49%
603	999	CRP2	3550	3910	4195	4450	4757	5026	7.28%	6.07%	6.89%	5.65%	28.54%
632	218	CRN,WWT	3727	4089	4606	4880	5192	5557	12.64%	5.94%	6.39%	7.03%	35.90%
632	523	CRP1	3727	4070	4260	4481	5037	5504	4.65%	5.19%	12.42%	9.26%	35.21%
632	999	CRP2	3727	4072	4264	4405	4522	4663	4.71%	3.30%	2.65%	3.11%	14.51%
643	131	CRN,CRN,SOY	1787	1928	2414	2630	2885	3275	25.20%	8.94%	9.69%	13.51%	69.86%
643	131	CRP1	1787	2063	2410	2811	3055	3355	16.80%	16.65%	8.66%	9.84%	62.61%
643	999	CRP2	1787	2065	2411	2708	3026	3344	16.75%	12.31%	11.74%	10.50%	61.93%

CRP1 - Represents scenario under CRP from 1986 to 2006 (20 years) and converted back to dominant crop rotation from 2007 to 2030
CRP2 - Represents scenario under CRP from 1986 to 2030

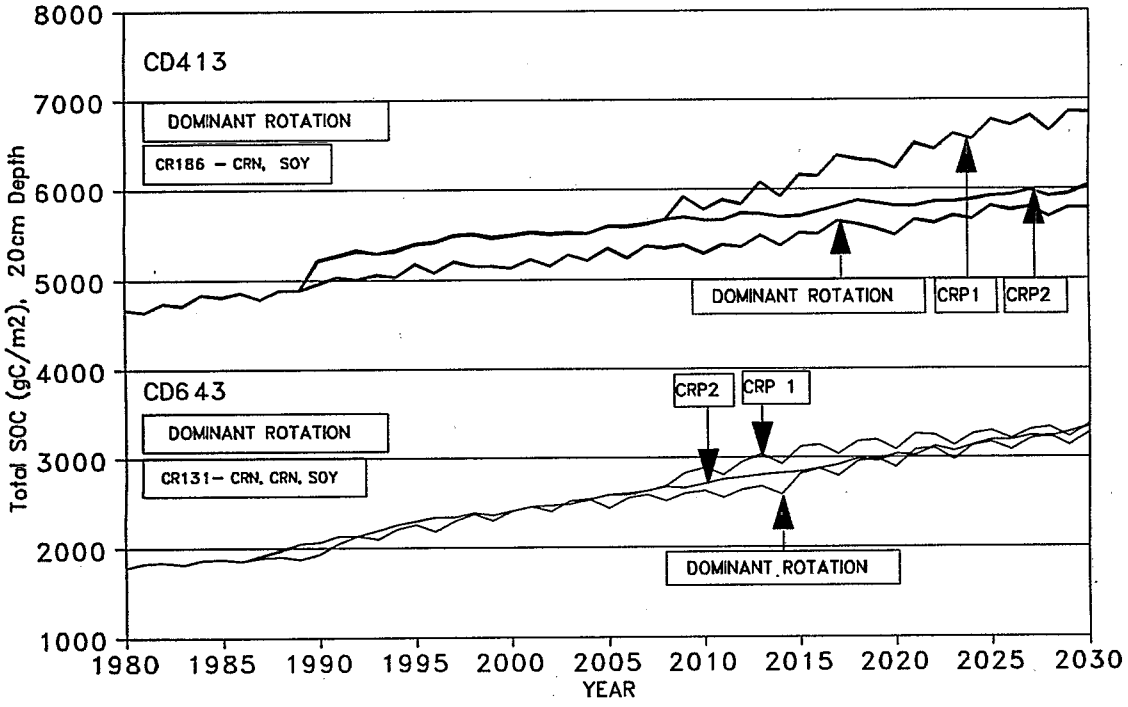


Figure 6.19. Impacts of CRP Scenarios on Total SOC in CDs 413 and 643

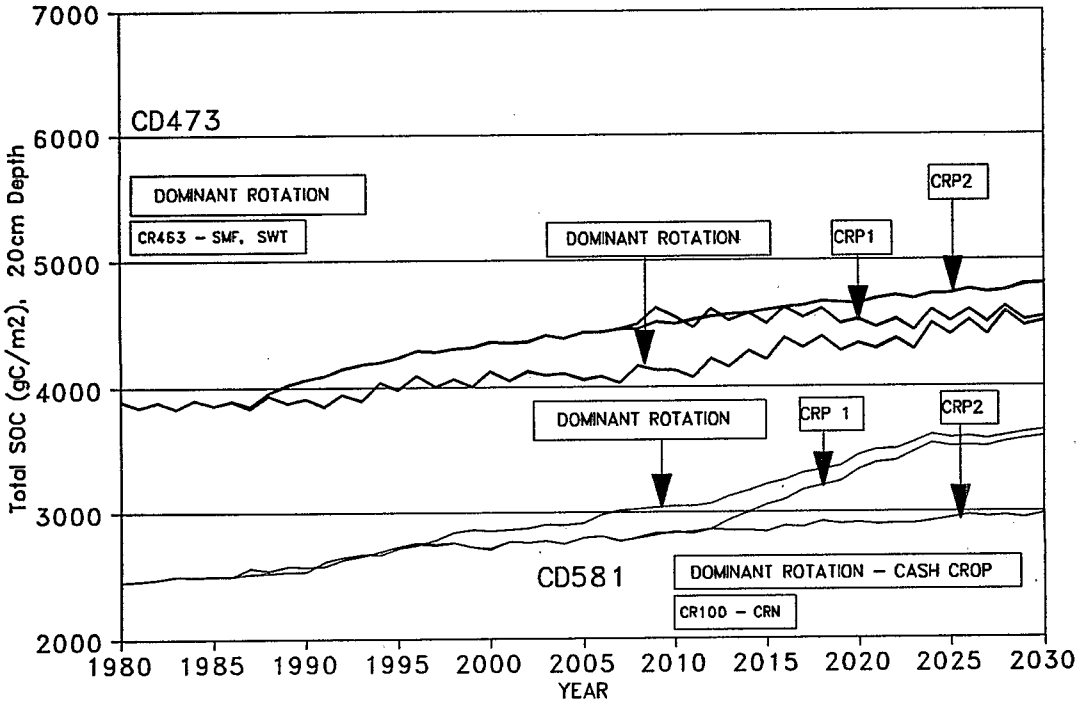


Figure 6.20. Impacts of CRP Scenarios on Total SOC in CDs 473 and 581

2. As shown in Figures 6.19 and 6.20, the SOC values for CRP1 change at the end of the 20-year enrollment when the grass is plowed under in preparation of the return to crop production. The CRP2 curves do not show this change since the land remains as uncultivated grassland.

3. The CRP2 values are often, but not always, the lowest in terms of the change during the projection period. The relative positions depend on many factors, including the nature of the dominant rotation, irrigation practices, and soil and climate conditions. In Figure 6.20, for CD 473 the CRP2 curve leads to the greatest increase by 2030; the dominant rotation in this CD is wheat-fallow with relatively low carbon inputs. For CD 581, CRP2 is the lowest and the Dominant Rotation is the highest by 2030 because the rotation is continuous corn with high carbon inputs.

6.3.2 Study Region Impacts of CRP Scenarios

To obtain the Study Region impacts, the CRP1 and CRP2 CENTURY simulations were multiplied by the appropriate areas under CRP and dominant rotation conditions for each CRP scenario, as discussed above and in Section 5.4. Table 6.7 shows the absolute and percent change in soil carbon for both CRP scenarios and the dominant crop rotation, as a base for comparison, while Table 6.8 shows the relative changes, both absolute and percent, for CRP1 and CRP2 compared to the dominant rotation for SOC values in 2030. Figures 6.21 and 6.22 show the spatial variation in the percent difference for CRP1 and CRP2, respectively, compared to the dominant rotation in 2030. Maps of the absolute and weighted differences, and percent differences are included in Appendix D.

Some observations from these results are as follows:

1. The average percent changes from 1990 to 2030 for the Dominant Rotation, CRP1 and CRP2 are 32%, 30% and 19.0%, respectively. Thus, both CRP scenarios show a decrease in SOC over the dominant rotation, but the overall Study Region differences are small. Among the CDs, the maximum changes for the three scenarios were 70%, 63%, and 62%, respectively, while the minimum changes were 11%, 12%, and 7%.

2. From the bottom of Table 6.7, the net difference for CRP1 is 4.0 MtC, or 4.9% less than the SOC for the dominant rotation. For CRP2, the net difference is 31.4 MtC, or 39% less than the Dominant Rotation.

3. There are great differences among the various CDs in terms of CRP impacts relative to the Dominant Rotation, ranging from -35% to +65% difference in SOC for CRP1, and -78% to +141% for CRP2, compared to the dominant rotation. The averages of these ranges for CRP1 and CRP2 are -5% and -27%, respectively, as shown at the end of Table 6.8.

Table 6.7 Absolute and Percent Change in Total Soil Carbon from 1990 to 2030 in the Study Region for CRP Scenarios and Dominant Crop Rotation

CD #	Dominant Rotation Absolute [ktC]	Dominant Rotation Percent [%]	CRP1 Absolute [ktC]	CRP1 Percent [%]	CRP2 Absolute [ktC]	CRP2 Percent [%]
221	3.70	28.90%	3.00	22.05%	1.83	13.49%
222	1.03	29.44%	0.84	22.56%	0.51	13.71%
223	1.09	30.13%	0.86	21.87%	0.52	13.14%
231	74.91	33.03%	54.85	22.58%	40.78	16.77%
232	469.48	39.95%	314.49	25.07%	199.18	15.85%
241	191.61	39.57%	124.80	25.57%	58.03	11.85%
242	323.47	43.53%	222.57	29.34%	127.76	16.79%
251	2.79	20.43%	3.08	21.96%	2.68	19.11%
252	740.73	35.27%	628.17	28.78%	449.71	20.53%
253	136.51	23.57%	146.98	24.35%	134.81	22.27%
261	28.11	28.75%	19.95	18.84%	15.85	14.94%
262	200.24	39.04%	135.48	24.04%	100.94	17.84%
271	111.47	35.35%	80.77	25.14%	52.91	16.42%
272	778.47	45.05%	551.90	30.66%	364.60	20.17%
281	44.79	24.18%	52.97	27.04%	38.25	19.44%
282	56.06	28.27%	64.56	30.74%	41.78	19.74%
311	72.54	35.43%	66.57	29.77%	49.44	22.00%
312	55.55	37.89%	56.91	35.58%	46.96	29.21%
313	13.52	32.51%	15.11	33.03%	15.17	33.01%
314	75.24	40.02%	74.03	36.10%	55.13	26.75%
321	902.02	45.39%	657.14	30.20%	511.75	23.39%
322	469.66	44.40%	329.99	28.30%	253.69	21.62%
323	175.78	46.74%	132.32	32.05%	107.58	25.89%
341	455.47	32.58%	585.34	39.64%	477.98	32.08%
342	988.42	37.21%	1185.64	42.04%	911.89	31.92%
351	558.89	44.27%	420.38	31.82%	299.88	22.60%
352	1726.06	46.07%	1292.68	33.14%	900.36	22.92%
353	518.91	41.19%	436.55	33.01%	365.74	27.46%
391	163.02	28.26%	128.21	21.43%	92.62	15.48%
392	3808.90	36.83%	2725.43	25.55%	1676.90	15.71%
393	2158.03	45.84%	1443.52	29.69%	777.93	15.98%
401	436.80	33.46%	336.21	25.57%	148.79	11.31%
402	1895.40	41.99%	1349.94	29.68%	516.49	11.35%
403	2463.04	46.23%	1760.00	32.84%	618.45	11.52%
411	2218.69	33.31%	1755.19	25.48%	1099.82	15.95%
412	627.63	30.45%	524.34	24.57%	362.93	16.97%
413	1285.44	16.59%	2029.81	25.26%	1265.16	15.72%
414	2798.92	32.59%	2427.24	27.15%	1656.64	18.48%
415	1159.70	33.79%	970.38	27.02%	667.64	18.53%
416	1622.88	33.66%	1398.72	27.87%	986.66	19.58%
421	2003.97	40.99%	1508.58	29.62%	1056.82	20.68%
422	1976.62	47.73%	1504.25	35.23%	1025.44	23.88%
431	457.15	46.66%	348.25	34.38%	244.77	24.04%
432	818.74	53.06%	617.00	38.43%	438.83	27.19%
433	693.88	50.65%	569.24	39.80%	457.90	31.79%

Table 6.7 (contd.)

CD #	Dominant Rotation Absolute [ktC]	Dominant Rotation Percent [%]	CRP1 Absolute [ktC]	CRP1 Percent [%]	CRP2 Absolute [ktC]	CRP2 Percent [%]
441	15.81	18.22%	24.29	26.23%	29.72	31.88%
442	914.56	34.68%	1089.00	38.93%	1176.50	41.70%
443	413.47	33.03%	558.22	41.25%	675.43	49.40%
444	803.08	45.25%	921.26	47.99%	994.84	51.30%
471	1344.70	16.02%	1080.82	12.21%	1233.96	13.94%
472	1902.08	17.30%	1805.00	15.72%	1958.40	17.06%
473	885.06	15.16%	892.09	14.73%	1111.54	18.36%
474	665.04	15.19%	704.81	15.07%	873.12	18.66%
475	493.52	13.49%	542.67	14.11%	731.36	19.01%
531	531.93	13.08%	570.01	12.83%	753.27	16.95%
532	1060.00	14.16%	1092.60	13.14%	1605.00	19.30%
533	741.28	11.07%	1133.62	15.48%	1785.40	24.38%
561	784.74	51.53%	723.57	46.53%	274.70	17.66%
562	643.20	56.67%	519.22	44.89%	198.65	17.17%
571	1828.83	43.14%	1443.73	32.96%	670.41	15.31%
572	2558.25	46.86%	2032.45	35.34%	1036.80	18.03%
573	1154.71	48.23%	997.34	40.01%	624.09	25.04%
581	1693.71	43.63%	1153.56	29.36%	619.65	15.75%
582	2984.69	27.57%	4929.43	47.10%	714.95	6.81%
583	2003.30	28.19%	2795.94	40.03%	802.10	11.45%
584	1377.00	31.38%	2034.14	47.11%	630.18	14.54%
591	1879.02	55.24%	1410.45	41.27%	432.07	12.64%
592	711.68	61.26%	612.47	51.50%	238.52	20.06%
601	532.39	22.51%	718.18	28.62%	528.52	20.98%
602	2220.87	29.85%	2818.97	36.60%	1980.14	25.61%
603	3179.04	29.12%	4121.74	35.80%	3303.36	28.54%
611	21.29	25.22%	29.67	32.78%	29.88	32.81%
612	18.79	32.96%	26.47	41.90%	33.28	52.30%
631	2490.64	50.29%	1752.39	34.96%	536.71	10.70%
632	3332.36	35.90%	3256.45	35.26%	1341.57	14.51%
633	1973.16	31.69%	2036.86	32.33%	1082.16	17.16%
634	2796.27	30.55%	3045.57	32.28%	1887.42	19.92%
641	432.03	37.07%	384.07	31.73%	356.59	29.43%
642	797.88	53.24%	695.09	44.54%	561.69	35.95%
643	280.18	69.87%	268.99	62.72%	266.03	61.94%
Avg.	1015.37	35.61%	965.94	30.98%	622.47	21.89%
Max.	3808.90	69.87%	4929.43	62.72%	3303.36	61.94%
Min.	1.03	11.07%	0.84	12.21%	0.51	6.81%
Total Study Region Change from 1990	81229.86	32.23%	77275.40	29.58%	49797.48	19.02%

CRP1 - Represents scenario under CRP from 1986 to 2030 (20 years) and converted back to dominant crop rotation from 2007 to 2030.

CRP2 - Represents scenario under CRP from 1986 to 2030.

Table 6.8 Absolute and Percent Difference in Total Soil Carbon for the CRP Scenarios Relative to Dominant Crop Rotation

	Relative Change CRP1		Relative Change CRP2	
	Absolute [ktC]	Percent [%]	Absolute [ktC]	Percent [%]
221	-0.71	-19.08%	-1.87	-50.47%
222	-0.18	-17.78%	-0.51	-50.00%
223	-0.23	-21.35%	-0.58	-52.72%
231	-20.06	-26.78%	-34.14	-45.57%
232	-154.98	-33.01%	-270.29	-57.57%
241	-66.81	-34.87%	-133.58	-69.72%
242	-100.89	-31.19%	-195.70	-60.50%
251	0.28	10.20%	-0.11	-4.04%
252	-112.55	-15.20%	-291.02	-39.29%
253	10.47	7.67%	-1.70	-1.25%
261	-8.16	-29.04%	-12.26	-43.62%
262	-64.76	-32.34%	-99.31	-49.59%
271	-30.70	-27.54%	-58.56	-52.54%
272	-226.57	-29.10%	-413.87	-53.16%
281	8.18	18.27%	-6.54	-14.60%
282	8.50	15.17%	-14.29	-25.48%
311	-5.97	-8.23%	-23.10	-31.85%
312	1.36	2.45%	-8.59	-15.47%
313	1.60	11.81%	1.65	12.24%
314	-1.21	-1.60%	-20.11	-26.73%
321	-244.87	-27.15%	-390.27	-43.27%
322	-139.67	-29.74%	-215.97	-45.98%
323	-43.46	-24.73%	-68.20	-38.80%
341	129.88	28.52%	22.51	4.94%
342	197.22	19.95%	-76.53	-7.74%
351	-138.51	-24.78%	-259.01	-46.34%
352	-433.37	-25.11%	-825.70	-47.84%
353	-82.36	-15.87%	-153.17	-29.52%
391	-34.81	-21.35%	-70.40	-43.18%
392	-1083.47	-28.45%	-2132.00	-55.97%
393	-714.51	-33.11%	-1380.10	-63.95%
401	-100.59	-23.03%	-288.02	-65.94%
402	-545.45	-28.78%	-1378.91	-72.75%
403	-703.04	-28.54%	-1844.60	-74.89%
411	-463.50	-20.89%	-1118.87	-50.43%
412	-103.29	-16.46%	-264.69	-42.17%
413	744.37	57.91%	-20.28	-1.58%
414	-371.68	-13.28%	-1142.28	-40.81%
415	-189.32	-16.32%	-492.06	-42.43%
416	-224.17	-13.81%	-636.22	-39.20%
421	-495.39	-24.72%	-947.15	-47.26%
422	-472.37	-23.90%	-951.18	-48.12%
431	-108.90	-23.82%	-212.38	-46.46%
432	-201.74	-24.64%	-379.91	-46.40%
433	-124.64	-17.96%	-235.98	-34.01%

Table 6.8 (contd.)

	Relative Change CRP1		Relative Change CRP2	
	Absolute [ktC]	Percent [%]	Absolute [ktC]	Percent [%]
441	8.48	53.60%	13.91	87.96%
442	174.44	19.07%	261.94	28.64%
443	144.75	35.01%	261.96	63.36%
444	118.18	14.72%	191.76	23.88%
471	-263.88	-19.62%	-110.74	-8.24%
472	-97.08	-5.10%	56.32	2.96%
473	7.03	0.79%	226.48	25.59%
474	39.77	5.98%	208.08	31.29%
475	49.15	9.96%	237.84	48.19%
531	38.08	7.16%	221.34	41.61%
532	32.60	3.08%	545.00	51.42%
533	392.34	52.93%	1044.12	140.85%
561	-61.17	-7.80%	-510.04	-64.99%
562	-123.98	-19.28%	-444.56	-69.12%
571	-385.09	-21.06%	-1158.42	-63.34%
572	-525.80	-20.55%	-1521.45	-59.47%
573	-157.37	-13.63%	-530.62	-45.95%
581	-540.15	-31.89%	-1074.06	-63.41%
582	1944.74	65.16%	-2269.74	-76.05%
583	792.64	39.57%	-1201.20	-59.96%
584	657.14	47.72%	-746.82	-54.24%
591	-468.57	-24.94%	-1446.95	-77.01%
592	-99.21	-13.94%	-473.16	-66.48%
601	185.79	34.90%	-3.88	-0.73%
602	598.10	26.93%	-240.73	-10.84%
603	942.70	29.65%	124.32	3.91%
611	8.38	39.37%	8.59	40.35%
612	7.67	40.84%	14.48	77.07%
631	-738.25	-29.64%	-1953.93	-78.45%
632	-75.91	-2.28%	-1990.79	-59.74%
633	63.70	3.23%	-891.00	-45.16%
634	249.30	8.92%	-908.85	-32.50%
641	-47.96	-11.10%	-75.44	-17.46%
642	-102.79	-12.88%	-236.19	-29.60%
643	-11.19	-3.99%	-14.14	-5.05%
Ave.	-49.43	-4.51%	-392.90	-26.53%
Max.	1944.74	65.16%	1044.12	140.85%
Min.	-1083.47	-34.87%	-2269.74	-78.45%

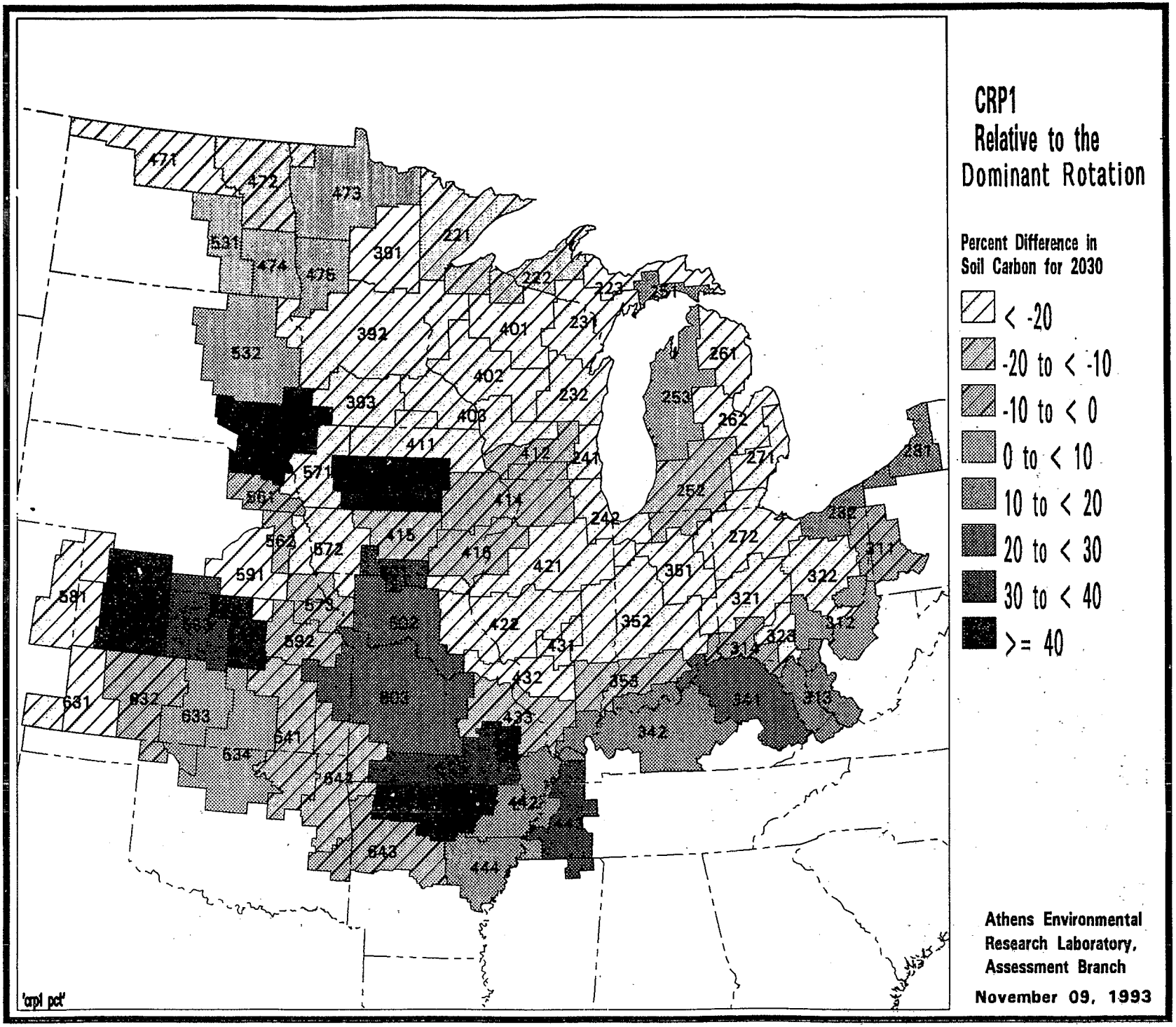


Figure 6.21 Percent difference in Soil Carbon within the study region for 2030 for CRP1 relative to the Dominant Rotation

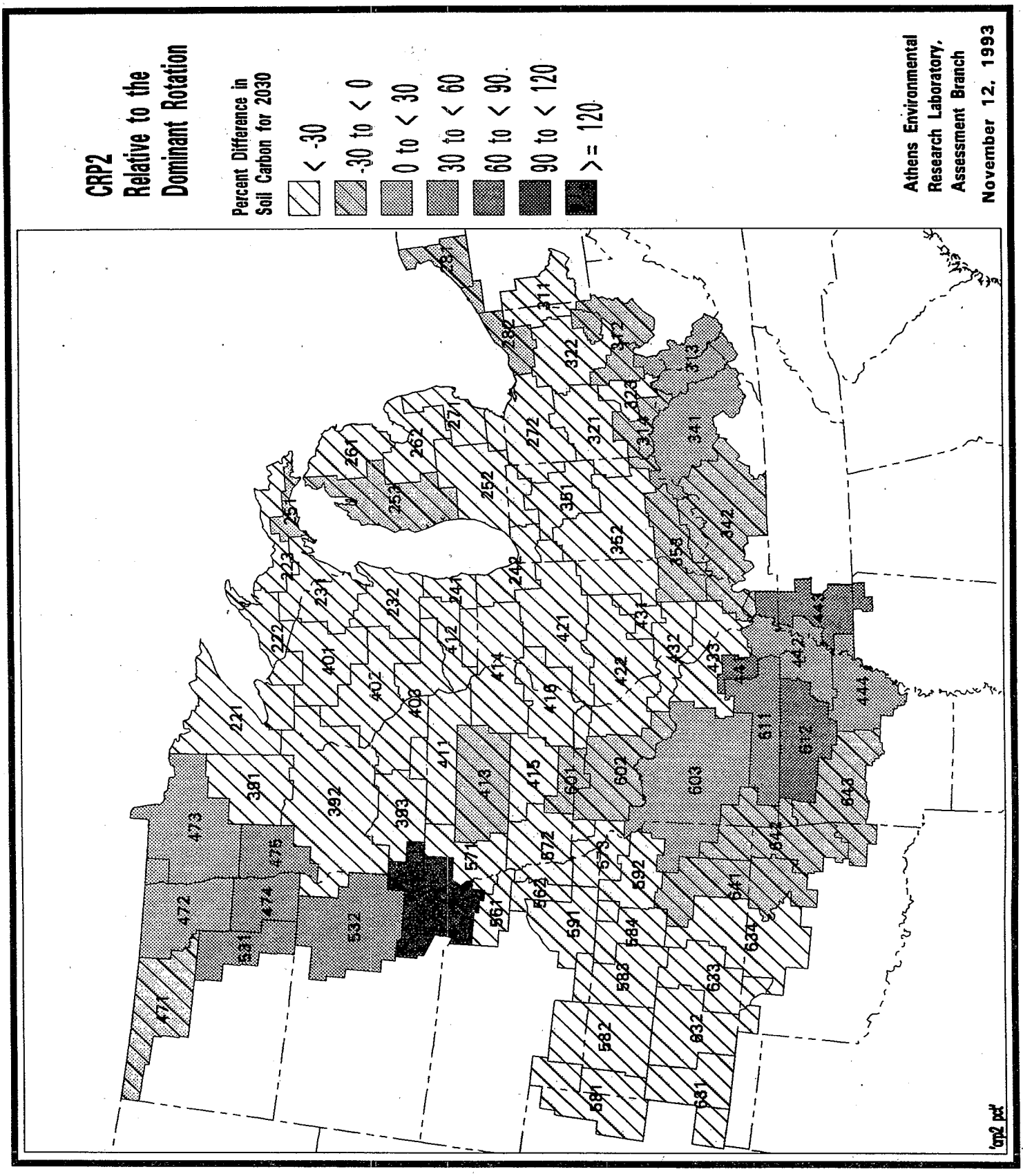


Figure 6.22 Percent difference in Soil Carbon within the study region for 2030 for CRP2 relative to the Dominant Rotation

4. The spatial variation in the relative percent difference for CRP1 and CRP2, shown in Figures 6.21 and 6.22, respectively, are the net results of the effects of climate, soil conditions, and differences between CRP lands and the dominant rotation for each CD. Most of the Study Region shows decreases in SOC, as shown by the cross-hatched areas. The greatest increases (both absolute and percent) are generally in the southern and western portions of the Study Region, while the smallest and negative changes are often in the north and east. However, the patterns are quite complex due to the combined impacts noted above.

5. For CRP1 (Figure 6.21), the differences are mostly in the range of -10% to -20% compared to the Dominant Rotation, although a number of CDs scattered throughout the southern and western areas show significant increases. (see Table 6.8). For CRP2 (Figure 6.22), the Study Region shows a more even display of SOC losses (i.e. negative percent differences) throughout the Study Region mostly with greater losses as compared to the Dominant Rotation. As expected, many of the same CDs that gained SOC under CRP1 also gained under CRP2. CRP2 also shows a much greater range of impacts among the CDs than CRP1, as shown by Figures 6.21, 6.22, and those in Appendix D.

These initial results are considered **preliminary**, for a number of reasons:

a. The CRP land of 15 million acres is separate from the Study Region cropland area of 216 million acres. Any comprehensive consideration of carbon sequestration on CRP land, and its impacts on the Study Region, must include the land character and conditions prior to and following CRP, and the relative changes in SOC on these areas. Thus, the CRP land should be included as part of the Study Region cropland in any future assessments.

b. Our methodology assumes that the CRP land is converted from the Dominant Rotation, or Dominant Cash Crop Rotation, in 1986, and under CRP1 reverts back to that rotation in 2005. This assumption was necessary because the CRP land was not included as part of the RAMS analysis for the Status Quo and alternative scenarios. To accurately assess the SOC impacts of these changes in land use, CARD needs to identify the specific rotations in each PA that are converted to CRP. Similarly, the return of CRP land to crop production must be defined in terms of the specific crops and rotations expected for the returned lands. Thus for each PA, we need to know the crop rotation distribution both with and without CRP in order to effectively evaluate the SOC impacts of these scenarios. If an increase in CRP land is proposed, then similar information is needed for the new, or additional land converted to CRP.

c. The specific nature of the agronomic activities, vegetation, and soils associated with CRP land needs better definition, along with the variation in these

characteristics throughout the Study Region. This assessment assumed the same soils characteristics on CRP land as for the other croplands, growth of native temperate grasses with the same species characterization throughout the area, and no human intervention related to agronomic activities. These assumptions need to be confirmed and/or revised to more realistically represent the SOC on CRP lands.

All of these issues need to be resolved before we can identify needed changes to the methodology for a more realistic assessment of the impacts of CRP on carbon sequestration within the Study Region.

6.4 STUDY REGION IMPACTS OF ALTERNATIVE YIELD INCREASES

The critical importance of the assumption of the annual crop yield increase has been noted earlier in Section 3, Section 5, and above in the discussion of the study results produced with an annual increase of 1.5%. Because of the impact of this assumption, and given the automated calibration and Study Region modeling capabilities developed by the EPA Athens Laboratory, **the entire suite of CENTURY simulations for all 80 CDs, all C/R/T combinations, and all policy scenarios (excluding CRP) were re-done for the 1990-2030 projection period for two additional levels of crop yield increases: 1.0% and 0.5 % per year.** Although all detailed results in this report are derived from the model runs with the 1.5% annual crop yield increase assumption, the same information has been generated for these two additional yield levels.

Table 6.9 shows the summary results of those simulations, along with the results for the 1.5%/year increase level, in terms of both the Total SOC change (in GtC) over the 40-year projection period, and the percent change from the 1990 value and relative to the Status Quo scenario. Figure 6.23 graphically shows the timeline of Total SOC changes for the projection period for selected combinations of scenarios and annual yield increase levels that bracket the range of SOC increases.

The Status Quo scenario results for the three yield levels were shown earlier in Figure 1.3 for the projection period, along with the entire historical simulation from 1907 through 2030. The curves in Figure 1.3 show **steady, almost linear increases in SOC from 1970 through 2030.** For the historical period of 1970 to 1990 the increase occurs at an annual rate of about 0.6% per year, which is also about the same rate as for the 1990-2030 increase under the 0.5% crop yield increase. For the 1.5% and 1.0% yield increase levels during the 1990-2030 projection period, the Total SOC increases at 1.2% and 0.9% per year, respectively. If this general pattern is accurate, agricultural SOC within the Study Region is making a comeback from a low of about 50% of original (i.e., native vegetation) levels in 1950-70, to about 60% of these levels in 1990. Continuing the increase would lead to 2030 Total SOC levels that approach 75% to 90% of the original SOC prior to the onset of agricultural production (circa 1900).

Table 6.9 Impacts of Alternative Annual Crop Yield Increases on Study Region Total Soil Organic Carbon for Status Quo and Policy Scenarios

	Total SOC, GtC			Percent Increase	
	1990	2030	1990-2030 Gain	from 1990 Value	from Status Quo
Status Quo					
1.5 % Yield Increase	3.66	5.45	1.80	49.1	--
1.0 % Yield Increase	3.66	5.01	1.36	37.1	--
0.5% Yield Increase	3.66	4.60	0.95	26.0	--
Low Conservation					
1.5 % Yield Increase	3.66	5.47	1.81	49.4	0.7
1.0 % Yield Increase	3.66	5.02	1.37	37.4	0.9
0.5% Yield Increase	3.66	4.62	0.96	26.2	1.1
Medium Conservation					
1.5 % Yield Increase	3.66	5.48	1.82	49.9	1.7
1.0 % Yield Increase	3.66	5.04	1.39	37.9	2.2
0.5% Yield Increase	3.66	4.63	0.97	26.6	2.6
High Conservation					
1.5 % Yield Increase	3.66	5.57	1.90	52.0	6.1
1.0 % Yield Increase	3.66	5.13	1.47	40.1	8.2
0.5% Yield Increase	3.66	4.72	1.06	28.8	11.2
Cover Crops					
1.5 % Yield Increase	3.66	5.60	1.94	53.1	8.3
1.0 % Yield Increase	3.66	5.14	1.49	40.7	9.9
0.5% Yield Increase	3.66	4.74	1.08	29.7	14.2

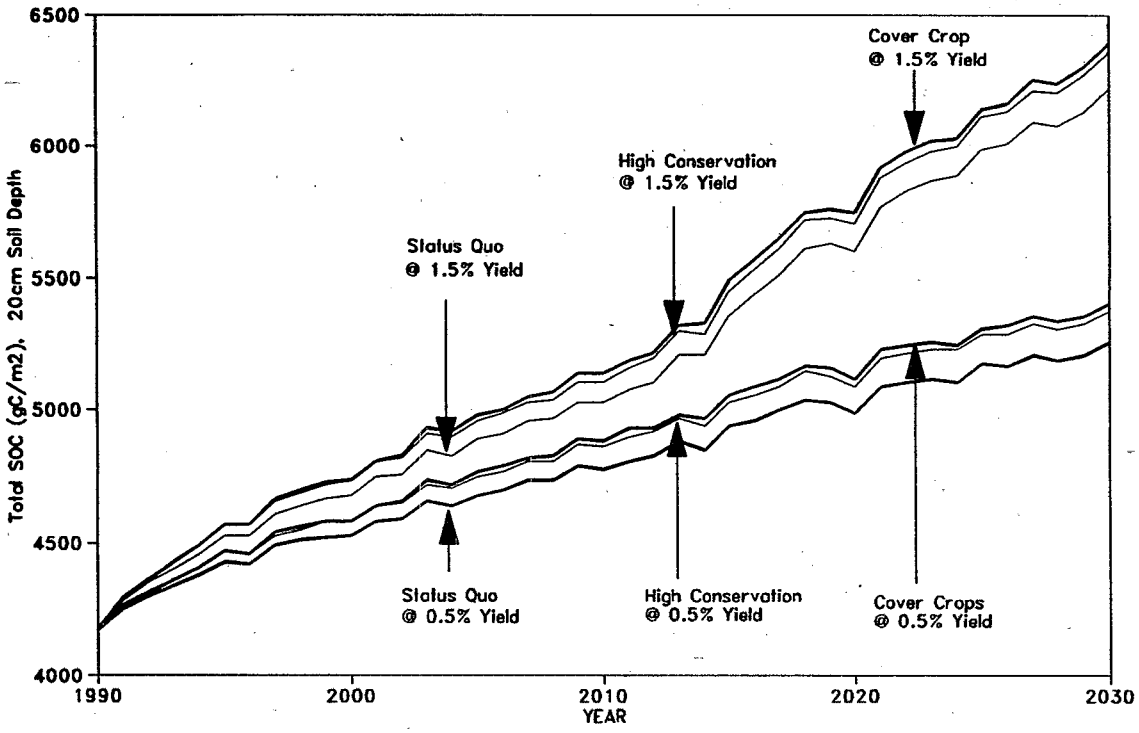


Figure 6.23 Simulated Total SOC Impacts for Selected Scenarios and Alternative Annual Crop Yield Increases

Table 6.9 shows that changing the annual level of crop yield increase from 0.5 % to 1.5 % leads to almost a doubling of the Total SOC gain during the 40-year projection period, i.e. changing the annual yield increase by a factor of 3 leads to about a 80% to 90% gain in Total SOC. This is fairly consistent for all policy scenarios. The absolute gain ranges from about 1 GtC to 2 GtC across all scenario and yield increase combinations; this corresponds to a percentage gain of about 30% to 50% compared to the 1990 Total SOC levels. For the 0.5% yield increase level, the Total SOC gains range from 26% for the Status Quo to 30% for Cover Crops, with the alternative tillage scenarios in between. Similarly, for the 1.5% level, the range is 49% to 53%. In Figure 6.23, the timelines for Status Quo, High Conservation, and Cover Crops are plotted for yield increases of 1.5% and 0.5% per year; these combinations cover the range of Total SOC gains listed in Table 6.9.

Comparing the policy scenarios to the Status Quo condition, each level of conservation tillage leads to increased gains in Total SOC, and these gains also increase with each higher level of increasing crop yields. The final column in Table 6.9 shows the percent change from the Status Quo scenario. Although the absolute gain increases with the yield increase, the percent change is higher for the lower level of crop yield increase because the gain in SOC is divided by a smaller absolute SOC level. Thus, for Cover Crops, at the 0.5% yield level the SOC is 14.2 % higher than the Status Quo, and only 8.3 % higher at the 1.5% yield level.

SECTION 7.0

PROJECT FINDINGS AND RECOMMENDED FUTURE WORK

This section summarizes the study findings and provides recommendations for future research and investigations needed to improve and evaluate the methodology and modeling procedures. To set the stage for this discussion, we review some of the **key assumptions** in both the methodology and the modeling in Section 7.1 below. The study findings are summarized in Section 7.2, and Section 7.3 discusses future recommended efforts to extend this methodology for assessment of carbon sequestration in other parts of the U.S., to perform further field site model testing, and to pursue selected research issues identified during the course of the work.

7.1 REVIEW OF METHODOLOGY AND MODELING ASSUMPTIONS

The study results presented in Section 6.0 are based on a variety of both methodology and modeling assumptions. Sections 3.0 and 5.0 described the methodology and scenario assumptions, respectively, which were employed to represent the range of climatic, soils, and agronomic conditions throughout the Study Region, and projections of these conditions under alternative future scenarios. The modeling assumptions are basic to the CENTURY model framework, structure, and algorithms, and were described briefly in Sections 2.4 and 3.2. Below we discuss each of these two categories of assumptions so that the reader can have a more informed basis for evaluating the current study results.

7.1.1 Key Methodology Assumptions and Impacts

Annual 1.5% Increase in Crop Yield: The assumed 1.5% annual increase in crop yields during the projection period may be the most critical assumption in terms of the projected level of increase in SOC throughout the projection period. As noted in Sections 3.5 and 5.2, this assumed increase was applied uniformly for all crops and rotations; the resulting yield levels were then used as targets for calibration of the CENTURY crop production (PRDX) parameter. Section 6.4 presented summary results for the entire Study Region of alternative annual yield increase levels of 1.0% per year and 0.5% per year. Even at the lowest level of 0.5% per year, SOC increased approximately 26% to 30% from 1990 to 2030, while the increase for the 1.5% level was 49% to 53%.

Because of this sensitivity, this assumption needs to be re-evaluated and/or confirmed in order to establish the reliability of the study projections. Even if the final judgement is that the 1.5% per year increase is the best we can predict at this time, the increase should be re-assessed individually for each crop and differentially for different portions

of the Study Region. In addition, we need to determine if yield increases will be accompanied by similar increases in crop biomass and residues, so that appropriate changes in the model crop parameters can be implemented.

Equal Yields for All Tillage Practices: As noted in Section 6.1, the yield calibration involved adjusting crop parameters for each rotation so that individual crop yields would match both the historical data and the future projected yields, within a small tolerance of a few percent. The CENTURY model then simulates crop yields that are essentially the same for **all tillage practices**, within a reasonable tolerance. The sentiment among the Project Team members was that farmers would likely adjust practices, such as fertilizer applications, so that yields would not diminish under RT and NT. The impact of this assumption is to eliminate yield variations due to tillage as a consideration in projecting alternative future conditions. The large body of conflicting evidence on this subject would appear to warrant this type of approach for this study.

Automatic Fertilizer and Irrigation Applications: In Section 5.1, we described CENTURY model options used in this study to automatically calculate the fertilizer N and irrigation needs of each crop, based on user-defined control parameters. The automatic fertilizer option was used for all crops, except legume hay and CRP lands, while the irrigation option was only used in CDs and rotations identified by CARD as being irrigated. The impact of this is to eliminate nutrient stress conditions for all crops and CDs, and moisture stress conditions for the irrigated CDs and crop rotations. The fertilizer option effectively eliminated over-fertilization as all nutrient sources, including mineralization, atmospheric deposition, manure applications on forage crops (see below), etc. are available for satisfying crop needs.

Animal Waste Applied to Forage Crops: Section 5.1 described the assumptions and procedures used for returning animal waste nutrients (C and N) to forage croplands that produce animal feeds. These procedures were applied only to corn-silage, legume hay, and non-legume hay croplands which collectively comprise 26% of the cropland (see Table 5.1). They were needed due to the lack of an appropriate database of animal waste production and application for the Study Region. Considering the spatial extent of our CDs and the fact that animal waste, corn-silage, and hay are not usually transported great distances, the return of C and N associated with the harvested crop to the same CD in which it was grown is a reasonable assumption for this study. However, future efforts should consider a more detailed assessment of this component of the C and N balances within the CDs, including distributions of animal populations, actual animal waste production and application, and waste resulting from grain production for animal feeds, which was not considered here.

Erosion Impacts: Although CENTURY allows the model user to input monthly erosion rates, erosion was not included in our simulations. The reasons for this were as follows:

a. Carbon sequestration was estimated as the change in SOC over the 40-year projection period. Including erosion losses would under-estimate sequestration since SOC losses by erosion would lead to smaller increases in SOC; these field level losses are more likely to be landscape-level movement as the C associated with erosion leaves the field and is deposited in other field areas, wetlands, and waterbodies.

b. Simple calculations using the range of typical erosion rates, SOC levels for surface soils, and enrichment ratios show that SOC losses by erosion could reach 0.5% to 1.0% per year, producing up to 20% to 40% loss of SOC over a 40-year projection period. Modeling this extent of soil and SOC loss would need to consider elevation and horizon shifts in the soil surface, a capability not included in CENTURY nor most other SOM models.

c. The RAMS output provides average annual erosion for each crop rotation, but not for each crop-year within the rotation. Thus additional effort would have been required to develop reasonable erosion rates for each crop under different rotations, tillage practices, and climatic conditions in each CD.

Based on the above, we feel it is appropriate to ignore erosion in this study; however, the impacts of this assumption on the study results need to be considered. The primary impacts appear to be related to the effects of alternative tillage practices and calculation of initial SOC conditions for projection purposes. **Ignoring erosion may have reduced the real impacts of RT and NT on SOC changes.** Since erosion rates (and associated SOC losses) would be significantly greater for CT than either RT or NT, the increases in SOC through 2030 for all tillage practices would have been much less if erosion had been included, but the relative impacts for CT would have been greater than for RT or NT. In other words, ignoring erosion eliminates one of the key differences among the three tillage alternatives.

The impact of ignoring erosion on the calculation of initial SOC conditions is even more complex, and may need to be reconsidered. The historical pattern of changes in SOC for different crop rotations for the 1907-1988 time period was discussed in Section 6.2; the overall pattern was shown to be generally consistent with the literature, and the consistency checks for crop yields and SOC observations indicated reasonable agreement. The pattern resulted from the simulations performed under the historical management practices summarized in Table 5.11 and discussed in Section 5.2. If erosion had been included as part of the simulation, the initial SOC conditions (i.e., in 1989) for the projection period would have been lower and may have a subsequent impact on the SOC

projections. In effect, the assumed historical practices appear to have masked the impact of ignoring erosion. In future efforts to refine and re-evaluate these results, it may be appropriate to consider including erosion in conjunction with a review of the historical practice assumptions and their impacts on the starting SOC conditions.

Climatic Data Assumptions: As described in Section 5.1, the climatic data used in the model simulations was extracted from a national data base for the period of 1948 to 1988, and the 41-year data base was repeated for time periods prior to and following the historical time span. Although CENTURY includes an option to stochastically generate monthly precipitation for any time period, testing with this option showed much greater year-to-year variations in the simulation results than using the historic data. Also, the historic air temperature data would still be needed since the stochastic option is not available for air temperature.

The net effect of this assumption is that the projections and historical SOC conditions are estimated under unchanging climatic patterns. That is, the 40-year projection is made assuming that the climate for the next 40 years will not be different from the last 40 years, with an analogous assumption for the historic climate pattern.

Spatial Scale of the Assessment: Section 4.0 described the development of the Climate Divisions (CD) as the basic spatial unit of the analysis. The CD boundaries were developed from analysis of the precipitation and air temperature patterns, and were adjusted to conform to county boundaries to be consistent with the soils data and RAMS agronomic information. The CDs, which are aggregates of counties, are a reasonable spatial compromise between a county-level analysis and a PA-level analysis; simulating crop rotations in each of the 1300 counties in the Study Region would not have been feasible, and the PAs used in the RAMS assessment were too large for an accurate representation of meteorologic and soils variability. Greater spatial detail from the RAMS assessment would be needed, perhaps at the county level, before a finer spatial analysis would be warranted.

Representation of Tillage Practices: The modeling of alternative tillage practices with CENTURY was discussed in Section 5.1.2. Although CENTURY provides relatively detailed mechanisms for representing alternative practices, the impacts of practices on SOC are a direct result of how the individual mechanisms are parameterized, i.e., the specific parameter values used in the model will determine the simulated impacts on SOC. Some of the specific areas where parameters values need to be re-evaluated are as follows:

a. **Incorporation of Surface Residues** - Table 5.6 listed the type and number of tillage operations used for each tillage practice, and Table 5.5 provided the parameters for each operation controlling their impact on the incorporation and disposition of the residue. It is clear from these tables that NT has only two growing season operations, neither of which

incorporate crop residues into the soil; whereas, both CT and RT have numerous operations that move the residue into the soil column. The harvest operation transforms 50% of the total residue into the 'standing dead' pool and 50% to the 'surface residue' pool (see Table 5.8 and Figure 5.2). Under NT, the parameters that control the disposition of these pools and the rate of C transfer to the soil need to be re-evaluated. It may be appropriate to consider periodic inversion (i.e., moldboard plowing) every 5 to 10 years for NT rotations, or a constant annual rate of surface residue incorporation to account for processes not specifically included in the model (e.g., earthworm activity).

b. **Tillage Equipment Parameters** - Table 5.5 listed the parameters that control the impacts of individual tillage equipment operations in terms of the disposition of crop residues and effects on decomposition. The chisel plow and cultivator operation parameters need to be re-evaluated as these equipment are used for RT and NT practices, and prior testing of CENTURY has not focussed extensively on these types of operations.

c. **Parameters for Different Crops** - An underlying concern related to both Items b and c above is that much of the past field testing experience with CENTURY has focussed primarily on grasslands and wheat-dominated cropping systems. Many of the model parameters are derived from this past experience and therefore may not accurately represent the corn and soybean dominated rotations that are prevalent throughout the Study Region. Consequently, all model parameters that may vary as a function of crop type and associated tillage operations (e.g., standing dead fall rate, surface residue decomposition rate, residue incorporation, etc.) need to be re-assessed and confirmed. Experience in the central and eastern portions of the Study Region (e.g., Paustian et al., 1992; Blevins et al., 1983) would be especially relevant in this effort.

As part of the EPA BIOME Study, Li and Cialella (1992) applied the DNDC model (discussed in Section 2.4) to selected CDs in seven different states within the Study Region. Using fertilizer applications and initial conditions calculated by CENTURY, they ran simulations for the 40-year projection period for each dominant rotation under the four different tillage practices (CTFP, CTSP, RT, NT). Their results showed consistent and significant trends as a function of tillage practice, i.e., conventional tillage enhanced SOC losses, while RT and NT conserved SOC. For the corn-based rotations in the seven CDs, SOC increased 24% under conventional tillage and 58% under No-Till. For non-legume hay and wheat-fallow rotations, in MO and MN, respectively, SOC decreased 28% under Conventional Tillage and only 12% under No-Till.

Although these results are generally consistent with conventional expectations and the CENTURY model results (with some exceptions and unknowns, discussed below), they further reinforce the need to examine the process representation and parameterization of models before accepting their results for decision-making purposes. The DNDC model provides detailed algorithms for simulating soil N processes, but uses relatively simple assumptions for the impacts of tillage. Thus, tillage impacts are modeled by the following changes in the model parameters (C. Li, 1993, personal communication):

a. Depth of tillage is 0 cm, 15 cm, and 25 cm, respectively for NT, RT, and both CTFP and CTSP, regardless of the type of tillage equipment used.

b. Decomposition rates are increased by a factor of **3.0** for conventional tillage, and by a factor of **1.5** for RT, as compared to NT, which is represented by the default rate in the model.

c. Denitrifier populations are decreased by **30%** for both conventional and RT,as compared to NT.

In contrast, the CENTURY model parameters used in this study were based on only a **60%** increase in the decomposition rate for moldboard, a **40%** increase for chisel plows, and a **30%** increase for a row cultivator. Furthermore, there is no indication of the crop yields simulated by DNDC, or how yields varied across the four tillage treatments and for future projections through 2030. As noted earlier, the crop yield increase has a critical impact on SOC changes for any C/R/T combination. Consequently, although the two models represent tillage impacts in different ways, the differences in model results could be due entirely to the differences assumed for the decomposition effect, or differences in simulated crop yields. These differences in model parameterization need to be resolved as part of further work on assessing the complex impacts of alternative tillage practices.

7.1.2 Key Model Assumptions and Impacts

Nitrogen Cycle Representation: The N cycle component of CENTURY is a relatively simplified representation of soil N processes based on parameters that calculate process fluxes as constant rates or adjusted for selected soil and/or environmental conditions. Also, the parameter values in the model are derived primarily from experience and testing on native grassland and wheat cropping systems; how well the parameters represent corn and soybean systems is unclear. The CENTURY model tests performed by Metherell (Appendix A) and Chinnaswamy et al. (Appendix B) both noted problems with the soil N simulation related to soil mineral N storages, crop N uptake, impacts of fertilization and tillage practices, volatile N losses, and non-symbiotic N fixation. Since N_2O is an important greenhouse gas and since CENTURY does not separately represent N_2O emissions from total volatile N emissions, future model development and refinement

efforts should consider improvements to the soil N model. CSU/NREL staff have indicated that research activities related to the N model are currently in progress (W. Parton, 1992, personal communication). The type of soil N process modeling algorithms in the DNDC model may be appropriate for incorporation into CENTURY.

Monthly Simulation Time Step: The monthly time step in CENTURY is one of the reasons the model can be run efficiently for long periods of time such as the 120-year span of our model runs. However, the monthly time step also presented some difficulties in this study in attempting to represent temporal differences in planting, tillage, and harvest times among the CDs in the Study Region (see Section 5.1). Also, representation of selected agronomic practices, such as double cropping, cover crops, etc. that have two or more operations within a calendar month are difficult to include with a monthly time step. Thus, including a capability for a shorter time step, such as daily or weekly, should be considered in future model refinements; Paustian (1993, personal communication) has indicated that a research version of CENTURY with a daily time step is currently being tested. This finer temporal resolution will help to better differentiate and represent agricultural production systems within the Study Region and other parts of the U.S.

20 cm Soil Layer Depth: Currently, CENTURY uses a 20 cm soil layer depth for representation of all carbon and nutrient processes, whereas many soil nutrient models use a larger soil depth (e.g., 30 cm in DNDC, up to 45 cm in Frissel and van Veen), or one that is user-defined (e.g., NCSWAP, EPIC). Crop rooting depths and some tillage operations extend below the 20 cm depth for many parts of the Study Region. Metherell (Appendix A) noted potential problems related to mineralization of N below the 20 cm depth available for crop uptake that could impact the simulated N balance. Future refinements to CENTURY should consider use of a deeper, or variable, soil depth, possibly with **multiple layers** to better represent root zone soil processes and tillage practices.

SOC Changes Do Not Impact Crop Yields: CENTURY does not currently include a linkage between changes in SOC and crop yields or productivity. In this study, we imposed an increase in yields during the projection period due to improvements in crop management and genetics. Future improvements in CENTURY should consider a direct impact of changes in SOC on crop yields.

7.2 CAPSULE SUMMARY OF STUDY FINDINGS

Below are **capsule** conclusions and recommendations derived from the study results:

1. Reasonable extrapolation of current agricultural practices and trends will lead to an increase (sequestration) of **about 1 to 2 Gt C** within the Study Region by the year 2030. This represents about a **25% to 50% increase** over current 1990

levels. Nationwide the increase could be 50% greater since our Study Region includes only 60-70% of total U.S. cropland.

2. The key assumption underlying these predictions is the projection of **annual crop yield increase from 1990 to 2030;** the lower range reflects an increase of **0.5% per year,** while the upper limit of 50% increase reflects a **1.5% per year crop yield increase.** The validity of this assumption needs to be re-assessed or confirmed, and if valid, policies and research need to be promoted to support the chances of agriculture attaining this level of yield increase.

3. **Conservation tillage practices** can significantly increase soil carbon, but the impacts are highly variable across the Study Region. The degree of impact is due to complex interactions of combinations of crops and rotations, soils, and climate. For many combinations, SOC increased 10% to 15% for Reduced Till and up to 50% for No Till, while much lower changes occurred in other C/R/Ts and CDs.

4. The overall impact of increased Reduced Till (RT) and No Till (NT) practices in terms of **Total SOC change for the Study Region,** ranged from 2% to 3% higher than Status Quo under the Medium Conservation Policy, and 6% to 11% higher under the High Conservation Policy. These conclusions should be considered preliminary, given the capabilities of current models and our limited knowledge of the quantitative impacts of tillage practices. Moreover, current (i.e. 1992) nation-wide levels of No Till and Conservation Tillage (i.e. combined NT and RT) **exceed** the levels included under the Medium Conservation scenario; within the Cornbelt both NT and RT currently approach the levels included in the High Conservation scenario. Thus, the conservation scenarios assume relatively modest changes in practices as compared to more current CTIC data. Further evaluation of the study procedures, conservation tillage usage, model parameter sensitivity, and more research is needed in this area of tillage impacts before these **preliminary** conclusions can be confirmed.

5. **Cover Crops** can lead to significant increases in soil carbon in crop, soil and climate regimes where they are feasible and appropriate. Although only 12% of the Study Region cropland included cover crops (under the Cover Crop scenario), this increased soil carbon by **140 Mt** through 2030. Since southern and eastern portions of our Study Region were most appropriate for cover crops, this may be an attractive alternative for promoting carbon gains in the South and Southeastern U.S.

6. The results of the CRP simulations are mixed. In many cases, 20 years of CRP leads to SOC values higher than the dominant rotation by the year 2030, and usually higher than under continuous CRP. In other CDs, the dominant rotation maintains the highest SOC throughout the projection period. The key factor is likely the relative carbon inputs of the dominant rotation as compared to the CRP

conditions. When the dominant rotation is a corn-based rotation, its 2030 SOC is usually the highest. However, this is not always true, especially if only one year of corn is in the rotation. The percent difference for the CRP simulations can range from a few percentage points to up to 20% or higher.

7.3 RECOMMENDED FUTURE STUDY EFFORTS

7.3.1 Extension of Methodology to Other Portions of the U.S.

Part of the original objective of the U.S. EPA BIOME program was to develop an assessment methodology for agricultural production systems that could be used to project changes in soil carbon for **all** regions of the U.S. The methodology developed in this study satisfies that objective in that it can be applied to other sections of the U.S. given the availability of the required input data. In this study, we focussed the assessment on the RAMS study region because the RAMS output provided the information on cropping systems, rotations, tillage practices, etc. needed to define the agricultural production systems in sufficient detail for CENTURY simulations. Since RAMS has not been applied to the remaining portions of the U.S., a significant effort would be required to apply RAMS to the remaining regions so that the study methodology developed herein could be used (D. Holtkamp, 1993, personal communication). The climate and soils data bases used in this study provide national coverage, so the cropping system information provided by RAMS (noted above), and changes in this information for alternative policy scenarios, is the only missing element needed to attempt a **national-level** analysis.

It may be possible to assess SOC changes under the **Status Quo Scenario** for other regions by developing the needed cropping system information from other sources, such as the CTIC, ERS, ASCS, etc. This would allow application of the study methodology to project, on a national level, the SOC impacts of current trends in crop yields, tillage practices, and possibly cover crops and CRP; additional CENTURY model testing for other crops and rotations would be needed. Evaluation of alternative future conditions, such as increased Reduced Till and No Till could also be evaluated in terms of resulting SOC changes and associated carbon sequestration. However, the direct linkage to policy and alternative policy scenarios would require the complete RAMS analysis for the entire U.S. for a national scope assessment similar to the effort in this study.

A possible alternative to application of the full study methodology, to all land areas of a new study region, would be to apply the methodology to pre-selected test CDs as was done in the early testing stages of this effort. With careful selection of these test CDs, based on the degree to which soils, climate, and cropping practices are representative of the entire study region, the results of the methodology applied to the test CDs can be extrapolated to the larger study region. For example, the seven PAs that included the test CDs of our study represented about 40% of the cropland of the entire Study Region. The change in SOC under Status Quo conditions for these seven PAs was almost exactly 40% of the change for the entire Study Region. This was the result of careful selection of the test CDs to represent the geographic

extent of the Study Region, while including the range of variation in climate, soils, and cropping practices (as noted in Section 5.0). For other potential study regions within the United States, the required soils and climate databases are available and need only be supplemented with cropping information in order to have the data needed for selection of potential test CDs.

7.3.2 Future Model Field Site Testing

As part of this study, field site testing of CENTURY was performed for a wheat-fallow rotation in Sydney, NE (Appendix A) and a corn rotation in Lexington, KY (Appendix B). In addition, consistency checks for the model results were performed with observed crop yields and regional estimates of agricultural SOC by Kern and Johnson (1991). Further model testing and evaluation is needed in two primary areas:

1. Comparison of the historical pattern of SOC changes predicted by the methodology used for estimating starting 1989 SOC levels with long-term field data is needed.

2. Testing and evaluation of model behavior and parameter values for selected crops (e.g., soybeans), regions, and tillage practices is highly recommended.

The SOC data base currently being consolidated by Paul and Elliott (1993, in press), as part of the EPA BIOME study, will be an extremely valuable resource for both testing efforts. Although CENTURY has undergone more field site testing than any other currently operational SOC model, testing on legumes and in selected portions of the Study Region (i.e., eastern and southeastern regions) has been limited. In addition, as noted above, many of the parameter values were originally derived from experience with grassland and wheat-based crop rotations. Further model testing for a wider range of crop, climate, soils, and tillage practices is warranted for increased confidence in the model predictions for our Study Region and other agricultural sectors of the U.S.

7.3.3 Future Research Issues for Investigation

In addition to the model and methodology testing recommended above, a number of research issues have been identified during this study that may require longer term investigations. These issues, some of which have also been noted under the modeling assumptions above, include:

a. Review and establishment of expected increases in crop yields, plus crop biomass and residues, for major crops and regions of the country in order to determine how best to include this aspect of predicting future SOC conditions, and associated carbon sequestration, under alternative policy scenarios. The importance of these issues is evident in the study results.

b. Projections of the impacts of future climate scenarios on the assessment of carbon sequestration under alternative policy scenarios. The current study results are based on future climatic conditions that are the same as historic conditions. An assessment is needed of how the study results would change if climate changes, and asssociated feedbacks to agricultural production systems should also be considered. Additional model capabilities, such as yield changes due to increased CO_2, may need to be implemented.

c. Development of appropriate data bases and modeling procedures for representation of the C and N balances in agricultural systems impacted by animal waste applications. Accurate databases on animal waste production, including sources, quantities, composition, treatment, storage, and applications to croplands are non-existent.

d. Development and/or aggregation of databases for improved historical crop yield, cropping and crop rotations, agronomic practices, and economic (production) data, especially as related to soil and climate conditions, in order to evaluate and improve the historical simulations of SOC changes.

e. Continuing investigation into the impacts of cropping and tillage practices on SOC, and development of appropriate modeling procedures to accurately represent these effects. In particular, the impacts of No Till on the entire range of soil physical, chemical and biological processes demands further study; we currently have very limited detailed (quantitative) knowledge of these impacts which have critical effects on SOC.

f. Further study of the potential impacts of CRP with particular focus on the land characteristics (e.g. soils, topography, cropping and crop rotations) of the areas taken out of production. To more accurately assess CRP changes, including increases or decreases in CRP land, more detailed cropping information is needed (perhaps from the RAMS assessment) to define the production systems from which, and to which, CRP land is transferred.

g. More detailed representation of the N cycle in agricultural soils in close integration with the soil carbon cycle, including calculation of N_2O emissions, as impacted by various agricultural production systems.

h. Investigation into the ultimate fate and disposition of erosional SOC losses in terms of both field and landscape level impacts with regard to greenhouse gas emissions from agricultural systems. In conjunction with item c (above), estimates of historical erosion losses and associated agricultural practices are needed to better represent the historical pattern of SOC changes and current conditions, as a basis for projecting future changes, directions, and alternative policy impacts.

To establish the current state of knowledge on many of these research issues, and to help direct future assessments and needed research, we recommend convening a workshop of both regional and national experts on agronomy, plant physiology, soil carbon processes, tillage practices, agricultural policy, and SOC/SOM modeling. The focus of the workshop would be on the issues identified above to: (1) identify improvements to the assessment methodology; (2) assist in determining parameter adjustments to best represent regional and crop differences in tillage practices and impacts; (3) identify both available and needed databases on tillage practices, crop rotations, animal waste production and disposition, soils characteristics, climate, etc.; (4) establish regional historical agricultural practices and erosional impacts on SOC; and (5) identify associated ongoing research efforts and priorities for future research activities.

SECTION 8.0

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SECTION 9.0

APPENDICES

A. Simulation of Wheat-Fallow Cropping Systems
B. Application of the CENTURY Model to the Lexington, KY Site
C. Tabulated Simulation Results by CD
D. Map Displays of Simulation Results and Study Region Characteristics
E. Land Use and Soil Physical Properties for All Climate Divisions

APPENDIX A

SIMULATION OF WHEAT-FALLOW CROPPING SYSTEMS

SIMULATION OF WHEAT-FALLOW CROPPING SYSTEMS[1]

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INTRODUCTION

Management interacts with natural driving variables in an agroecosystem to have a major impact on the processes that control the ecosystem properties. Soil organic matter is an important component of the ecosystem, influencing both physical and chemical soil properties. Soil organic matter is also a major pool in the global C cycle. The management of agricultural systems has had a major impact on soil organic matter with the cultivation of soils in the Great Plains of North America resulting in large losses of C and N (Burke *et al.*, 1989). This raises questions as to whether the loss of organic matter will continue and whether alternative agricultural management practices can reduce the rate of loss or even reverse the trend. The CENTURY soil organic matter model (Parton *et al.*, 1987; Parton *et al.*, 1988) integrates the effects of climate and soil driving variables with agricultural management to simulate C, N, and water dynamics in the soil-plant system, with an emphasis on long-term soil organic matter dynamics. A new agroecosystem version of the CENTURY model has been designed for the simulation of complex agricultural management systems including crop rotations, a variety of tillage practices, fertilizer, and irrigation.

Moisture is the main limitation to agricultural production in the semi-arid western half of the Great Plains of the United States and Canada. Consequently the majority of dryland farmers use summer fallow, in a wheat - fallow "rotation", where in alternate years all plant growth is controlled by cultivation or herbicides, to conserve moisture for the succeeding crop. Production in one season is forfeited in anticipation that there will be at least partial compensation by increased crop production the next season. With this system of farming, in contrast to continuous cropping, the variation in crop yields due to climatic factors is minimized, risk is reduced and the farm business has greater economic stability (Haas *et al.*, 1974).

The key to successful summer fallow management is the control of weed growth, which would otherwise result in transpiration of water from the soil profile. Traditionally farmers have used

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cultivation for weed control. Cultivation methods have evolved from the "dust mulch" with moldboard plowing and frequent harrowing after each significant rain, through "conventional bare fallow," which utilizes shallow disking and bare rodweeders, to "stubble-mulch," which uses implements, which undercut the soil surface, killing the weeds but leaving crop residues on the soil surface (Greb, 1979). The surface residues reduce the evaporative loss of water thus increasing the efficiency of water storage over the fallow period and also provide protection from wind and water erosion (Greb *et al.*, 1979). The fallow water storage efficiency is greatest with no-till management where herbicides are used to control the weed growth (Smika and Wicks, 1968). With no-till management the accumulation of surface residues is maximized and there is no moisture loss associated with stirring of the soil during tillage.

Summer fallow, particularly when associated with intensive cultivation, increases the mineralization of soil organic matter (Haas *et al.*, 1957) resulting in the degradation of soil structure, reduced water infiltration, and increased susceptibility to erosion. Furthermore, because a crop is only grown every second year, the inputs of C to the soil are also considerably lower than with grassland or continuous cropping. Thus the agricultural management of the semi-arid Great Plains has resulted in a dramatic loss of soil organic matter (Haas *et al.*, 1957; Burke *et al.*, 1989).

The prediction of the effects of different agricultural management strategies on soil organic matter levels is one of the main uses of the CENTURY model (Parton *et al.*, 1987). However, the model had not been formally validated for the effects of tillage methods on crop production and soil organic matter dynamics. The long-term tillage experiments at Sidney, Nebraska, provide an ideal data set for verification, calibration and validation of the revised CENTURY model described in Chapter 2 (Metherell 1992, Ph.D. Dissertation).

METHOD

The Sidney tillage experiments

In 1969 and 1970 experiments were initiated at two locations on the High Plains Agricultural Laboratory research area near Sidney, Nebraska to compare the effects of fallow tillage methods on the wheat-fallow cropping system (Fenster and Peterson, 1979). The first location was on an Alliance silt loam, a fine silty, mixed, mesic Aridic Argiustoll, derived from mixed loess and loamy calcareous residuum over weathered sandstone. The land had been farmed from 1920 to 1957, when it was reseeded to crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.). The experimental site was broken out of sod with a moldboard plow in 1967. This location has frequently been referred to as the "reseeded sod" or "previously cultivated" site. The second location was on a Duroc loam, a fine silty, mixed, mesic Pachic Haplustoll derived from mixed loess and alluvium. The land had remained in native grasses until the sod was broken with a moldboard plow in 1970. Hence, this location has been called the "native sod site". The experiments at this location have a unique feature in that strips of the native sod were left intact and incorporated into the experimental design. The predominant grasses on the site are western

wheatgrass (*Pascopyrum smithii* Rybd. A. Love), needleandthread (*Stipa comata* Trin. & Rupr.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) and sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray) (Lyon *et al*, 1992).

Each location was divided into two major blocks, which were fallowed or grew wheat in alternate years (Figure A1). On the Alliance soil, site A has had wheat harvested in even years and been fallowed in odd years, while site B has had wheat harvested in odd years and been fallowed in even years. Sites A and B were first sown to wheat in 1969 and 1970, respectively. On the Duroc soil, site C, also referred to as the west side, has had wheat harvested in odd years and been fallowed in even years, while site D, on the east side, has had wheat harvested in even years and been fallowed in odd years. Proso millet was planted on site D after plowing of the native sod in the spring of 1970. The site was fallowed in the summer of 1971 and wheat was sown in September 1971. Wheat was planted on site C in September 1970, but the crop failed and millet was sown in the spring of 1971 (G.A. Peterson, pers. comm.).

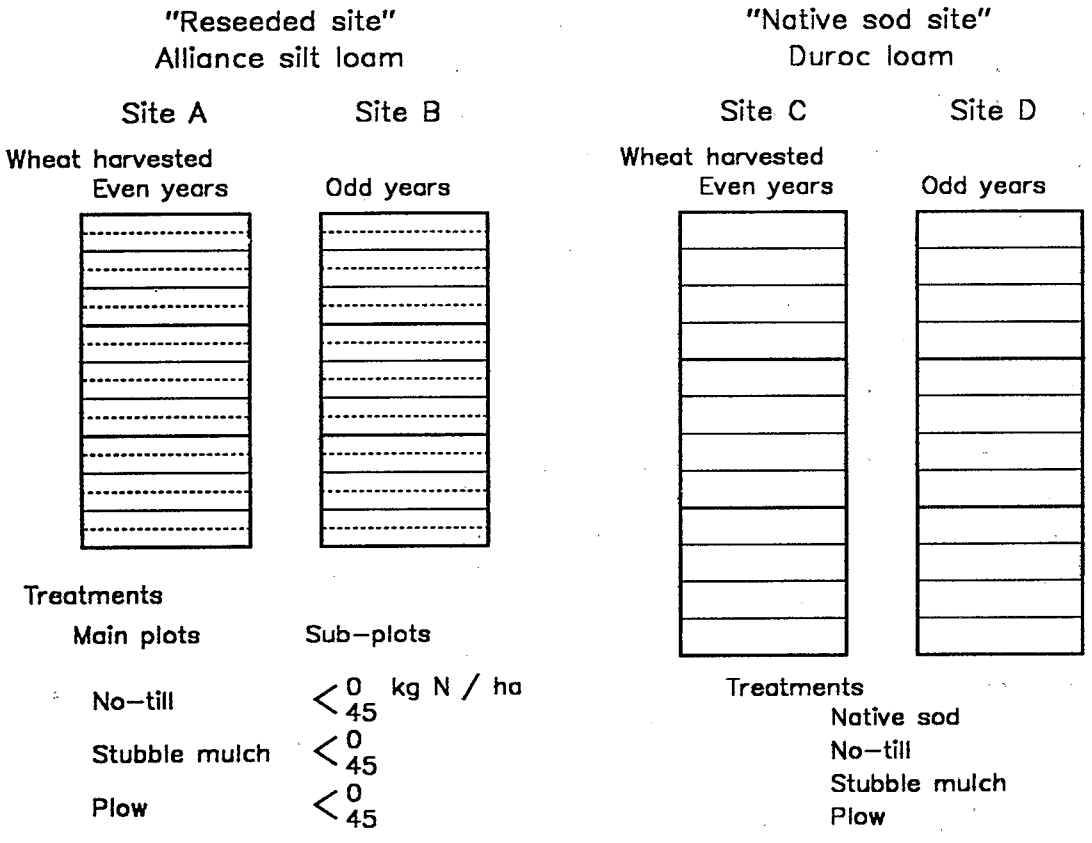

Figure A1 Layout of the Sidney tillage experiments.

Both experiments compared bare fallow or plow tillage with stubble-mulch and no-till treatments (Fenster and Peterson, 1979). On each site (A, B, C and D) there were three replicates of the tillage treatments in a randomized block design. On the Alliance soil (sites A and B), each tillage treatment plot was split with one half receiving ammonium nitrate fertilizer at 45 kg N/ha during wheat growth in April. The bare fallow and stubble-mulch plots were tilled with conventional farm machinery. Bare fallow plots were moldboard plowed in the spring, followed by two to three operations of the field cultivator, and then one to two operations with the rotary rodweeder. The stubble-mulch plots were tilled with 90-150 cm V-blades (sweep) from two to four times, then one to two times with the rotary rodweeder. Initial tillage operations were 10 to 15 cm in depth and each subsequent operation was at a decreasing depth to develop a firm seedbed. Weeds were sprayed in the no-till plots when they were 5 to 10 cm tall. Grassy weeds were controlled after harvest and/or in the spring with paraquat and later in the summer with glyphosate. If only broadleaf weeds were present 2,4-D plus dicamba was used.

All wheat plots were seeded each September with a drill equipped with large coulters, slot openers for the seed, and press wheels spaced 30 cm apart. The drill causes minimal disturbance in the no-till plots (G.A. Peterson, pers. comm.). For the period 1969 to 1983, Centurk hard red winter wheat was sown. Since then a variety of cultivars have been used. Wheat was harvested each July with a combine. Grain yield, grain protein, and crop residue (standing stubble plus surface litter) were measured.

The experiments have been the subject of a large number of studies looking at different aspects of soil organic matter, soil chemistry, soil microbiology, soil physics, soil water and nutrient cycling. I have collated many of these results from various sources to initialize, and compare with predictions from, the CENTURY model (Lyon *et al.*, 1992).

Simulation strategy

Sites C and D, which incorporate the native sod plots, have been the subject of many soil organic matter studies (Broder *et al.*, 1984; Lamb *et al.*, 1985b; Mielke *et al.*, 1986; Follet and Peterson, 1988; Cambardella and Elliott, 1992; J. Doran, unpublished; C. Cambardella, unpublished). Therefore these plots were used for validation of the CENTURY model's predictions of soil organic matter dynamics, while sites A and B, which incorporate the N fertilizer treatment were used to calibrate the wheat growth sub-model. No information from any of these sites was used for parameterization of the soil organic matter decomposition sub-model, except that the control on the maximum possible C/N ratio for the slow pool was set at 18, rather than 20, in order that the model gave a better match to the measured C/N ratios in the native sod plots. The most recent estimates for decomposition parameters were made by simulating a variety of grassland and forest ecosystems (W.J. Parton, pers. comm.). The parameters for the effect of cultivation on decomposition rates were set on the basis of a subjective assessment of the degree of stirring for the various tillage implements.

Weather data

The mean monthly precipitations and temperatures used as the climate driving variables for the CENTURY model were based on the Sidney 6NNW weather station located at the High Plains Agricultural Laboratory. Historical daily weather records were obtained from computer laser optical disk (EarthInfo, 1992). Records were available for the Sidney 6NNW station from 1971 to 1991. To create a weather record from 1949 to 1970 and to fill in missing days for the 1971 to 1991 period, I derived equations using multiple linear regression of the monthly precipitation sums, and minimum and maximum temperature means for the Sidney 6NNW station against data from Sidney 3S, Potter and Dalton weather stations for the period since 1971. Only those months that had a complete record (up to 5 missing days were allowed for temperatures) were used in the regressions. I then used the equation, which incorporated the maximum number of stations with a complete record for a particular month, to create the monthly weather file from 1948 to 1970 and to fill in missing daily values from 1971 to 1991. Mean annual precipitation and mean annual temperature at the High Plains Agricultural Laboratory are 38 cm and 8.2 °C respectively, with maximum precipitation during the summer months (Figure A2). Standard deviation and skewness values were calculated from the monthly precipitation record to drive the CENTURY model's stochastic precipitation generator, used for the simulation period prior to 1949.

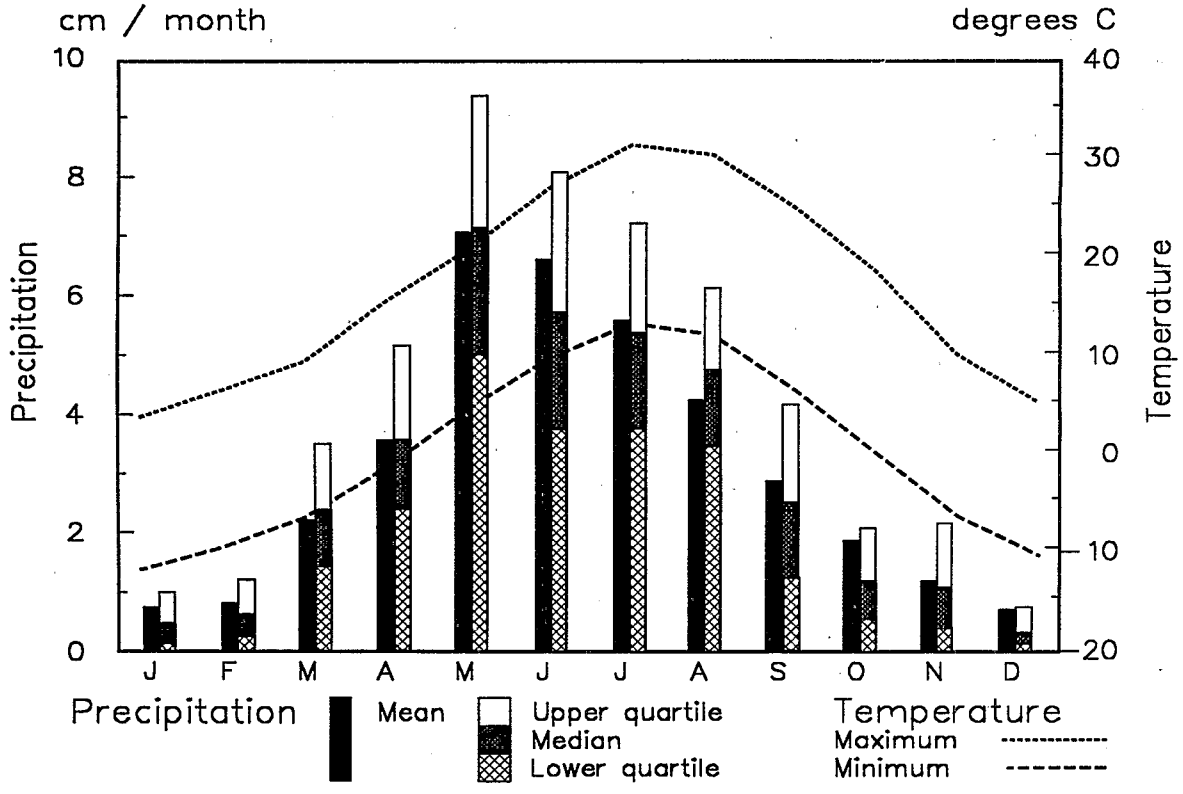

Figure A2 Monthly precipitation and minimum and maximum temperatures at the High Plains Agricultural Laboratory, near Sidney, Nebraska.

Atmospheric N deposition

Wet deposition data (National Atmospheric Deposition Program (NRSP-3)/National Trends Network, 1991) were obtained for the Pawnee and North Platte sites, located approximately 155 km west south west and 184 km east of Sidney, respectively. Ammonium deposition was adjusted by a factor of 1.58 to account for NH_4^+ losses prior to analysis (Ramundo and Seastedt, 1990). On average 67% of the total N deposition occurred as NH_4^+. Total N (NH_4^+-N plus NO_3^--N) wet deposition for these two sites showed little relationship to annual precipitation (Figure A3) and had an overall mean value of 0.32 g N / m^2. The only relevant result for annual dry deposition of N was for one year at the Pawnee site (Meyers *et al.*, 1991). The value of 0.22 g N / m^2 indicated a substantial fraction of atmospheric N inputs occurs as dry deposition. For the simulations reported here, I used a value of 0.5 g N / m^2 / year for total atmospheric N deposition.

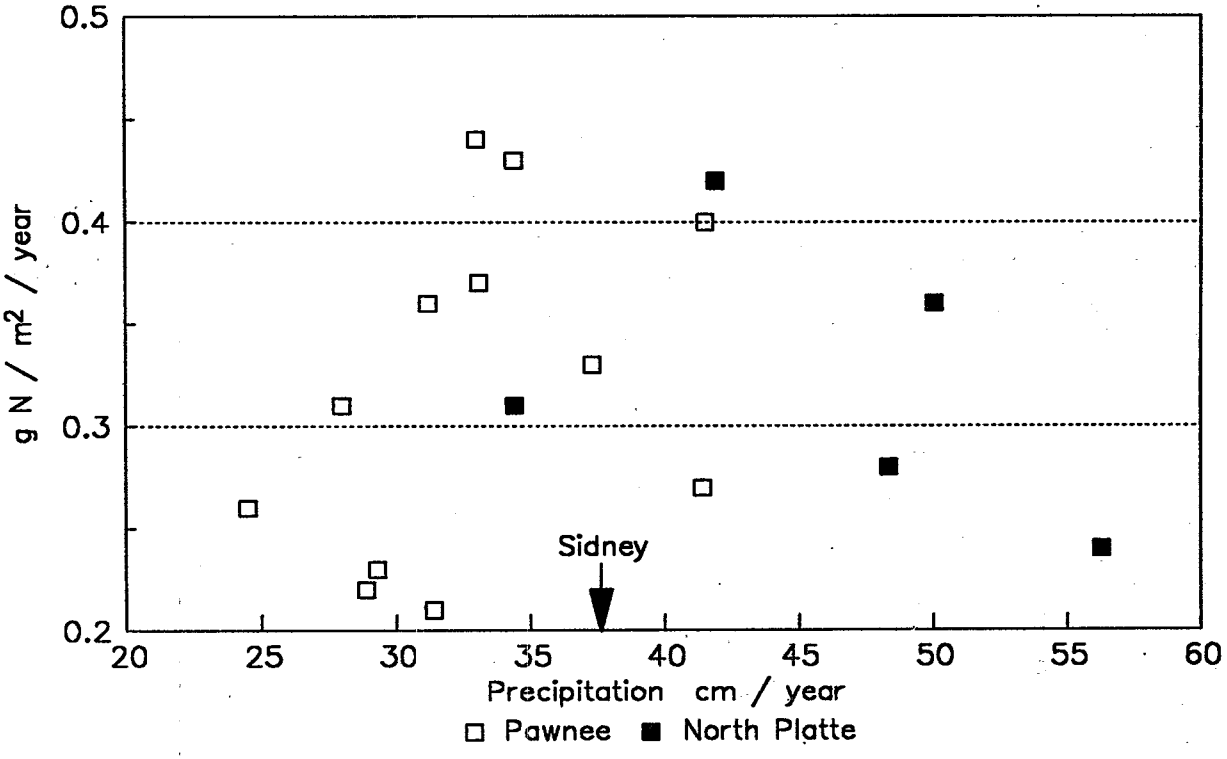

Figure A3 Annual nitrogen wet atmospheric deposition (adjusted for NH_4^+ losses) versus annual precipitation for Pawnee, Colorado and North Platte, Nebraska NADP/NTN sites.

Soil texture

Soil samples to 20 cm depth were collected for soil texture analyses on site C in 1990 (Cambardella, 1992) and site D in 1991 (Cambardella, unpublished). Some texture analyses with samples taken to shallower depths on site C have shown differences between treatments (O'Halloran, 1987; Elliott, pers. comm.). This was apparently due to mixing of horizons in the cultivated plots because the difference between treatments was not statistically significant for the 20 cm deep samples. However, there was a distinct difference between site C and D (Table A1), even though the plots are adjacent to each other. To parameterize the CENTURY model for sites A and B, the data for 0 - 15 cm samples published by Mielke *et al.* (1986) were used.

The depth for the soil water sub-model was set at 120 cm for sites A and B and at 180 cm for sites C and D.

Table A1 Soil texture (%, 0 - 20 cm) on the long-term tillage plots at the High Plains Agricultural Laboratory near Sidney, Nebraska.

	Sites A & B	Site C	Site D
Sand	37.1	37.5	47.8
Silt	40.0	31.8	31.2
Clay	22.9	30.7	21.0

Soil organic matter initialization

The CENTURY model was run for 5000 years to reach equilibrium under native grassland conditions for each site, using the stochastic precipitation generator and mean monthly temperatures. The grass type representing a 50/50 mix of warm and cool season species was used (Parton *et al.*, 1992). For sites C and D no grazing was simulated after 1940. Because the historical grazing intensity is largely unknown, this factor was used to calibrate the model to closely match the soil organic matter C and N measured on sites C and D in 1990 (Cambardella and Elliott, 1992) and 1991 (Cambardella, unpublished), respectively (Figures 13 and 14). I also ensured that the grazing intensity gave appropriate levels of consumption and residual biomass for the live and dead pools for summer and winter periods. During summer months, the grazing option was set to remove 27% of live shoots and 2% of the standing dead per month and in winter months removal rates were 15% of live shoots and 7% of the standing dead per month. For both periods, 30% of the C and 80% of the N was returned as excreta with 50% of the N returned in faecal (organic) matter. The CENTURY model grazing option, which has a negative linear effect on potential plant production as live biomass removal increases (Parton *et al.*, 1992) was used.

For sites A and B a sequence of historical crop management events was simulated from 1920 to 1956 followed by 10 years in cool season grasses. The historical management was chosen to be appropriate to the period, to give grain yields similar to the county average yields and to result in soil organic matter levels similar to those measured on the experimental plots. However, there is some uncertainty regarding the initial soil organic matter C and N levels for sites A and B because the single measurement made in 1969 (Fenster and Peterson, 1979) is lower in C and especially N, than most other analyses for samplings between 1978 and 1981. The simulated historical management sequence from 1920 to 1938 involved continuous wheat with low harvest index varieties (maximum harvest index = 0.30), plow cultivation, no fertilizer, and 50% of the straw removed. From 1939 to 1956 it involved wheat fallow with medium harvest index varieties (maximum harvest index = 0.35), bare fallow cultivation, N fertilizer and no straw removal. N fertilizer was added to this sequence because of the apparent lack of N in the subsequent simulation of the experimental treatments, but soil organic N was only increased 6 g N / m^2 by this addition. The simulated soil organic matter C and N levels prior to wheat planting in 1969 were 2791 g C / m^2 and 275 g N / m^2.

Simulation treatments

Management operations were scheduled using the CENTURY model's event scheduler, EVENT100, to simulate, as closely as possible, the management of the field experiments. Native grass simulations were set up to grow from April to October with senescence in November. Wheat simulations had October as the planting month and July as the harvest month. To represent modern wheat varieties the maximum harvest index was set at 0.42. In the simulation of the stubble mulch and plow treatments, weeds were allowed to grow after wheat harvest until the start of fallow tillage, that is, August to March inclusive. The bare fallow or plow treatment was represented by using the model options for a plow in April, a field cultivator in May, June and July, and a rodweeder in August and September. Stubble mulch simulations used a sweep in April, May, June, and July, and a rodweeder in August and September. All three treatments used a no-till drill with minimal disturbance in October. The different tillage implements have different parameters for the transfer of material between the various plant and litter pools and different multipliers for the effect of cultivation on decomposition rate (Table A2).

N at 4.5 g N/m^2 was added to the plus N treatment on sites A and B in April. For sites C and D the following events were also considered: planting of millet on site D in 1970 and on site C after the failure of the wheat crop in 1971, floods in June 1974 and July 1981, use of a conventional drill with greater soil and residue disturbance on site C in 1984, winterkill of the wheat crop on the plow treatment on site C in 1976-77 and on the stubble mulch and no-till treatments in 1978-79, no harvest due to hail on site D in 1988 and the no-till treatment on site D in 1980, and no harvest due to drought and downy brome infestation on site C in 1989.

RESULTS

Simulation of sites A and B

The primary variables used for calibration of the plant production sub-model were wheat yields and grain N content. However, simulation results were also compared to field data for crop residue levels, soil water, and mineral N in the soil profile.

I was able to calibrate the wheat parameters so that the model matched the field data for grain yield and grain N content for the plus N fertilizer treatment, but CENTURY underestimated both yields and N content for the zero fertilizer treatment (Figures A4 and A5). The field results showed no response to N during the first 10 years of the experiment, whereas in the second 10 years, there were 11% and 14% responses in the stubble mulch and no-till treatments, respectively (Brown *et al.*, 1991). Similarly, the effect of fertilizer on grain N content only reached statistical significance in the second ten years. However, the CENTURY model predicted a large response to the application of 4.5 g N / m^2 from the beginning of the experiment. A test simulation using the automatic fertilizer option in CENTURY predicted that on average a fertilizer application of 3.0 g N / m^2 / crop would be required to achieve maximum wheat yields at minimum plant N concentrations.
The N deficit in the CENTURY simulations was also reflected in the results for soil mineral N (Figure A6). Field results (Lamb *et al.*, 1985a) showed that there was a large accumulation of nitrate in the soil profile during the fallow, but the model only predicted a small accumulation

Table A2 CENTURY model cultivation options and parameter values used for the simulation of the Sidney sites.

	From	To	Plow	Cultivator	Sweep	Rodweeder	Conventional drill	No-till drill	Herbicide
Fraction transfered	Live	Dead	0.0	0.0	0.75	0.4	0.05	0.05	1.0
		Surface	0.1	0.5	0.25	0.4	0.05	0.05	0
		Soil	0.9	0.5	0.05	0.2	0.1	0	0
	Dead	Surface	0.1	0.5	0.1	0.2	0.05	0.05	0
		Soil	0.9	0.5	0.1	0.2	0.15	0.05	0
	Surface	Soil	0.9	0.5	0.1	0.2	0.2	0.05	0
	Roots	Soil	1.0	1.0	1.0	1.0	0.2	0.1	1.0
Multiplicative effect on decomposition rate			1.5	1.5	1.3	1.3	1.1	1.0	1.0

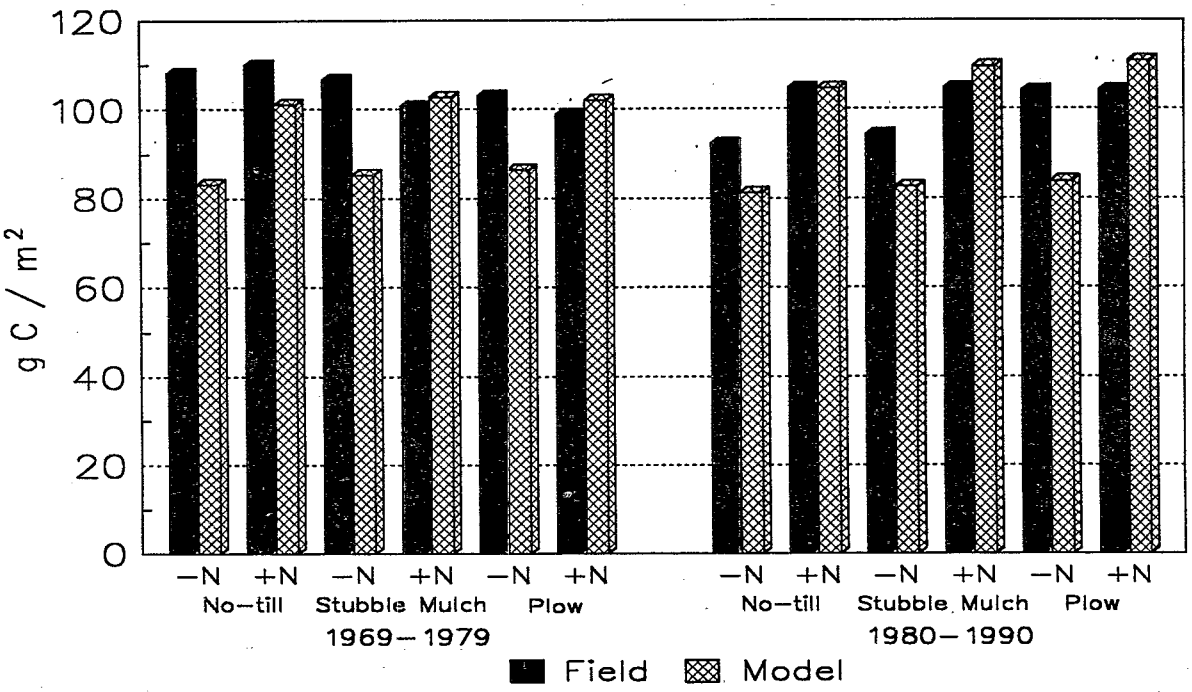

Figure A4 Simulated versus actual grain yields for two periods by three fallow tillage treatments by two nitrogen treatments for the Sidney A and B sites.

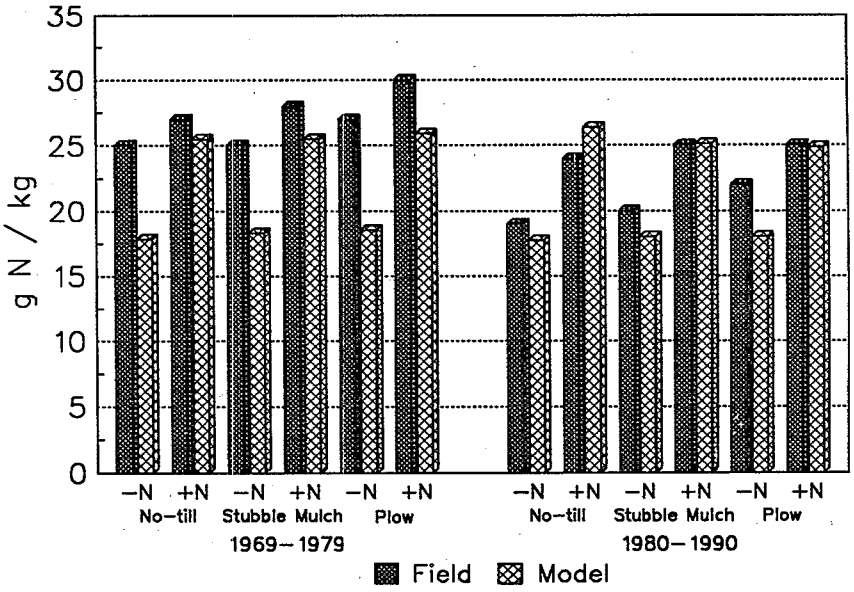

Figure A5 Simulated versus actual grain nitrogen concentrations for two periods by three fallow tillage treatments by two nitrogen fertilizer treatments for the Sidney A and B sites.

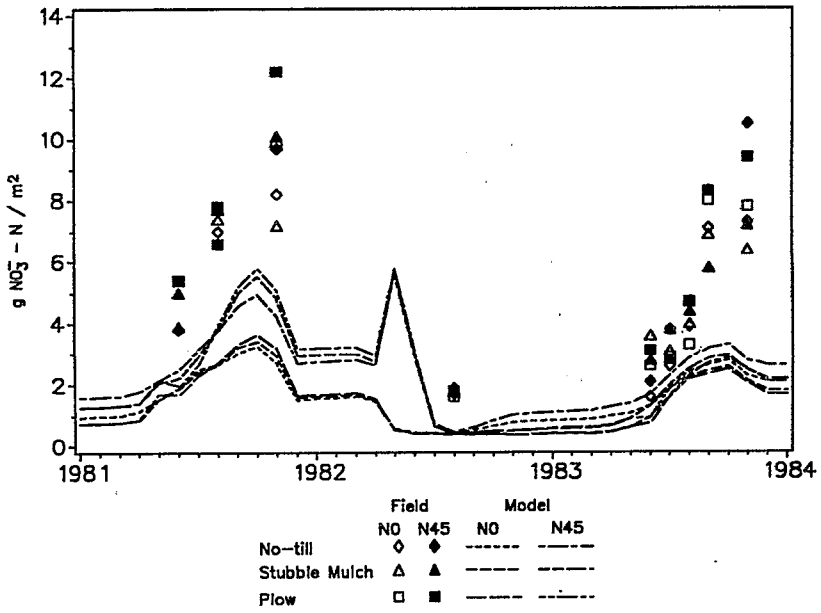

Figure A6 Simulated versus measured mineral nitrogen in the soil profile at Sidney site A.

of mineral N. In seven out of eight years, on sites A and B, in which nitrate was measured in the soil profile in the fall close to the time of wheat planting, the model underestimated mineral N in the profile by about 2 to 9 g N / m^2.

The simulated crop residue levels (standing dead plus surface litter) showed the seasonal patterns expected from the different tillage treatments and were of a similar magnitude to the field data (Fenster and Peterson, 1979) (Figure A8).

From field measurements of total soil water (Fenster and Peterson, 1979), I estimated wilting point by calculating the mean of the measurements made after wheat harvest. To estimate available soil water at wheat planting, for comparison with the model output, this mean was subtracted from total soil water measured at wheat planting. A moderate amount of weed growth was included in the simulations of the stubble mulch and plow treatments, from after wheat harvest until the start of the spring cultivations, in order to reduce the water storage during this period. The simulated soil water status showed the expected biennial cycle, with the maximum levels of available soil water being similar to those estimated from the field data (Figure A7). However, the model failed to predict the low water storage in all treatments on site B in 1972, and in the plow treatment and, to lesser extent, the stubble mulch treatment in 1974. Such discrepancies may have been due to variations in the efficiency of weed control in the field experiments. In many years, the model did not predict very large differences between the tillage treatments in soil water storage, although, where differences did occur, they were in the expected descending order of no-till, stubble mulch, and plow.

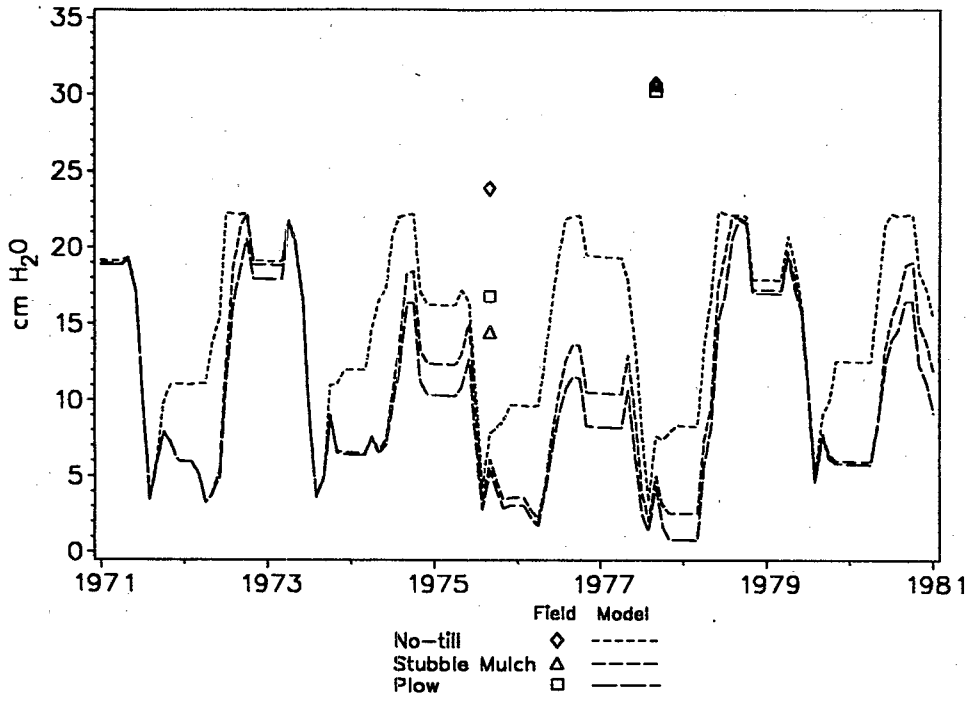

Figure A7 Simulated versus measured available soil water for the no nitrogen treatments at Sidney site B.

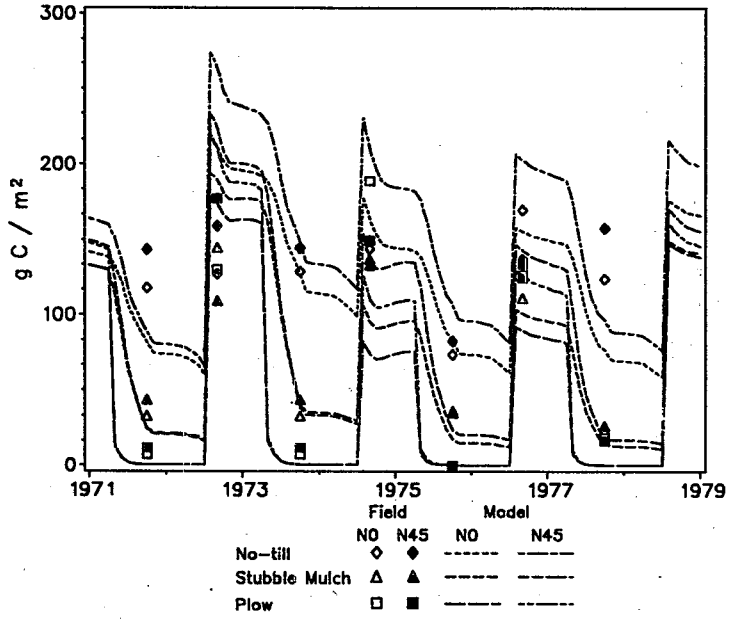

Figure A8 Simulated versus measured crop residue (standing dead plus surface litter) at Sidney site A.

Simulation of sites C and D

In view of the fact that the land had previously been cultivated for 36 years, it was unusual that the field experiment on sites A and B did not show a greater response to N fertilizer. Sites C and D had a much higher fertility status, having been in native sod until the start of the experiment and it seemed unlikely that the simulation would predict a N deficiency. Thus, despite the problem with the N deficit in the simulations of sites A and B we decided to use the same parameters and schedules of management events for the simulations of sites C and D, in order to validate the CENTURY model's predictions of soil organic matter dynamics.

Notwithstanding the above factors, the model again underpredicted the accumulation of mineral N during the fallow (Figure A9) indicating that the problem was not associated with the initial soil organic matter level at the beginning of the experiment.

However, simulated wheat yields were not markedly reduced by N deficiency, except in the first crop on site C immediately after breaking the sod. Simulated yields tended to be slightly higher than observed yields (Figure A10) and were only moderately correlated ($r^2 = 0.36$).

The CENTURY model predicted a gradual decline in soil organic matter in all three wheat fallow tillage treatments (Figures A11 and A12). The relative change was greater for C than for N resulting in a narrowing of the C/N ratio. The decline was greatest in the plow treatment and least in the no-till treatment. Almost all of the field data gave the same ranking of the treatments, but there was considerable variation between sampling dates in the absolute C and N levels measured. The data were compiled from a variety of published and unpublished sources and this variation is assumed to be due to four factors: different sampling methods, some differences in depth sampled, although the results presented are all nominally for 20 cm depth, differences in sample preparation, especially the amount of residue and roots removed, and differences in analytical methods. There were two data sets in which we had more confidence in the results. The first set was for samples collected in 1981 and 1982 with results first published by Lamb *et al.* (1985b). The soil samples had been stored and we reanalyzed them for C, obtaining much higher results than originally published, but more in line with the other data. The N results reported here are those originally published. The second dataset was for samples that were collected from site C in 1990 (Cambardella and Elliott, 1992) and site D in 1991 (Cambardella, unpublished). As only small changes would be expected in soil organic matter in the native sod treatment between 1981/82 and 1990/91 it can be seen that the results for these two datasets are consistent with each other (Figures A13 and A14).

In the native sod treatment simulated soil organic matter levels increased slightly from 1970 to 1992, reflecting the change from an equilibrium established with grazing prior to 1940, to ungrazed conditions after 1940. The simulated and actual soil organic matter C and N levels in the native sod treatment were lower on site D than on site C reflecting the higher sand content on site D. While there had been some calibration of grazing intensity in order to match the simulated and field soil organic matter data, the fact that the simulation results agreed fairly

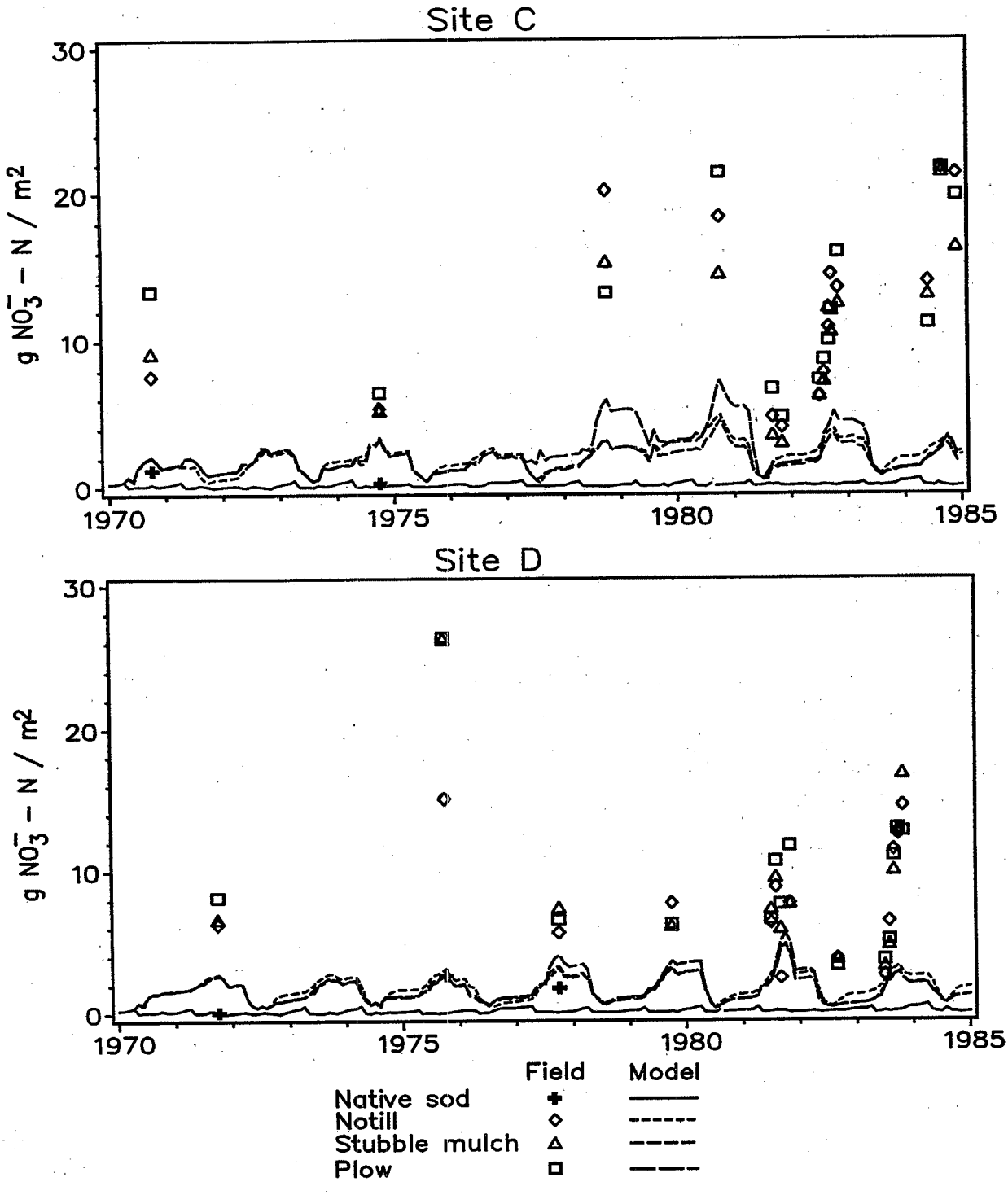

Figure A9 Simulated mineral nitrogen and measured nitrate nitrogen to a depth of 180 cm.

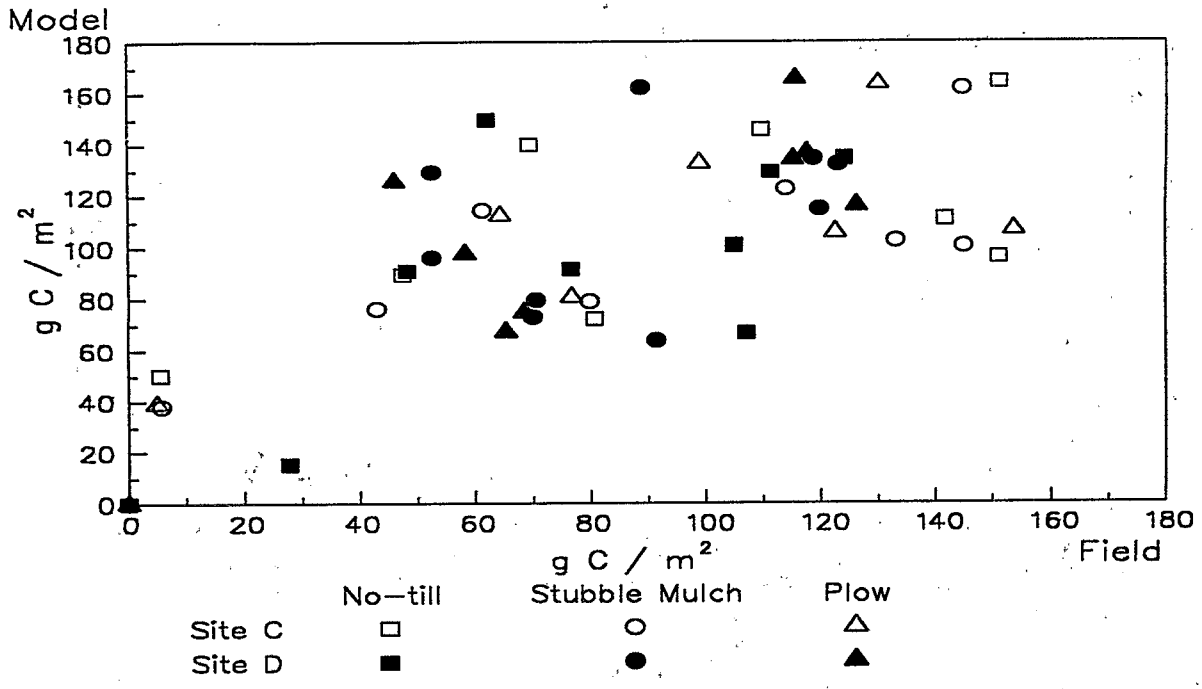

Figure A10 Simulated versus observed wheat yields for sites C and D.

closely with the field data for the native sod plots on both sites for the 1981/82 and 1990/91 sampling dates indicate that CENTURY correctly predicted the effect of soil texture on native grassland soil organic matter levels. The model predicted C/N ratios of 11.9 and 12.5 for sites C and D, respectively, compared to measured C/N ratios of 11.6 and 11.1. Thus, on site D, the C levels were slightly overestimated, while N levels were slightly underestimated.

For the 1981/82 and 1990/91 datasets, the simulated soil organic C (Figure A13) and N (Figure A14) agreed fairly closely with the field data for all treatments. Differences between simulated and observed data were mostly within the degree of variation in the field data, shown on the figures as the standard error of the difference between treatments (SED). The largest discrepancy was for results for the plow treatment in 1981/82. In general, there was more differentiation between the tillage treatments than was predicted by the model. Coefficients of determination (r^2) for simulated versus observed data were 0.86 and 0.69 for soil organic C and N, respectively. In both cases, the slopes of the regression lines were not significantly different ($p > 0.05$) from 1.0 and the intercepts were not significantly different ($p > 0.05$) from 0.0.

The CENTURY model predicted that the average annual effect on decomposition rate was 1.66, 2.06, and 2.34 times greater than the native sod treatment for no-till, stubble mulch, and plow, respectively (Figure A15). The field data suggest that the decline in soil organic matter had been rapid and then levels stabilized, whereas the model predicts a more gradual and continual decline.

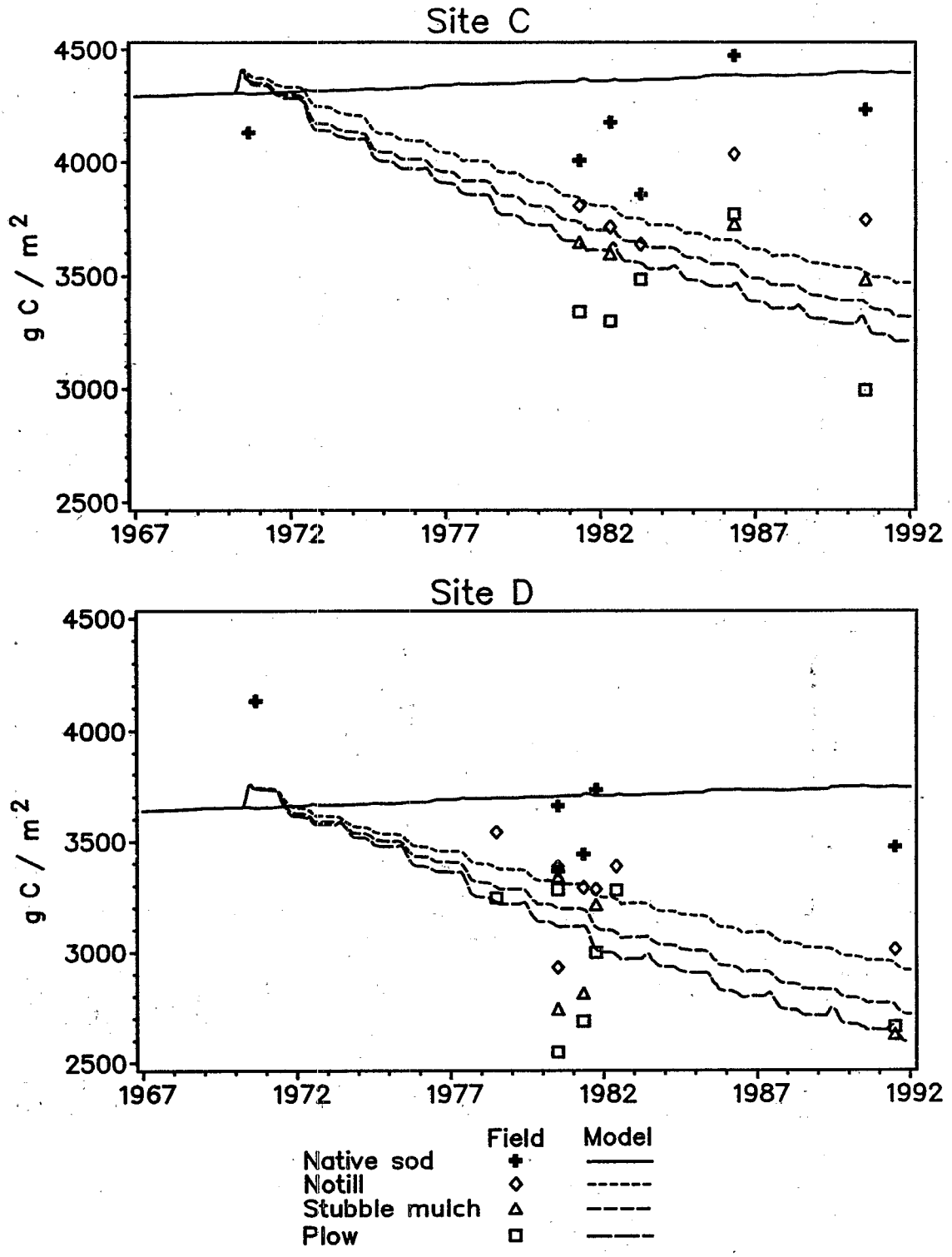

Figure A11 The effect of tillage treatment on simulated and measured soil organic carbon to 20 cm depth.

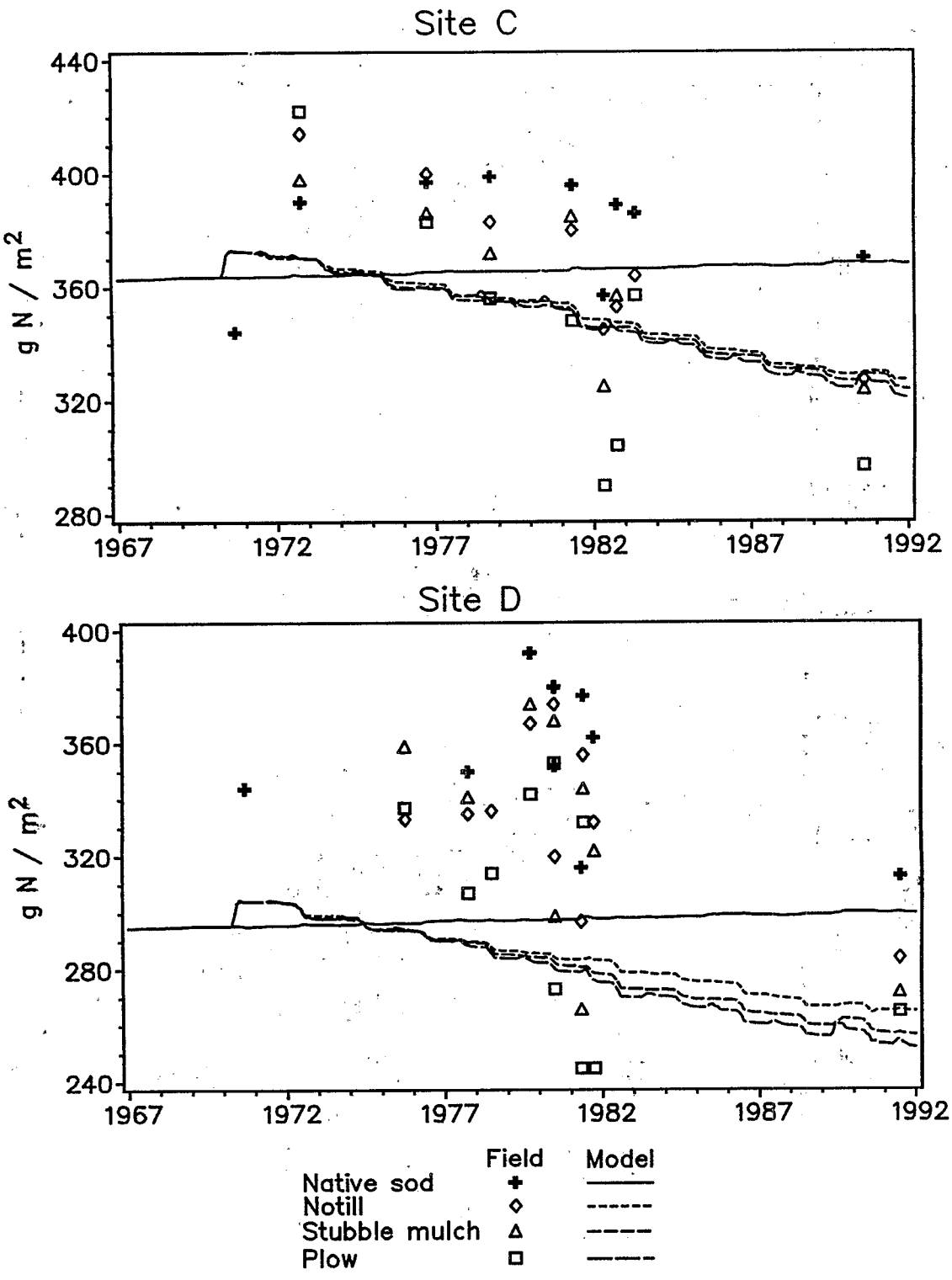

Figure A12 The effect of tillage treatment on simulated and measured soil organic nitrogen to 20 cm depth.

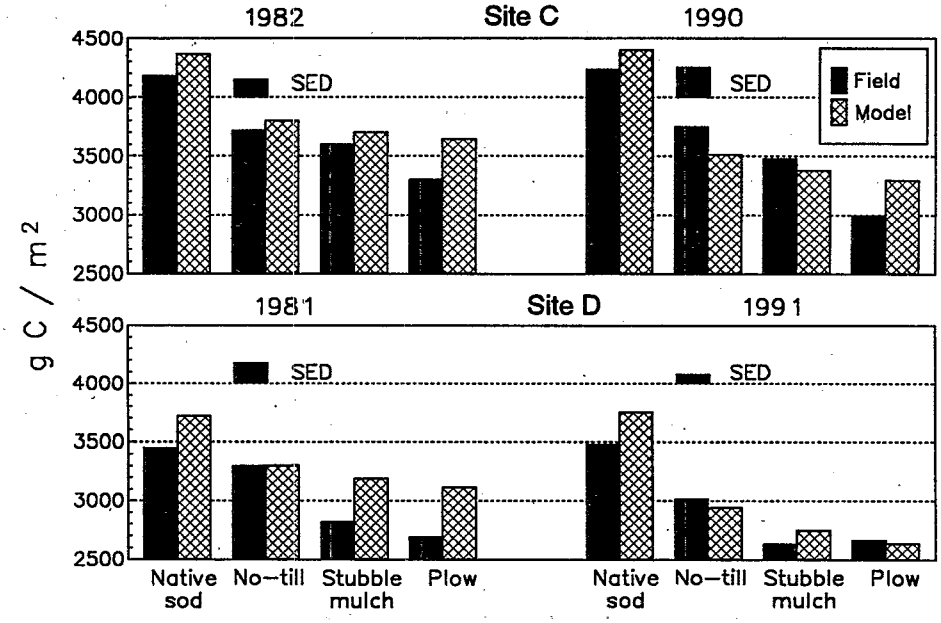

Figure A13 The effect of tillage treatment on simulated and measured soil organic carbon to 20 cm depth for the 1981/82 and 1990/91 datasets. SED = standard error of the difference for field data treatment means.

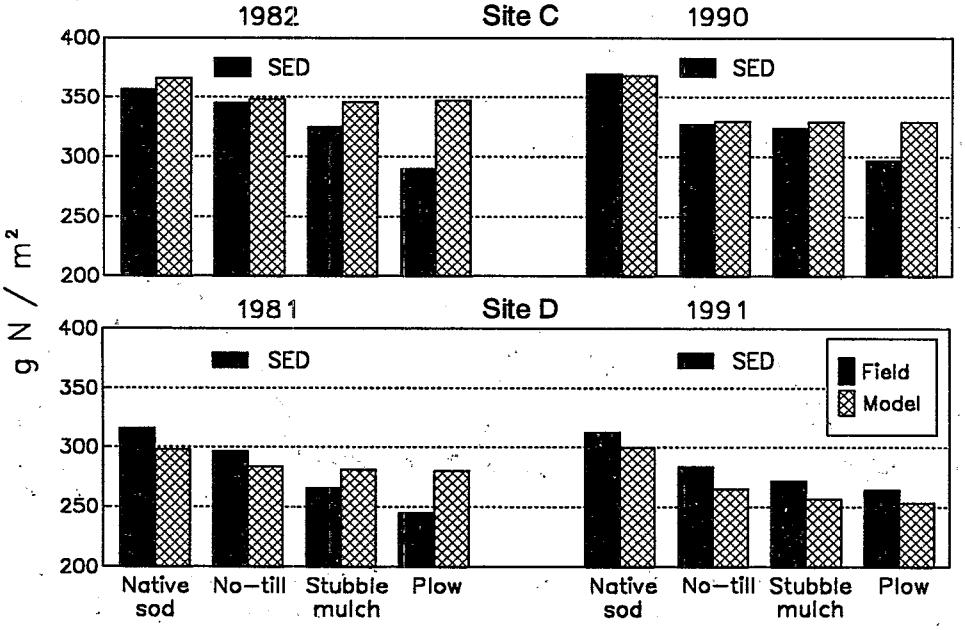

Figure A14 The effect of tillage treatment on simulated and observed soil organic nitrogen to 20 cm depth for the 1981/82 and 1990/91 datasets. SED = standard error of the difference for field treatment means

The soil organic matter pools in the CENTURY model are conceptual, kinetically defined pools that do not correspond exactly with chemical or physical soil organic matter fractions. However, soil organic matter fractionation schemes based on combinations of physical methods (Elliott and Cambardella, 1991) are likely to yield fractions related to the aggregate structure and soil organic matter quality, and hence, its rate of turnover. Thus, it is of considerable interest to compare the changes in the sizes of the CENTURY model pools with the soil organic matter fractions isolated from soil collected on Sidney site C in 1990 (Cambardella and Elliott, 1992). Particulate organic matter is organic matter which, after dispersion of the soil with sodium hexametaphosphate, is retained on a 53 μm sieve. Most of the particulate organic matter has a density less than 1.85 g / cm^3. The material that passes through the sieve is termed mineral associated organic matter. Within the mineral associated organic matter of macroaggregates Cambardella (1992) isolated, by gentle sonication, sieving, and flotation in sodium polytungstate a series of size-density fractions. The fraction of fine-silt sized particles (2-20 μm), with a density of 2.07-2.21 g / cm^3, termed the enriched labile fraction, contained 10-20% of the total soil C and 8-28% of the total

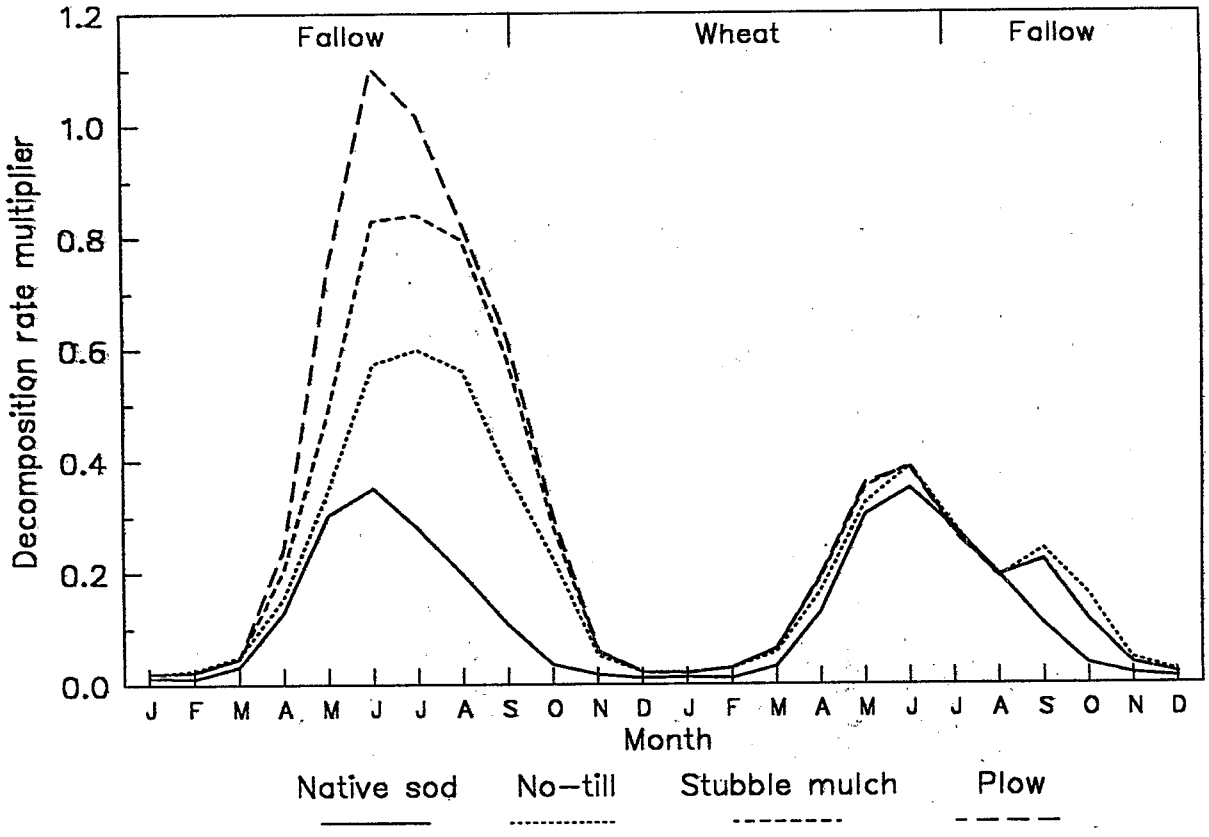

Figure A15 The average monthly combined effect of temperature, moisture, anaerobic conditions and cultivation on the decomposition rate multiplier for each tillage treatment.

soil N, depending upon the treatment. The specific rate of N mineralization in this fraction was much greater than for the intact aggregates, suggesting a labile, but physically protected pool. The mineralization rate of the enriched labile fraction was much higher in the native sod treatment than in the cropped soils.

Almost all of the differences in the amounts of soil organic matter in the four treatments could be accounted for by the changes in the size of the particulate organic matter fraction. This result was analogous to the CENTURY model's prediction that the change in size of the slow pool would account for almost all of the difference between treatments (Figures A16 and A17). However, the size of the slow pool is much larger than the size of the particulate organic matter fraction. The enriched labile fraction, which is physically protected from decomposition in the aggregate structure, may possibly account for most of the rest of the slow pool.

Stable C isotope measurements also indicated that the soil organic matter dynamics were associated with the particulate organic matter fraction rather than the mineral fraction. The change in vegetation from native grassland, which is a mixture of C3 and C4 species, to wheat, which is a C3 plant, has changed the stable C isotope signature of the vegetation, expressed as $\delta^{13}C$ values, from approximately -21‰ to -27‰. This, in turn, will induce a change in the

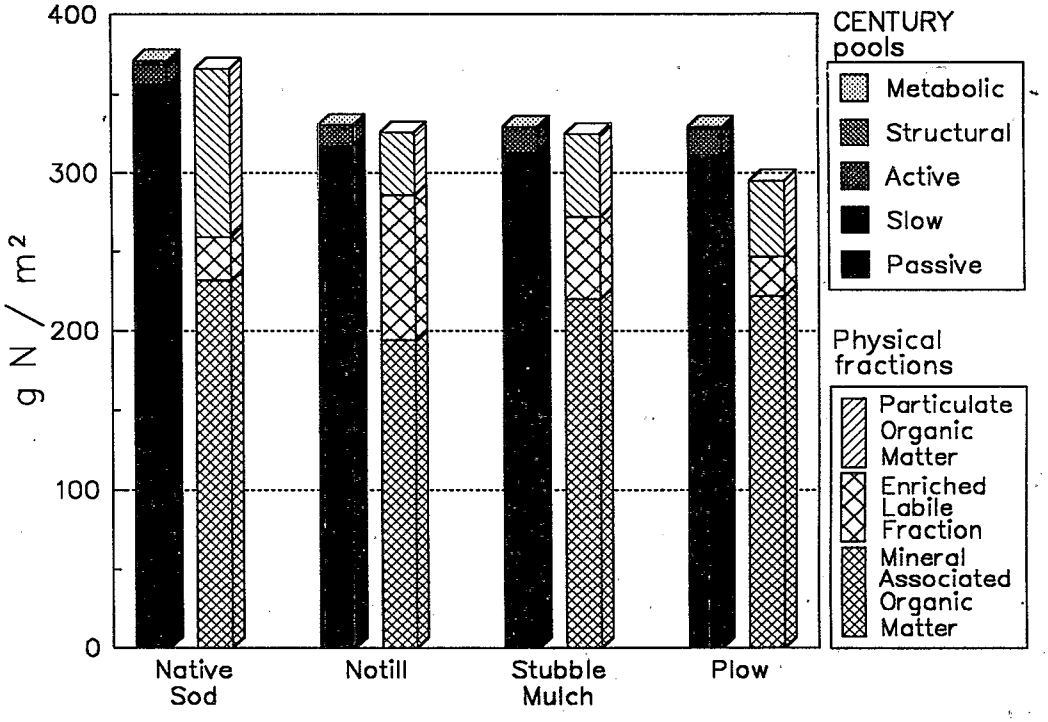

Figure A16 CENTURY model soil organic nitrogen pools compared with physical fractions of soil organic matter at Sidney site C, 1990 (after Camberdella, 1992)

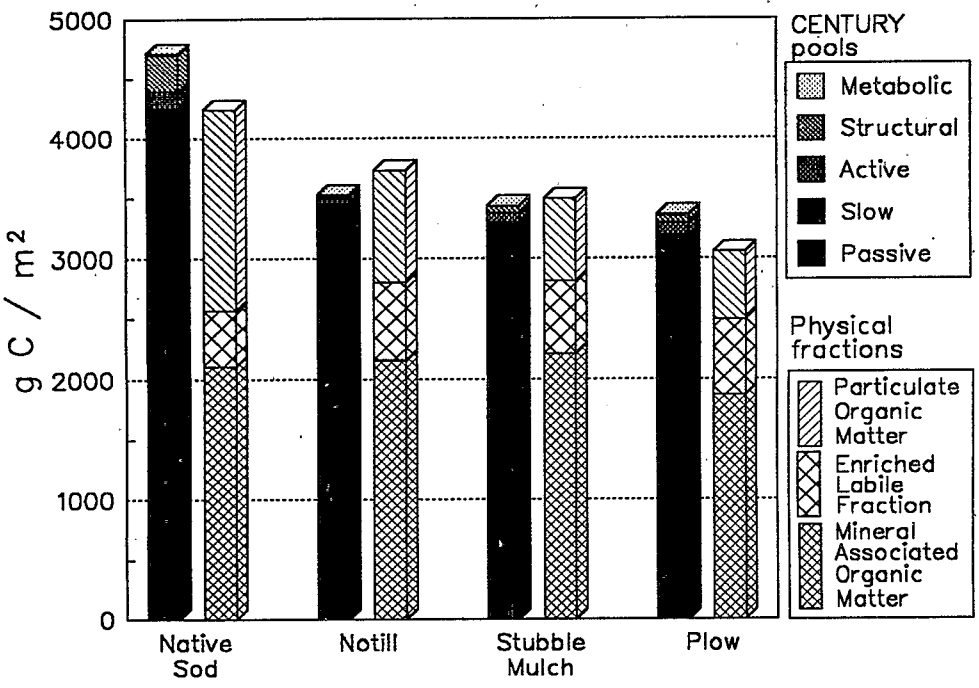

Figure A17 CENTURY model soil carbon pools compared with physical fractions of soil organic matter for Sidney site C, 1990 (after Camberdella, 1992).

signature of the soil organic matter (Balesdent *et al.*, 1988). Analysis of the particulate and mineral associated fractions (Cambardella, 1992) indicated that the signature had only changed in the particulate fraction (Figure A18). The CENTURY model predicted that the greatest change in $\delta^{13}C$ values would occur in the metabolic, structural, and active pools with inputs directly from plant material and in the pools with the fastest turnover times. There was a small, but definite change in the signature of the slow pool. No change in the $\delta^{13}C$ value of the passive pool corresponds to there being no change in the mineral associated organic matter isolated from the field soil samples. The model predictions do vary from the measurements of the particulate fraction in which the plow treatment was less depleted in ^{13}C than the no-till and stubble mulch treatments.

Under native grassland vegetation the lowest $\delta^{13}C$ value occurred in the structural pool reflecting the input of lignin, which is depleted in ^{13}C, to the structural pool. The $\delta^{13}C$ value was lower in the slow pool than in the passive pool, reflecting inputs to the slow pool from the structural pool. Fractionation during microbial respiration resulting in enrichment in ^{13}C as soil organic matter ages would also tend to result in a higher $\delta^{13}C$ value in the passive pool. A much lower $\delta^{13}C$ value in the particulate organic matter compared to the mineral organic matter is also likely to be a result of the 40 to 53% lignin content (Cambardella and Elliott, 1992) of the particulate organic matter.

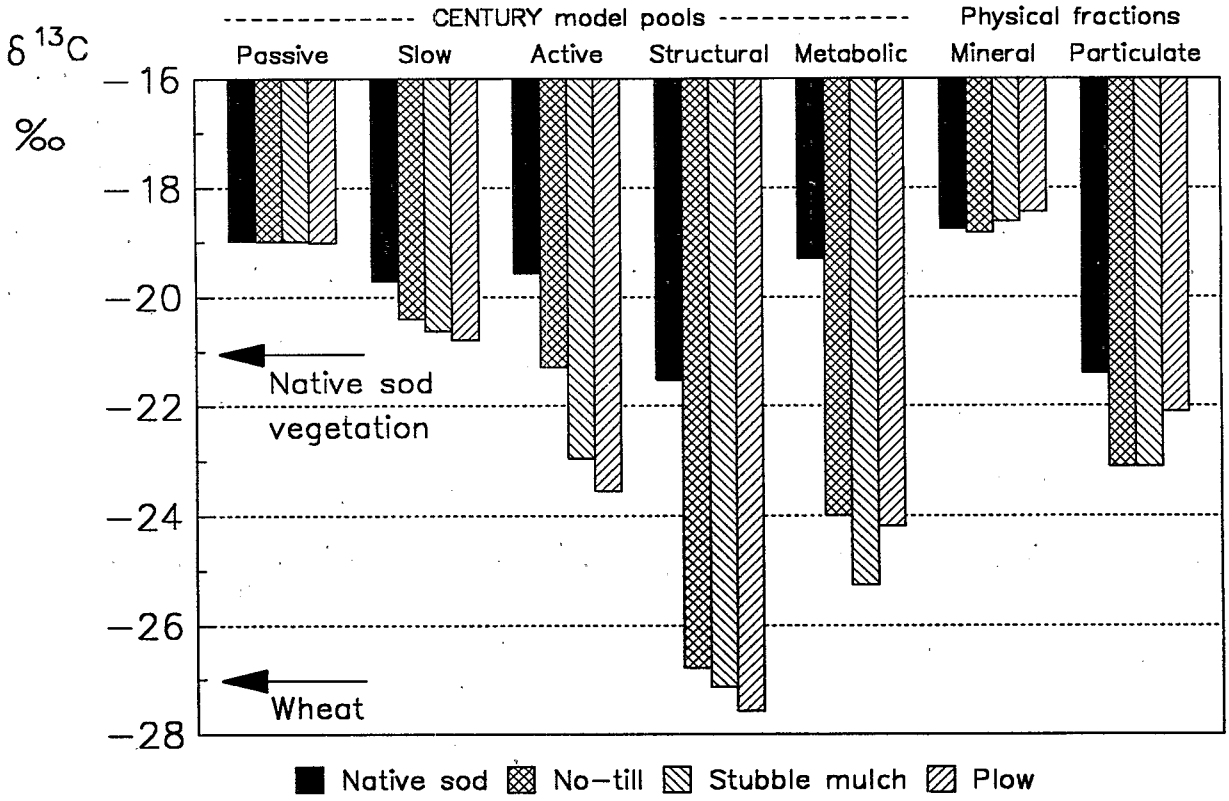

Figure A18 Stable carbon isotope ratios for the CENTURY model soil carbon pools and the physical fractions of soil organic matter for Sidney site C, 1990.

DISCUSSION

Nitrogen balance

The largest discrepancy between field data and model results was in the prediction of mineral N during the fallow period. The accumulation of mineral N in the soil profile was underestimated by amounts ranging from about 2 to over 20 g N / m^2. The low mineral N levels then reduced crop N uptake, and at sites A and B, in the absence of N fertilizer, the crop yields. Similar problems with the N balance have been experienced in the simulation of crop rotations at Pendleton, Oregon (W.J. Parton, pers. comm.). There is field evidence from sites C and D at Sidney that indicates that in the no-till treatment there was a positive N budget (Lamb *et al.*, 1985b) suggesting that there was an unaccounted N input. In that study, total mineralization of N was estimated by calculating the difference in total N, in the top 30 cm of soil, between the native sod and the wheat treatments. The loss of N from the surface 30 cm of the soil was less

than the N in the grain removed. When the difference in the amount of N leached to a depth of 7 or 15 m was considered, the budget became even more positive and amounted to additional inputs to the no-till treatment, over 11 or 12 years, of 24 and 38 g N / m^2 for sites C and D respectively. The N budget was balanced for the stubble mulch treatment on both sites, and for the plow treatment on site D. However, on site C there was an unaccounted loss of 51 g N / m^2 from the plow treatment. No estimate was made of volatile N losses.

The discrepancy between the CENTURY model's prediction of mineral N and the field measurements cannot be ascribed to a gross underestimation of mineralization rates in the surface soil because the model did a reasonably good job of predicting the decline in soil organic N in the surface 20 cm. Nor can the difference be explained by incorrect estimation of the effect of cultivation on mineralization rates because the problem occurred with no-till as well as the tilled treatments. Three processes are suggested that could have contributed to the simulated N deficiency.

Firstly, the CENTURY model is parameterized to simulate soil organic matter dynamics in the surface 20 cm of soil only. Although the concentration of organic matter is usually lower in soil layers below 20 cm there may still be a considerable reservoir of organic N, which, if mineralized, would be measured as nitrate in the deep soil samples and would be available for plant uptake by wheat which has a deep root system. Some evidence for N mineralization in deep soil layers comes from a study at Mandan, North Dakota (Haas *et al.*, 1957). After 30 years cropping, there had been a loss of organic N and C in the 15-30 cm and 30-60 cm layers (Table A3).

However, the data of Lamb *et al.* (1985b) for Sidney sites C and D do not support this hypothesis. In soil samples taken in 1981 and 1982 there was no significant difference between treatments in the quantities of total N and organic C (samples reanalyzed in 1991) in the 20-30 cm layer (Table A4). Although the C concentration was significantly higher in the native sod plots on site C, the difference in bulk density between treatments reduced the magnitude of the effect. These results do not rule out the hypothesis because they only measure a net effect and

Table A3 Percent loss of C and N in 3 soil layers after 30 years cropping at Mandan, North Dakota. Results are means for a variety of crop rotations including small grains, corn and fallow years (after Haas *et al*, 1957).

	Depth cm		
	0-15	15-30	30-60
Nitrogen	29.2	9.9	5.9
Carbon	32.9	10.3	7.8

some mineralization of soil organic matter would have been balanced by inputs of organic matter from roots below 20 cm, and the net losses over 11 or 12 years could have been smaller than could be detected statistically. From data for an Alliance soil in the EPIC model soils database (Sharpley and Williams, 1990), I calculated that there is about 300 g N / m^2 in soil organic matter between 20 and 66 cm depth. The CENTURY model predicts that about one percent of the organic N in the surface 20 cm mineralizes each year. The proportion mineralizing in lower soil layers is likely to be lower than in the surface soil. The average age of the soil organic matter is greater in subsurface layers (Jenkinson *et al.*, 1992) indicating greater resistance to decomposition. If one half of one percent of the N in the 20 to 66 cm layer mineralized each year then 1.5 g N / m^2 / year would be released. This would be sufficient to make up the deficit for crop production, but would not match the measured accumulation of nitrate in the profile during the fallow period. However, there would be a positive feedback from having more N cycling through the plants and crop residue.

The second process that could have contributed to the simulated N deficiency is an overestimation of volatile N losses. Note that CENTURY did not predict any deep leaching of mineral N, so that leaching losses were in fact underestimated. In the present formulation of the CENTURY model, volatile N losses are predicted from three sources. Firstly, volatile N losses due to nitrification are estimated as being 5% of gross mineralization. Secondly, denitrification losses are estimated as $^5/_{12}$% of the residual mineral N in the soil at the end of each month after all other processes have been accounted for. Thirdly, for crops there is a volatile loss of 4% of the N in the shoots, calculated when the crop is harvested. The first mechanism accounts for most of the volatile N loss. For Sidney sites C and D, the volatile losses associated with nitrification averaged 0.45, 0.67, 0.84, 0.97 g N / m^2 / year for native sod, no-till, stubble mulch, and plow treatments, respectively. Denitrification losses were insignificant, while under wheat-fallow the volatilization from shoots averaged 0.10 g N / m^2 / year. The nitrification loss was originally calibrated to balance the N budget in native grasslands, with volatile N losses being approximately equal to external N inputs. However, volatile losses from senescing herbage were ignored. Recent research (Zachariassen, 1992) has shown that volatilization of ammonia from native grasslands is greatest at the end of the season when the herbage is senescing. The net ammonia flux over the entire season was estimated to be 0.0593 g N / m^2 at the Konza prairie and 0.0744 g N / m^2 at the Pawnee grasslands. Given that there was net downward flux during the main growing season, the volatile losses during senescence could probably account for up to 0.15 g N / m^2 or approximately 15% of the N in the standing crop at the end of the season. If this pathway of N losses was accounted for in the grassland simulations, the volatile losses associated with nitrification could be reduced from 5 to 3% of gross mineralization. Hence, the simulated volatile N losses with wheat-fallow management would be reduced by up to 0.4 g N / m^2 / year. The simulated equilibrium soil organic matter level in native grasslands is very sensitive to the rate of N loss because net primary production is limited by N. Hence, further field research and model testing are necessary to establish the amounts and mechanisms of N losses in native grasslands.

Clearly, neither of the above mechanisms could account for all of the discrepancy between simulated and measured mineral N, I suggest that higher than predicted rates of non-symbiotic

Table A4 The effect of tillage on total soil N (from Lamb *et al*, 1985b) and organic C (samples reanalyzed in 1991) at 3 soil depths.

	Plow	Stubble Mulch	No-till	Native Sod	SED	
			g N / m^2			
Site C 1982						
0-10 cm	147	189	207	222	7.8	**
10-20 cm	143	136	138	135	7.4	ns
20-30 cm	96	99	107	103	5.3	ns
0-30 cm	386	424	452	460	15.1	**
Site D 1981						
0-10 cm	129	148	183	176	5.7	**
10-20 cm	116	118	114	140	5.7	*
20-30 cm	114	104	109	103	2.9	ns
0-30 cm	360	369	405	419	12.2	*
			g C / kg			
Site C 1982						
0-10 cm	17.6	22.0	22.3	27.9	1.19	**
10-20 cm	14.5	12.9	12.2	14.4	0.45	**
20-30 cm	9.5	9.5	9.4	10.8	0.38	*
Site D 1981						
0-10 cm	14.1	17.7	19.8	23.2	0.94	**
10-20 cm	12.1	9.7	10.9	11.6	0.78	ns
20-30 cm	9.2	8.8	9.3	9.6	0.35	ns
			g C /m^2			
Site C 1982						
0-10 cm	1755	2071	2305	2483	113	**
10-20 cm	1544	1526	1409	1695	52	**
20-30 cm	1201	1216	1176	1287	47	ns
0-20 cm	3299	3597	3714	4178	146	**
0-30 cm	4500	4814	4889	5465	179	**
Site D 1981						
0-10 cm	1400	1667	2049	2071	89	**
10-20 cm	1289	1149	1259	1373	90	ns
20-30 cm	1155	1131	1163	1151	45	ns
0-20 cm	2688	2815	3293	3443	170	*
0-30 cm	3843	3946	4472	4595	201	*

** = significant $p < 0.01$, * = significant $p < 0.05$, ns = not significant

N_2 fixation may have occurred in the wheat-fallow plots. Currently the CENTURY model predicts non-symbiotic N_2 fixation as a linear function of annual precipitation with no fixation when precipitation is less than 33 cm / year. The N inputs go directly into the mineral pool. At Sidney this varies between 0 and 0.51 g N / m^2 / year and averages 0.15 g N / m^2 / year. However, in the wheat-fallow system, which has a marked biennial cycle in soil moisture status, tying non-symbiotic N_2 fixation to annual precipitation is erroneous. Furthermore, there is some evidence that non-symbiotic N_2 fixation is enhanced by the decomposition of cellulose rich residues, such as wheat straw, when anaerobic microsites are available for N fixing anaerobes, such as *Clostridium* species (Rice and Paul, 1972; Lynch and Harper, 1983). N_2 fixation efficiencies ranged from 2.1 to 5.0 mg N / g straw added or from 11.5 to 16.1 mg N / g substrate consumed. During the fallow period the soil moisture status rises and there is the required combination of decomposing wheat straw and anaerobic microsites. If a gain of 5 mg N / g straw is assumed, and given that at Sidney the straw yields are approximately 400 g DM / m^2 / crop, there could be a potential for 1 g N_2 fixation / m^2 / year. In contrast to this calculation, Lamb *et al.* (1987) estimated from laboratory C_2H_2 reduction assays of the soils from the Sidney experiments, that the non-symbiotic N_2 fixation potential was only 0.033 g N / m^2 / year. However, because the incubations were conducted in complete darkness, which would not have allowed N_2 fixation by cyanobacteria, the authors concluded that the non-symbiotic N_2 fixation potential may have been underestimated.

In the assays of Lamb *et al.* (1987) the N_2 fixation potential was positively correlated with soil moisture content and was twice as high in the no-till treatment compared to the plowed soil. In soil samples collected during spring growth of wheat at Sidney the population and activity of anaerobic denitrifying organisms was greater in the surface soil of the no-till plots than in the cultivated plots (Broder *et al.*, 1984; Linn and Doran, 1984). These results were attributed to the greater water filled pore space in the no-till treatment. A higher rate of non-symbiotic N_2 fixation activity in the no-till plots helps to explain the difference in N budgets between treatments found by Lamb *et al.* (1985b).

The combined effect of the three mechanisms described above would result in additional 2.9 g N / m^2 / year. Combined with the positive feedback of producing more residue with a higher N content a large part of the discrepancy between model and field results could be accounted for.

Soil Organic Matter

The CENTURY model, within a reasonable degree of error, simulated the changes in soil organic C and N when native sod was converted to a wheat-fallow system on sites C and D. There was an indication that the model did not sufficiently differentiate between the tillage treatments. In particular, soil organic matter levels in the plow treatment declined at faster rate than was predicted by the model. An increase in the factor for the effect of cultivation on decomposition rates seems justified for the tillage practices with the greatest degree of soil stirring, such as plowing and use of a field cultivator.

Comparison of the CENTURY model pools with physical fractionations of soil organic matter indicated strong similarities between particulate soil organic matter and that part of the slow pool which is derived from the structural pools. I recommend that future development of the CENTURY model separate the slow pool into two parts. Material derived from the structural pools is very different in physical form and chemical composition from material derived from the active and surface microbe pools. The former is very likely to correspond with particulate soil organic matter and would thus provide a relatively simple laboratory technique for initialization and validation of changes in one of the pools. The latter part of the slow pool may correspond to the enriched labile fraction or similar components of the mineral associated organic matter.

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APPENDIX B

APPLICATION OF THE CENTURY MODEL TO THE LEXINGTON, KY, SITE

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B.1 INTRODUCTION

The CENTURY model developed by Parton et al. (1987, 1988) has been used for various field applications. Initially, the studies were limited to grassland conditions since the model did not have capabilities to represent crops such as corn, millet, soybean and wheat. During the past year model capabilities have been greatly enhanced by researchers at NREL at Colorado State University (Metherell, 1992), by incorporating crop parameters and algorithms to properly represent multiple commercial crops, crop rotations, and tillage practices, along with interactions with the various nutrient cycles simulated by the model.

The EPA Climate Change Study Region consists of the Corn Belt, the Great Lakes area and some portions of the Great Plains. The crops grown in this region are primarily corn, soybeans, and wheat. Within the study region, agronomic practices consist of complex cropping patterns, rotations, and tillage practices with these crops. Since the CENTURY model was being used for assessing the carbon sequestration potential of agroecosystems in the study region, field testing of the model (with the new crops) within the study region was necessary. Furthermore, the field testing could be used as a tool in estimating the model performance, particularly, in simulating the soil organic matter dynamics under various cropland and management conditions. In other words, the model testing and validation will help evaluate the accuracy of the assessment of carbon sequestration potential of agricultural lands based on the model predictions. Hence, two sites were chosen for field testing of the model: a continuous corn site with rye cover crop in Lexington, KY, and a wheat fallow rotation site in Sydney, NE (discussed in Appendix A).

The detailed information about the Lexington field experiments was provided by Drs. Keith Paustian, Robert Blevins and Wilbur Frye. Dr. Blevins clarified many doubts about the field experiments. Dr. Paustian provided valuable suggestions and greater insight into the model application during the study. Their indispensable help is gratefully acknowledged. The pioneers in the CENTURY model development, Drs. William Parton and Vernon Cole, and Dr. Alister Metherell offered many helpful suggestions.

The CENTURY model and its site data requirements are discussed in Section B.2. The Lexington, KY site and field experiments are then discussed briefly in Section B.3. Section B.4

presents the application of the CENTURY model to the site; results and discussions, and recommendations and conclusions are discussed in Sections B.5 and B.6, respectively.

B.2 CENTURY MODEL OVERVIEW

The CENTURY model simulates the dynamics of C, N, P and S in cultivated and grassland soils using a monthly time step for model simulations. The model is composed of five organic matter pools, two of which represent litter or crop residues and the remaining three representing soil organic matter. The fresh organic matter, which includes plant material and animal manure, is divided into metabolic and structural litter fractions, depending on its lignin:nitrogen ratio. The soil organic matter is divided into three fractions: 1) an "active" fraction that has a rapid turnover rate and consists of microbial biomass and metabolites, 2) a "slow" fraction with an intermediate turnover time that represents stabilized decomposition products, and 3) a "passive" fraction that represents the highly stabilized, recalcitrant organic matter.

In the model, soil moisture is calculated as a function of the ratio of monthly precipitation to monthly evapotranspiration, the soil temperature term is calculated as a function of average monthly soil temperature at the soil surface. First-order rate constants depending on soil temperature and moisture are used to represent the decomposition rates. The other factors that affect the organic matter transformation include soil texture and the lignin content of the litter. The soil texture influences the relative amount of decomposing organic matter that is either mineralized to CO_2 or enters the slow pool as decomposition products. The lignin content of the litter pool influences the relative amount of the structural material that is assimilated by microorganisms (transferred to active pool) or gets incorporated into the slow pool.

B.2.1 C and N cycles In CENTURY

The carbon cycle is depicted in Figure B.1, and Figure B.2 shows the nitrogen cycle. The carbon that is released due to decomposition gets partly mineralized and the remaining gets added as decomposition product to one or more organic matter pools. The carbon flow dictates the release of nitrogen as nitrogen is considered to be mainly in C-bonded forms (organic N). The C:N ratios of materials entering the soil organic pools are used to calculate the mineralization and immobilization of N. The model allows the representation of C:N ratios of the material entering the organic pool to be constant or to vary at specified time intervals. If the N content of decomposition products entering a given pool is less than the minimum required for the recipient pool, then mineral N is immobilized, and conversely if organic N content is in excess, then that amount is mineralized. The model uses simple equations to represent N inputs by atmospheric deposition and through plant and soil fixation. The losses of N forms represented include leaching, gaseous losses, crop removal, and erosion.

The CENTURY model has submodels for estimating plant growth and soil water balance. These submodels provide information on plant litter inputs and climatic variables for soil organic

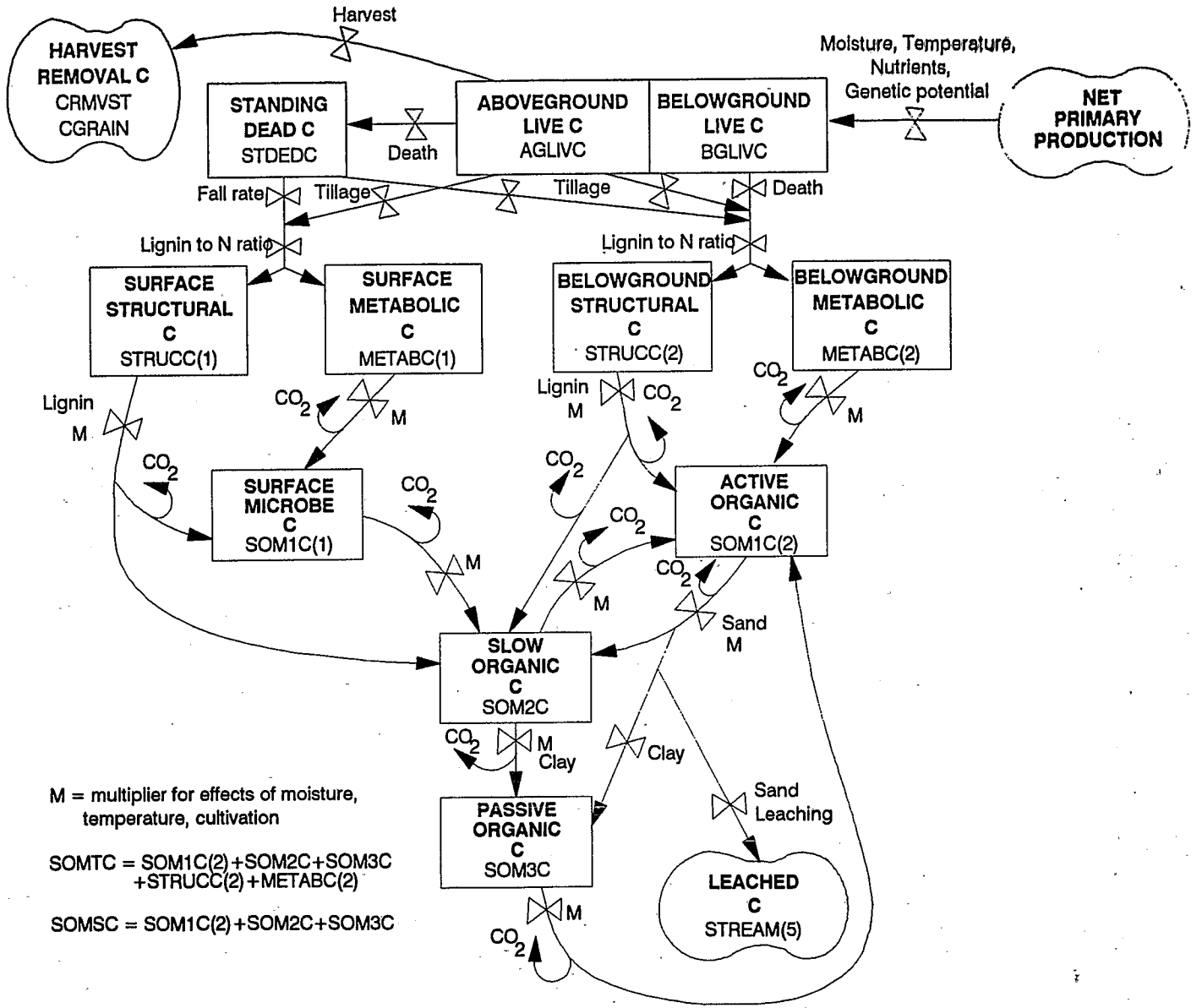


Figure B.1. Flow Diagram for the Soil Organic C Submodel (Parton et al., 1988)

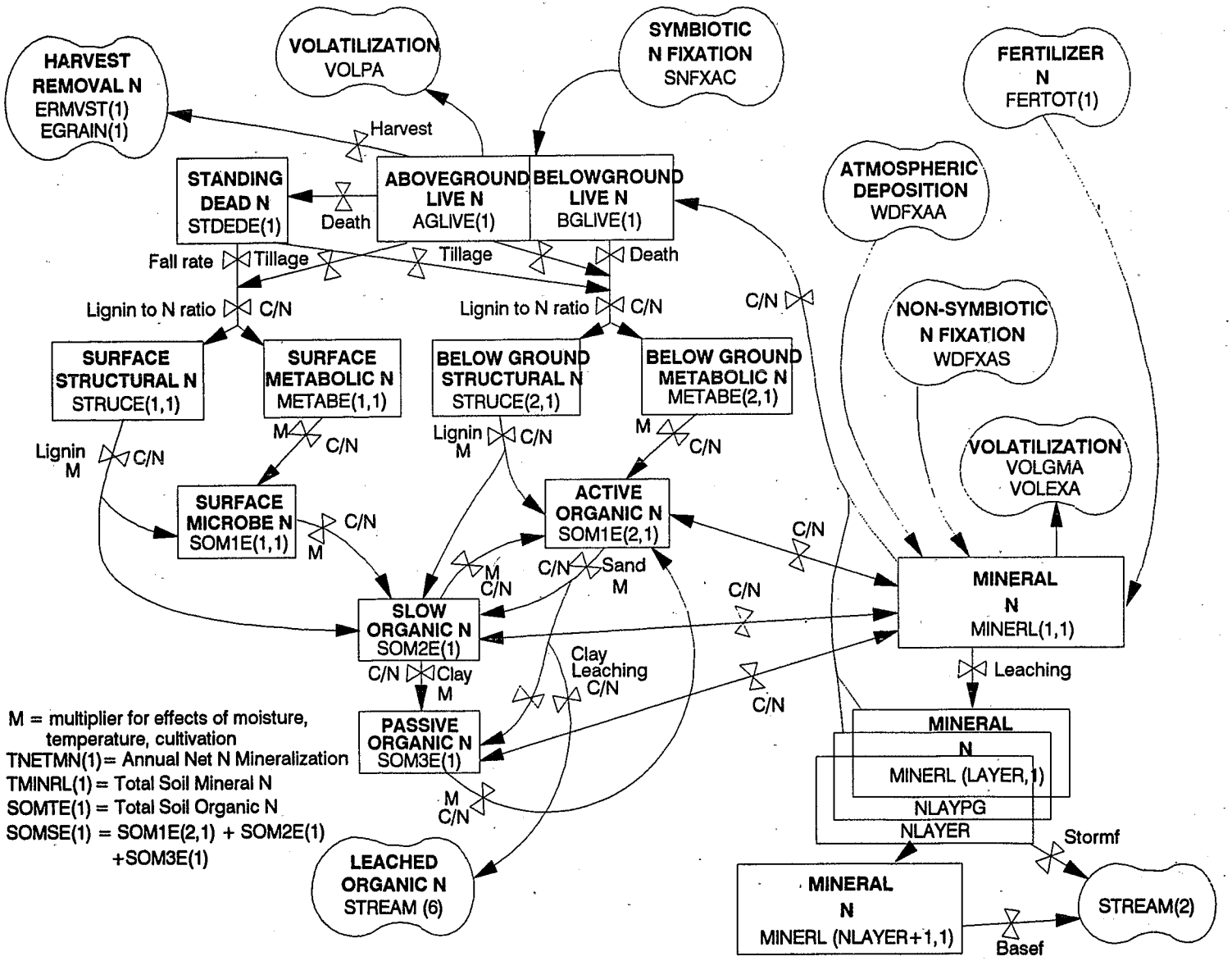


Figure B.2. Structure and State Variables for the N Submodel (Parton et al., 1988)

matter computations. Plant growth is expressed as a function of the growing season precipitation. The potential plant growth rate is used to calculate the crop nutrient demand. If nutrient availability is insufficient then the crop production is reduced based on the nutrient availability. The soil water content is calculated as a function of the ratio of monthly precipitation to monthly potential evapotranspiration.

Paustian et al. (1992) have applied the model to study the influence of organic amendments and N-fertilization on soil organic matter. Schimel et al. (1990) employed the CENTURY model to study grassland biogeochemistry and its link to the atmospheric processes. Burke et al. (1990) used CENTURY coupled with a geographic information system to study the spatial variability in storage and fluxes of C and N within grassland ecosystems. The model has also been used by Cole et al. (1989) to study the effects of soil organic matter dynamics in the North American Great Plains. Parton et al. (1989) applied the CENTURY model to simulate the regional patterns of soil C, N, and P dynamics in the U.S. central grasslands.

The CENTURY model has been validated by Parton et al. (1987) by simulating steady state C and N levels and aboveground plant production for 24 sites in the Great Plains. The simulation results were compared with mapped plant production and soil C and N levels for fine, medium, and sandy textured soils. The authors found that the model overestimated the C and N soil levels for fine textured soils, underestimated for sandy soils, and did an excellent job for medium textured soils. The effect of soil texture and climate on the soil C and N levels in the Great Plains was adequately represented by the model. The model results of aboveground plant production were in excellent agreement with the observed values.

B.2.2 Application of CENTURY model to Lexington Site

The application of the CENTURY model in this study was limited to the simulation of carbon and nitrogen dynamics in the soil profile. The crops that were simulated include corn and a winter cover crop of wheat; although rye was the winter cover crop at Lexington, it is not currently represented in the model. The application of CENTURY model consisted of simulating grassland conditions and the actual field experiments. The grassland conditions were simulated to achieve similar initial conditions for model inputs as represented by field measurements of soil organic carbon taken in 1970 at the beginning of the field experiment.

B.2.3 Data Requirements

The nutrient inputs along with organic matter (C and N) are estimated from equilibrium or steady state simulations performed for a period of 5000 years. The steady state conditions are achieved by simulating historic ecological conditions at the site and the initial organic matter and nutrient pools are estimated using regression equations developed by Burke et al. (1990). The following is a list of site-specific data requirements for the application of CENTURY to a particular field site:

Soils:	% sand, % silt, % clay Bulk density, pH Number of soil layers Drainage characteristics of soils Expected baseflow and stormflow fractions
Meteorological:	Monthly precipitation Monthly maximum temperature Monthly minimum temperature
Crops:	Crops grown Planting and harvesting months Timing of tillage and cultivation operations Timing and rate of fertilizer applications

B.3 LEXINGTON FIELD EXPERIMENTS

In the following sections, the Lexington site, the field experiments and the available data that are necessary for testing and validation of CENTURY model are described in detail.

B.3.1 Lexington Site Description

A field experiment was initiated in the spring of 1970 (Blevins et al., 1977, 1983a) at the Kentucky Agricultural Experiment Station Farm in Lexington. The soil type at the site was Maury silt loam which is classified as Typic Paleudalf (fine, mixed, mesic) with a 1 to 3% slope. The Maury soil is deep, well-drained and originated in residuum of phosphatic limestone.

The experimental area occupies a broad ridgetop that has been under bluegrass pasture for approximately 50 years before the start of the experiment (Blevins 1992, personal communication). The management practices on the pasture area consisted of low intensity grazing with cattle and horses, and occasional mowing. The ecosystem was altered from the permanent bluegrass pasture to continuous corn production in April 1970.

B.3.2 Field Experiment

The objective of the experiment was to study what effects the conventional and no-till systems have on chemical and physical properties of soils. The experimental design consisted of split-block design with four replications. The experimental area (46.1 x 48.4 m^2) was divided laterally into four strip blocks receiving four levels of ammonium nitrate fertilizer (0, 84, 168, and 336 kgN/ha), which was applied randomly at planting time to quarters split vertically within each block. The block was further split laterally, with conventional tillage and no-tillage randomly assigned across the entire block.

The plots under conventional tillage system were plowed in late April, about 1 to 2 weeks before corn plantation. The tillage implements consisted of a four bottom, 16 inch trailing moldboard plow. The depth of plowing was 15 to 18 cm. A tandem disk harrow was used for performing secondary tillage operation to depth of 10 cm. Corn was planted in May, and rye was broadcast on all plots in mid September, 2 weeks prior to harvesting corn, so as to produce a cover crop and additional mulch. In the beginning of 1985 half of the plots were seeded to rye and other half to hairy vetch. No cultivation practices were used for weed control, and no irrigation practices were followed.

The plots under no-till system were sprayed with herbicide in late April before planting corn. Corn was usually planted in May using No-till drill and rye was broadcast on all plots in mid-September, two weeks prior to harvesting corn in order to produce a cover crop and additional mulch. Table B.1 lists the management schedule at the site.

B.3.3 Available data

Following is a description of the type of data that was available to perform the CENTURY simulations:

Meteorologic Data:

The meteorologic data for the period of 1978-1991 was taken at the site. Data for the time periods of 1970-1989 is available at Lexington Airport which is approximately 4 miles west of the site. The data from the airport was used for CENTURY simulations.

Soils Data:

The following data was available at the beginning of the experiment in 1970 for the untreated plots

Depth cm	Sand %	Silt %	Clay %	Bulk Density g/cm^3	Organic C g/m^2
0-5	7.1	69.9	23.0	1.27	2419.35
5-15	7.1	69.9	23.0	1.28	2214.40
15-30	5.3	70.2	24.5	--	1728.00

Atmospheric Deposition:

NADP (National Atmospheric Deposition Program) wet deposition data either on a seasonal basis (summer, fall, winter, and

Table B.1. Management History at the Long-term Continuous Corn-Tillage Study at Lexington, KY (Blevins 1992, unpublished data)

Year	Corn Plant date	Corn harvest date	Corn Variety	Seed rate per ac	Amount(date) cover crop overseeded	Fertilizer K_2O lb/ac
1970	5/6	9/15	SX-29	25,000	Rye[1]	50
1971	5/10	9/28	Pioneer 3369A	18,000	Rye	
1972	5/17	9/28	Pioneer 3369A	22,500	Rye	
1973	5/17	9/27	Pioneer 3369A	22,500	Rye	
1974	5/17	9/27	Pioneer 3369A	22,500	Rye	
1975	5/23	9/30	Pioneer 3369A	22,500	Rye	
1976	5/24	10/1	Pioneer 3369A	22,500	Rye	
1977	5/20	9/29	Pioneer 3369A	22,500	Rye(9/20)	175
1978	5/18	9/21	Pioneer 3369A	22,500	Rye	175
1979	5/17	9/9	Pioneer 3369A	22,500	Rye	100
1980	5/15	9/25	Pioneer 3369A	22,500	Rye	100
1981	5/21	10/2	Pioneer 3369A	22,500	Rye	100
1982	5/13	9/24	Pioneer 3369A	22,500	Rye	100
1983	5/23	9/15[2]	B73xPA91	22,500	Rye	100
1984	5/17	9/26	B73xPA91	22,500	Rye	100
1985	4/30	9/20	B73xPA91	22,500	Rye+H.V.[3] (9/8)	100
1986	5/13	9/25	B73xPA91	22,500	Rye+H.V. (9/10)	100
1987	5/7	9/28	B73xPA91	22,500	Rye+H.V. (9/14)	100
1988	5/20	10/5	B73xPA91	22,500	Rye+H.V. (9/15)	100
1989	5/11	10/3	Pioneer 3165	22,500	Rye+H.V. (9/14)	100
1990	5/14	10/5	Pioneer 3165	22,500	Rye+H.V. (9/25)	100
1991	5/8	9/18	Pioneer 3165	22,500	Rye+H.V. (9/12)	100

1 Rye seeded at 2 bu/ac
2 For silage only
3 Hairy vetch overseeded at 30 lb/ac

spring) or an annual basis is available for the period of 1984 -1991. There are a total of four sites in Kentucky where data is collected. These sites, Lilley Cornett Woods, Clark State Fish Hatchery, Mackville and Land between Lakes are located approximately 100 miles south east, 100 miles north east, 25 miles west and 200 miles south west of Lexington, respectively. Based on the observed data, a constant atmospheric deposition of 0.6 $gN/m^2/yr$ was used in the model.

Crop and Nutrient Data:

The observed data available for the conventional and no till experiments conducted at the Lexington field sites is listed in Tables B.2 and B.3. The observed data of corn grain yields in Mg/ha for four fertilizer application rates representing the period of 1970-1991 is listed in Table B.2, note that there is no yield data for 1983 which was reported to be a drought year. Table B.3 lists organic carbon and organic nitrogen measurements taken at three depths (0-5 cm, 5-15 cm, and 15-30 cm) in the year 1975 and 1989 for the four fertilizer application rates. Observed soil organic matter content for the depths of 0-5 cm and 5-15 cm in 1975 and 1980 (Blevins et al., 1983a) is listed in Table B.4.

B.4 CENTURY MODEL APPLICATION

The CENTURY model was used to simulate the historic grassland conditions and then the long-term continuous corn-tillage experiments. The simulation of grassland conditions provided initial values for various organic matter pools that were in good agreement with the field data measured at the beginning of the experiment in 1970.

B.4.1 Simulation of Grassland Conditions and Analysis

As described in Section B.3, the native vegetation in the experimental area was mostly bluegrass pasture for about 50 years before the start of the experiment in 1970. The following assumptions were made regarding the past site conditions.

a. The site was under grassland conditions.
b. The period between April and October was the growing season for grass and November was the senescence month.
c. Grazing events occurred throughout the year with winter grazing during winter months of November, December, and January through March. We assumed that during winter grazing, 15 and 7% of the live and standing-dead biomass, respectively, were removed. For the remaining months, grazing events occured with 25 and 3% removal of the live

Table B.2. Corn Grain Yields in Mg/ha from Lexington, KY, site (Paustian, 1992, Personal Communication).

	Conventional Tillage Fertilizer Rates (kgN/ha)				No-Till Fertilizer Rates (kgN/ha)			
Year	0	84	168	336	0	84	168	338
1970	5.71	5.64	5.64	5.64	5.64	6.21	6.21	6.59
1971	9.47	11.29	9.97	10.16	6.21	10.41	10.66	10.85
1972	8.15	10.10	9.97	10.35	7.40	9.60	9.35	9.72
1973	4.14	7.71	8.09	8.47	4.14	7.46	7.9	7.59
1974	8.09	10.16	10.22	10.16	5.58	9.66	10.35	10.47
1975	4.89	5.02	5.14	6.02	3.76	6.08	6.27	6.65
1976	5.33	8.09	8.84	8.84	4.33	9.03	9.78	10.66
1977	5.52	7.71	7.97	8.28	3.64	6.65	6.84	7.21
1978	4.2	6.27	6.08	6.27	2.07	4.89	5.33	6.21
1979	4.26	8.15	7.78	7.71	4.58	7.4	7.71	7.59
1980	5.96	7.9	8.08	8.84	3.64	7.09	8.53	7.84
1981	4.95	6.96	7.78	8.97	4.95	7.34	9.03	9.41
1982	3.32	5.52	6.08	6.27	3.14	4.14	5.96	5.77
1984	3.45	4.64	5.39	5.02	3.76	5.77	6.9	5.9
1985	1.88	5.71	6.08	7.46	3.14	5.33	6.9	8.03
1986	2.63	4.01	4.2	4.2	3.14	4.33	4.89	5.21
1987	2.82	4.89	4.95	5.39	3.07	5.14	6.15	5.33
1988	3.32	4.08	3.64	3.51	3.26	4.33	4.89	5.21
1989	4.2	6.96	8.03	7.53	6.08	8.53	8.66	9.35
1990	3.2	5.46	8.34	7.34	4.33	5.96	7.65	6.08
1991	1.51	5.52	6.9	7.21	3.32	6.65	8.66	8.72

Table B.3. Observed Organic C and N data for Lexington, KY Site (Paustian, 1992, Personal Communication)

		Org-C g/kg			Org-N g/kg		
		0-5cm	5-15cm	15-30cm	0-5cm	5-15cm	15-30cm
Conventional Tillage Fertilizer Rates							
1975 Data							
0	kgN/ha	13.70	12.90	6.80	1.60	1.50	0.80
84	kgN/ha	15.10	14.70	9.10	1.60	1.40	1.00
168	kgN/ha	16.20	15.10	8.50	1.70	1.60	1.00
336	kgN/ha	16.80	14.60	7.90	1.60	1.50	1.00
1989 Data							
0	kgN/ha	19.20	20.70	9.50			
84	kgN/ha	20.30	21.30	12.10			
168	kgN/ha	19.60	23.10	11.20			
336	kgN/ha	21.90	24.30	12.40			
No-Till							
1975 Data							
0	kgN/ha	21.30	12.90	7.90	2.10	1.30	1.00
84	kgN/ha	23.00	13.20	7.90	2.20	1.30	1.10
168	kgN/ha	23.80	12.50	7.20	2.20	1.40	1.10
336	kgN/ha	26.30	14.30	8.40	2.50	1.50	1.10
1989 Data							
0	kgN/ha	32.80	20.80	8.90			
84	kgN/ha	39.50	22.60	9.00			
168	kgN/ha	34.30	22.20	8.70			
336	kgN/ha	43.20	23.40	10.70			

Table B.4. Soil Organic Matter Content (adapted from Blevins et al., 1983a)

N-Rate kg/ha	Untreated Sod Plots	Organic Matter Content % 1975 NT	1975 CT	1980 NT	1980 CT
			0-5 cm		
0	5.18	3.68	2.37	3.70	2.16
84	-	3.96	2.60	5.08	2.41
168	-	4.11	2.78	4.82	2.40
336	-	4.53	2.79	5.05	2.52
			5-15 cm		
0	2.47	2.22	2.23	1.88	2.38
84	-	2.28	2.53	2.21	2.40
168	-	2.15	2.60	2.34	2.31
336	-	2.46	2.52	1.98	2.57

and dead biomass, respectively.

d. A fire event occurred once every ten years in July. The fire intensity was assumed to be moderate.

An input (scheduler) file containing the above assumptions was setup and the model was run for a period of 5000 years using the option for stochastic generation of climate data in the model. The initial soil carbon levels in the various pools at the beginning of the historic run were established using the IVAUTO option in the CENTURY model. The IVAUTO option allows the user to estimate the beginning SOC conditions based on regression models developed by Burke et al., (1989) that estimate SOC as a function of soil texture and regional climate.

The analysis consisted of simulating the dynamics of carbon and nitrogen. The state variables such as total soil organic carbon and nitrogen from this run were then compared with the field data observed in 1970. The model under estimated the total soil organic carbon approximately by 4% and over estimated total soil organic nitrogen by 23%. The fact that the model-simulated organic nitrogen value is much higher than the observed value raised a question about the validity of the observed value corresponding to 1970. Therefore, an approximate organic nitrogen value for 1970 was estimated using the C/N corresponding to 1975. It is based on the fact that the C:N ratio does not vary much over a short period (Metherell, 1992, personal communications). The difference between the estimated organic nitrogen value (1970) and model simulated value was negligible (0.04%). Since the difference between the model estimation and the field observation (1970) was minimal, the conditions simulated by the model (at the end of 5000 yr) were used as the initial conditions for the simulation of tillage experiments.

B.4.2 Simulation of Tillage Experiments

The conventional tillage and no-till experiments conducted at the site between 1970 and 1991 were simulated using the CENTURY model. For each tillage type, the model was run with four input scenarios consisting of four fertilizer application rates (0, 84, 168, 336 kg N/ha). The scheduling of events in the simulation of experiments are presented in Tables B.5 and B.6. The following simulated variables were analyzed and compared with the available observed data:

a. Grain Yield
b. Soil Organic Carbon and Nitrogen
c. Concentration of N in Grain
d. Nitrogen uptake by plants
e. Available water in the soil.
f. Net carbon input into the soil

Initially, the simulation runs indicated that there was a considerable difference between the predicted values and observed data. For instance, the simulated organic carbon values for the three fertilizer rates, 84, 168, and 336 kg/ha, increased from the beginning of the simulation which was in contrast to the field data. This suggested the need for a reexamination of the

Table B.5. Schedule of Crops and Various Operations for the Simulation of CT Experiments.

Month	1970	Crop(s) 1971-91	Fertilizer Rate kg/ha	Tillage/Harvest Operation
Jan	Grass	Wheat	0	Winter grazing in 1970
Feb	Grass	Wheat	0	Winter grazing in 1970
Mar	Grass	Wheat	0	Winter grazing in 1970
April	Grass	Wheat	0	Plowed in
May	Corn	Corn	a	Cultivator used for planting
June	Corn	Corn	0	-
July	Corn	Corn	0	-
Aug	Corn	Corn	0	-
Sep	Corn	Corn	0	Harvested
Oct	Wheat	Wheat	0	No-Till Drill used for planting
Nov	Wheat	Wheat	0	-
Dec	Wheat	Wheat	0	-

Table B.6. Schedule of Crops and Various Operations for the Simulation of NT Experiments.

Month	1970	Crop(s) 1971-91	Fertilizer Rate kg/ha	Tillage/Harvest Operation
Jan	Grass	Wheat	0	Winter grazing in 1970
Feb	Grass	Wheat	0	Winter grazing in 1970
Mar	Grass	Wheat	0	Winter grazing in 1970
April	Grass	Wheat	0	Herbicide used for killing
May	Corn	Corn	a	No-Till Drill used for planting
June	Corn	Corn	0	-
July	Corn	Corn	0	-
Aug	Corn	Corn	0	-
Sep	Corn	Corn	0	Harvested
Oct	Wheat	Wheat	0	No-Till Drill used for planting
Nov	Wheat	Wheat	0	-
Dec	Wheat	Wheat	0	-

a - N fertilizer rates of 0, 84, 168, 336 kg/ha were used in four experiments.

default parameterization of the rate constants. Further, the net carbon input into the soil for the highest fertilizer rate was very high (900-1000 gC/m^2). An approximate estimation, assuming a harvest index of about 50%, indicated that the residue input rate for a maximum yield of about 10 Mg/ha would be about 450-650 gC/m^2. As a result, the crop production parameter (PRDX) for corn was reduced from 500 to 450 and maximum harvest index (HIMAX) was set to 0.53.

In addition, the slow pool decomposition rate constant was doubled and set to 0.4.
In the site specific file, the initial amounts of the litter (active) pool and slow pool from the equilibrium analysis appeared to be low and high, respectively. The initial C in the active pool was doubled and the C in the slow pool was decreased by the corresponding amount (Paustian, 1992, Personal Communication). The crop\tillage\management scenarios were simulated with these changes.

B.5. RESULTS AND DISCUSSION

In the following subsections the results obtained from the simulation analysis are presented and discussed.

B.5.1. Conventional Tillage Experiments

Corn Grain Production

The crop production parameters (crop production and harvest index) were calibrated to observed crop yields under the conventional tillage system, for the highest fertilizer application rate of 336 kg N ha^{-1}. These parameters were then used for both conventional tillage and no-till and for all the four fertilizer application rates. This approach was adopted to maintain consistency between tillage levels and to approximate the nitrogen stress induced at the lower nitrogen fertilizer applications. This procedure resulted in generally good agreement between the observed and simulated crop yields for most of the tillage and fertilizer treatments.

For all the N fertilizer rates, the model over estimated the average grain yield by approximately 6 to 10% (Table A.7). The simulated grain yields increased with the increasing N fertilizer rates as expected. Further, the variations in the annual yield values corresponding to low fertilizer rates (0 and 84 kg/ha) appeared to be maximum (Figure B.3) where as their counterparts at high fertilizer rates were minimum. These variations in the annual corn yield suggest that corn production was limited by nitrogen availability for crop growth. At higher fertilization levels, corn production was not limited by nitrogen availability. However, it may have been limited by the maximum crop production parameter as specified in the crop input file.

Soil Organic Carbon and Nitrogen

Simulated soil organic carbon (SOC) was compared with the observed data (Figure B.4). In general, the simulated carbon values for all the fertilizer rates followed the trend of the observed carbon values. However, the simulated carbon values corresponding to low fertilizer rates were

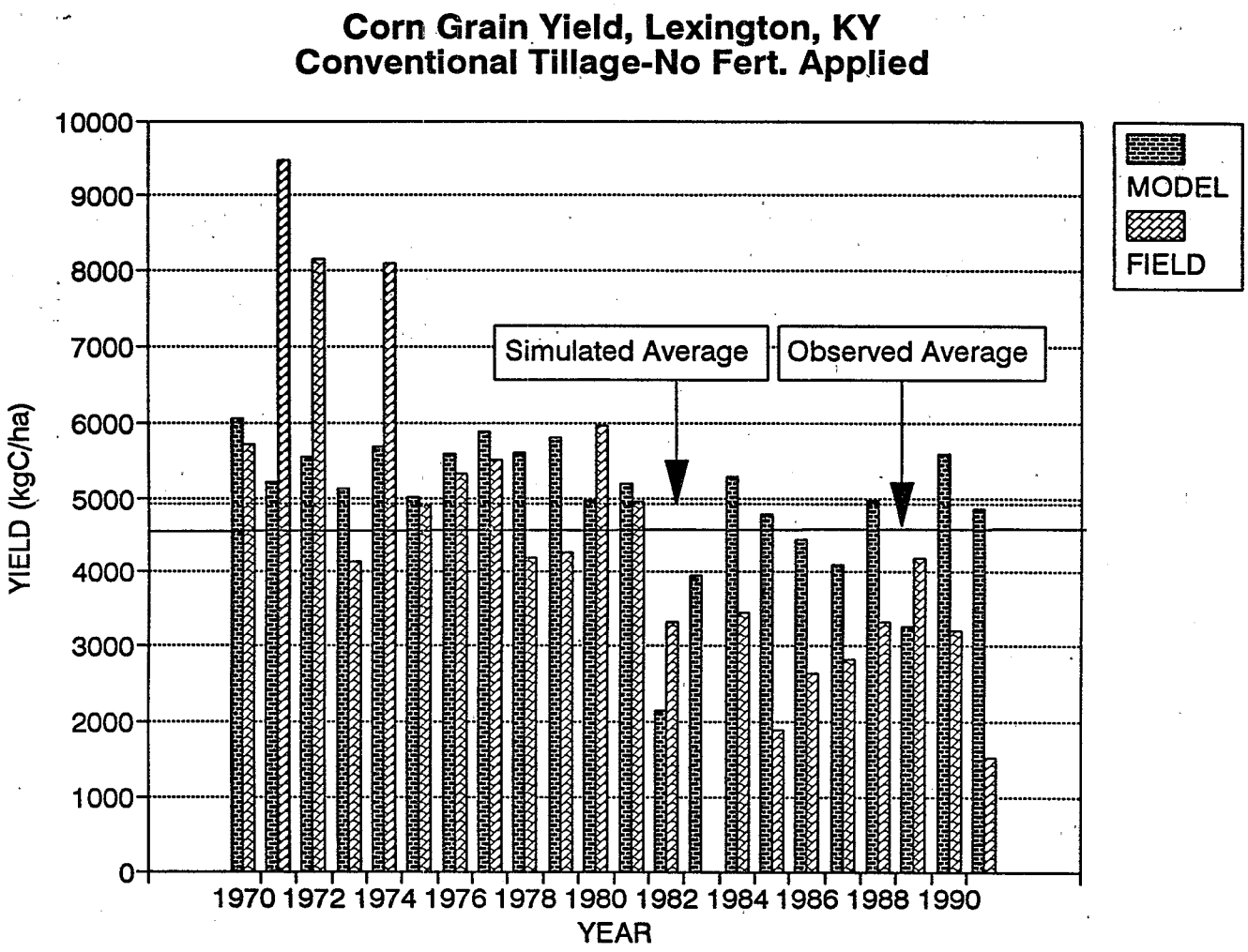


Figure B.3. Simulated Versus Actual Grain Yields for Conventional Tillage Treatment Without Fertilizer Addition.

Table B.7. Simulated and Observed Average Corn Yields (kg ha^{-1}, 21-year average, 1970-91)

Fertilizer Rates	Simulated Average	Simulated S.D.[1]	Observed Average	Observed S.D.[1]	% Difference Average	% Difference S.D.[1]
Conventional Tillage						
0	4947	924	4619	2004	9.2	35.0
84	7156	679	6752	1991	6.7	27.3
168	7780	699	7103	1856	9.3	24.9
336	7803	714	7316	1891	7.1	24.4
No-Till						
0	5306	979	4247	1279	19.9	26.3
84	6900	744	6762	1808	2.9	26.6
168	6953	782	7553	1688	-8.1	26.8
336	6962	783	7638	1820	-8.8	27.5

[1] - S.D. stands for Standard Deviation
Note: -ve Sign indicates under estimation

more in line with the observed data than those at the higher rates, indicating that CENTURY has a greater SOC response for higher fertilization levels. Nearly identical carbon inputs were simulated for the fertilization levels of 168 and 336 kg N ha^{-1} resulting in identical SOC for these two fertilizer rates.

Soil organic carbon values were greater with increasing N fertilizer rates. This is probably due to the fact that an increase in N fertilizer rate increases the crop production which in turn increases the surface residue after harvest. Incorporation of this residue into the soil results in increasing the soil organic matter. Blevins et al. (1977) reported similar observations in their conventional tillage experiments. Organic carbon corresponding to all the fertilizer rates indicated a net SOC loss at the end of the simulation compared to the original pasture soil, with the minimum loss for the highest fertilizer application and vice versa.

A decrease in soil organic matter is generally found when grassland or permanent pasture is cultivated (Allison, 1973). Plowing may increase decomposition rates in the disturbed plow layer and conversion of grassland to annual crops may also result in lower net carbon inputs of carbon to soil due to the export of organic matter in the harvested products. In simulations of

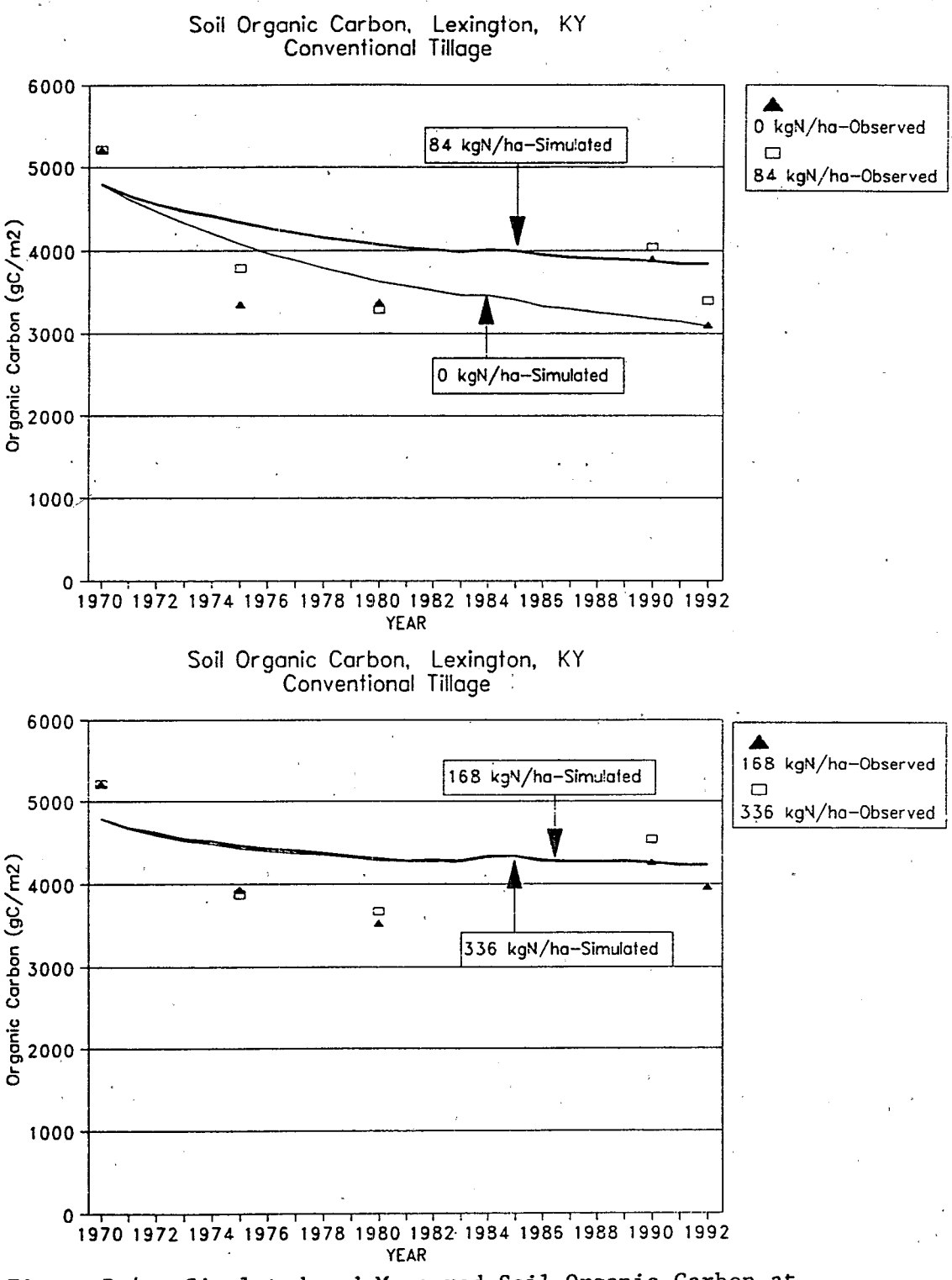


Figure B.4. Simulated and Measured Soil Organic Carbon at Different Nitrogen Fertilizer Additions.

long-term field experiments in Sweden, Paustian et al. (1992) also reported that simulated and measured SOM decreased in treatments receiving only crop residues as carbon inputs. Also, Blevins et al. (1983b) reported a similar observation at the end of a 10-year field (Lexington) experiment. The net SOC loss could be due to the fact that plowing increases the oxidation of the organic matter at least in the top 20 cm. This increased oxidation could increase the decomposition rate of the organic matter which in turn decreases the SOC.

For the three fertilizer N rates, 84, 168 and 336 kg/ha, the model over-estimated the carbon values at the end of the simulation by 5 to 10%. Error bars associated with the observed data, if available, would be useful in evaluating the model results more accurately.

Simulated soil organic nitrogen was compared with the observed data (Figure B.5). The organic N followed the trend of the observed data for the non fertilizer case. For the other three fertilizer rates, 84, 168 and 336 kg/ha, the organic N increased with increasing N fertilizer rates. It should be noted that the organic N data for 1990 and 1992 were not reported by the researchers at the Lexington field experiment station; these data points would be useful, if they were measured and available, in evaluating the model performance. In other words, additional field data will be useful in better establishing the trend of the observed organic N in the field and thereby provide a better basis for assessing the model predictions.

Grain Nitrogen Concentration and N Uptake by Plants

Simulated grain nitrogen concentration compared well with the observed data for the year 1980 (Figure B.6). On the other hand, they were not in good agreement for the year 1981. In comparison to literature reported range of 1.35 to 1.75 (Follet et al., 1991), the model under estimated the grain nitrogen concentrations for the low fertilizer rates. However, for the high fertilizer rates, 168 and 336 kg/ha, the model predictions were in the expected range.

The nitrogen uptake by plants increased with increasing N fertilizer rates (Figure B.6) with the highest uptake corresponding to the highest fertilizer rate. The average plant uptake for both tillage systems and for all fertilizer rates are presented in Table B.8. Typical corn plant N uptake as reported in the literature ranges from 135-168 kg N ha^{-1} (Tisdale et al., 1985). The observed plant N uptake was reported to be 100-160 kg N ha^{-1}. The model results compared well with the observed values for the N fertilizer rate of 84 kg/ha. For the N fertilizer rate of 168 kg/ha, the simulated value compared well with the observed value in 1980. However, the model under estimated the N uptake in the following year. The error bars associated with the observed N uptake by plants could be useful, if available, in validating the model results more accurately. Nevertheless, model's ability in predicting the N uptake by the plant (for conventional tillage) appears to be good. Paustian et al. (1992) reported similar observations.

Net Carbon Input into the Soil

The net carbon input into the soil increased with increasing N fertilizer rates (Table B.8). In comparison to the zero fertilizer case, the net carbon input increased approximately twice as

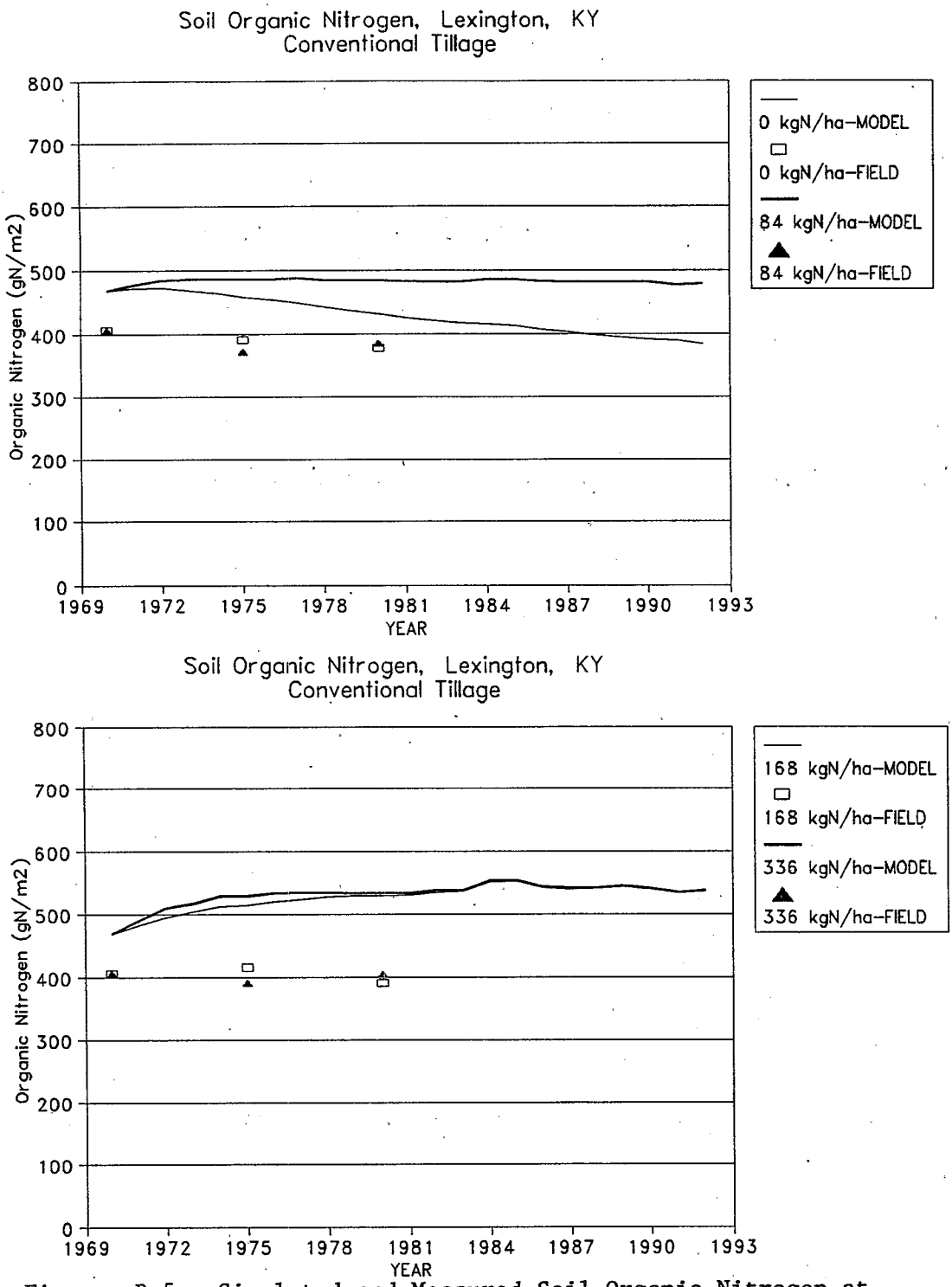
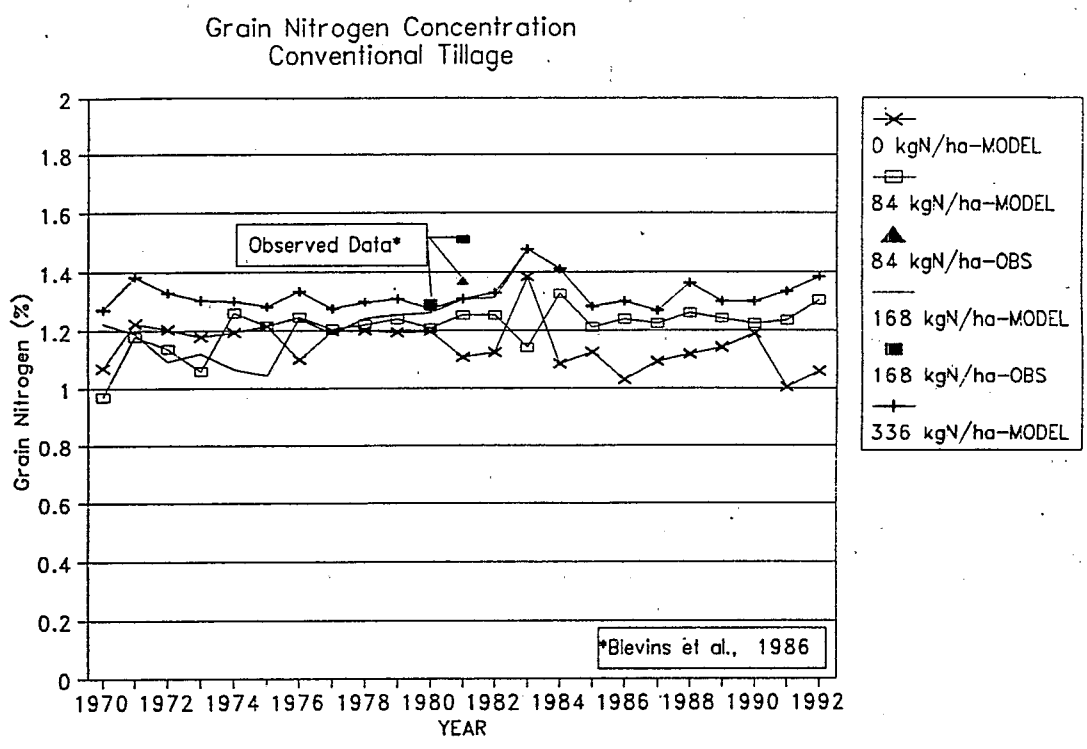


Figure B.5. Simulated and Measured Soil Organic Nitrogen at Different Nitrogen Fertilizer Additions.



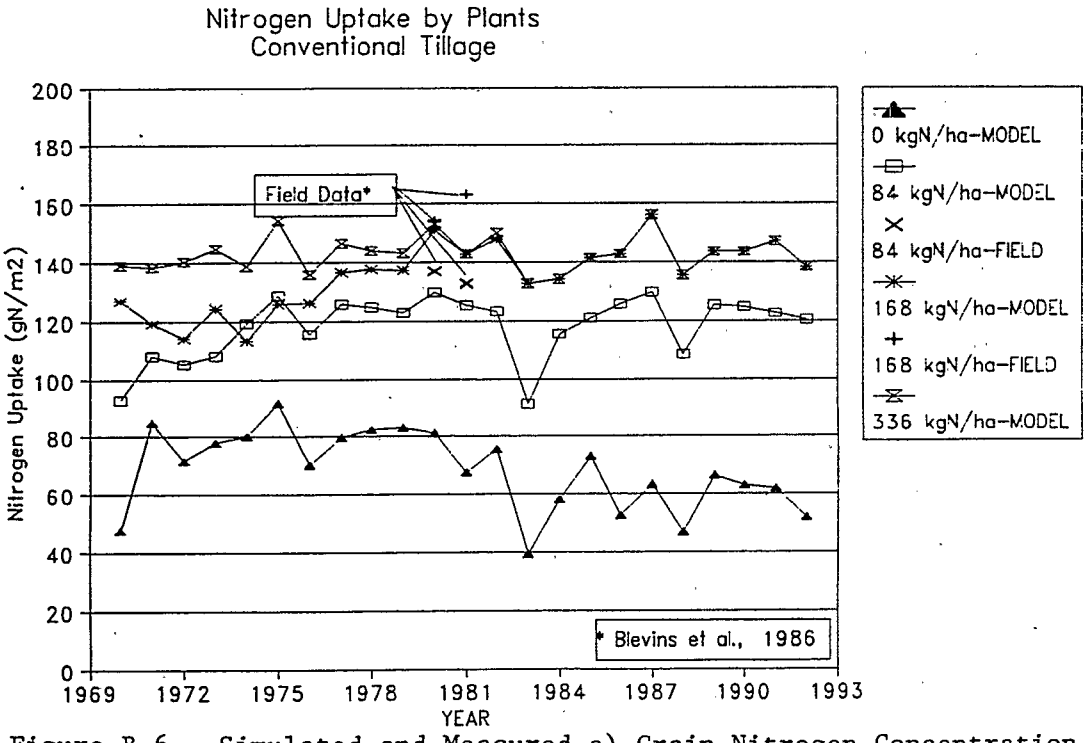


Figure B.6. Simulated and Measured a) Grain Nitrogen Concentration and b) Nitrogen Uptake by Plants, at Different Fertilizer Additions.

much for the other three N fertilizer rates. This is probably due to the fact that higher fertilizer rate results in higher crop growth which in turn results in higher crop residue after harvest. The incorporation of this residue into the soil results in higher carbon input into the soil. The maximum net carbon input corresponding to the highest fertilizer rate was in the range of 400-500 gC/m2, as expected.

Table B.8. Average Carbon Inputs and Plant Nitrogen Uptake, Predicted by CENTURY.

	Conventional Tillage		No-Till	
Fertilizer Rates kg N ha^{-1}	Carbon Inputs kg C ha^{-1}	Plant N Uptake kg N ha^{-1}	Carbon Inputs kg C ha^{-1}	Plant N Uptake kg N ha^{-1}
0	2570	68	2590	65
84	4100	118	3740	110
168	4680	136	3790	120
336	4710	143	3800	121

B.5.2 No-Till Experiments

Corn Grain Production

Simulated corn grain yields were compared with the observed data. The model over estimated the average grain yield by approximately 20% for the non fertilizer case (Table B.7). However, the model over estimated the average grain yield by approximately 2% for the N rate of 84 kg/ha. On the other hand, the average grain yields corresponding to the high fertilizer applications were under estimated by the model by approximately 10%. The simulated grain yields increased with increasing N fertilizer rates as observed. Additionally, there was significantly no difference between the average grain yields corresponding to the three fertilizer rates, 84, 168 and 336 kg/ha. As mentioned before, the crop production parameter limits the grain yields at high fertilizer rates (168 and 336 kg/ha).

Soil Organic Carbon and Nitrogen

Simulated soil organic carbon was compared with the observed data (Figure B.7). For the fertilizer rates, 0, 84 and 168 kg/ha, the simulated values appeared to follow the trend of the observed data. Also, the model predictions compared reasonably well with the observed data for 1980 and 1992. For the highest fertilizer rate, the simulated values neither followed the trend of the observed data nor compared well. Additionally, the observed data showed an increase in the organic C values from 1980.

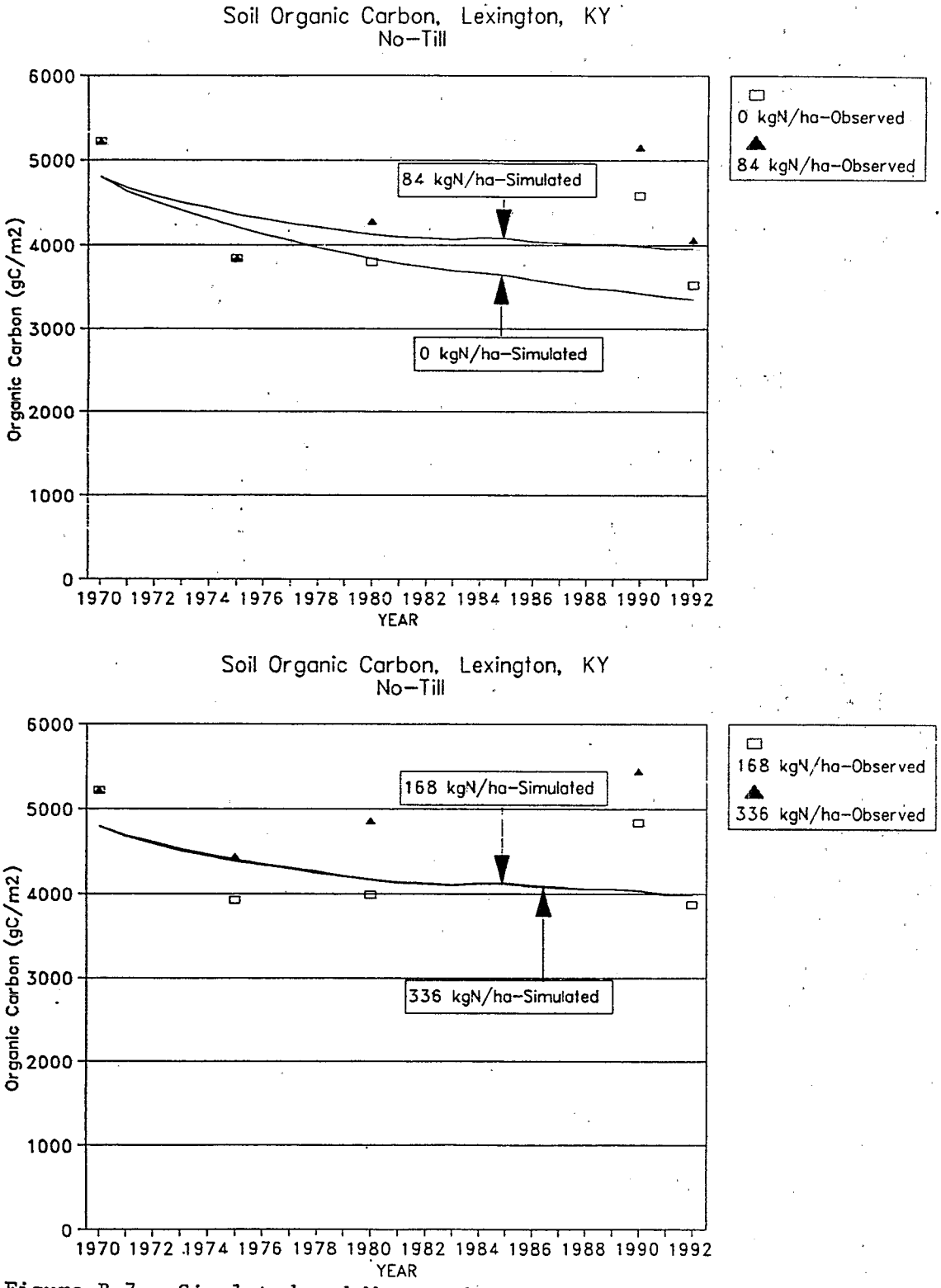


Figure B.7. Simulated and Measured Soil Organic Carbon at Different Nitrogen Fertilizer Additions.

Soil organic carbon levels corresponding to the three fertilizer rates were higher than those of the unfertilized treatment. However, there was not much difference between the simulated C values corresponding to the three fertilizer rates (84, 168 and 336 kg/ha). In fact, they appear to start stabilizing after 1980.

Simulations predicted a net loss in SOC levels for all the fertilizer rates compared to the original pasture soil. The observed data indicated the same except for the highest fertilizer rate where the data showed a net increase in SOC. Also, Blevins et al. (1983b) reported that under no-till system the organic C in the surface increased at the end of a 10-year field experiment. This suggests that the model could be modified to better represent the changes in the organic matter dynamics, especially for the no-till system, possibly by extending the model to a depth of 30 cm and addind a layered soil profile representation.

The comparison of simulated organic nitrogen with the observed data showed that the organic N did not compare well with the observed data for the three fertilizer rates (Figure B.8). However, the soil organic nitrogen increased with increasing N fertilizer rates as observed by Blevins et al. (1977). Also, fertilizer additions resulted in increasing the organic nitrogen approximately by 10% whereas zero fertilizer application resulted in 10% decrease. Paustian et al. (1992) reported similar observations in their CENTURY model application to Swedish field experiments.

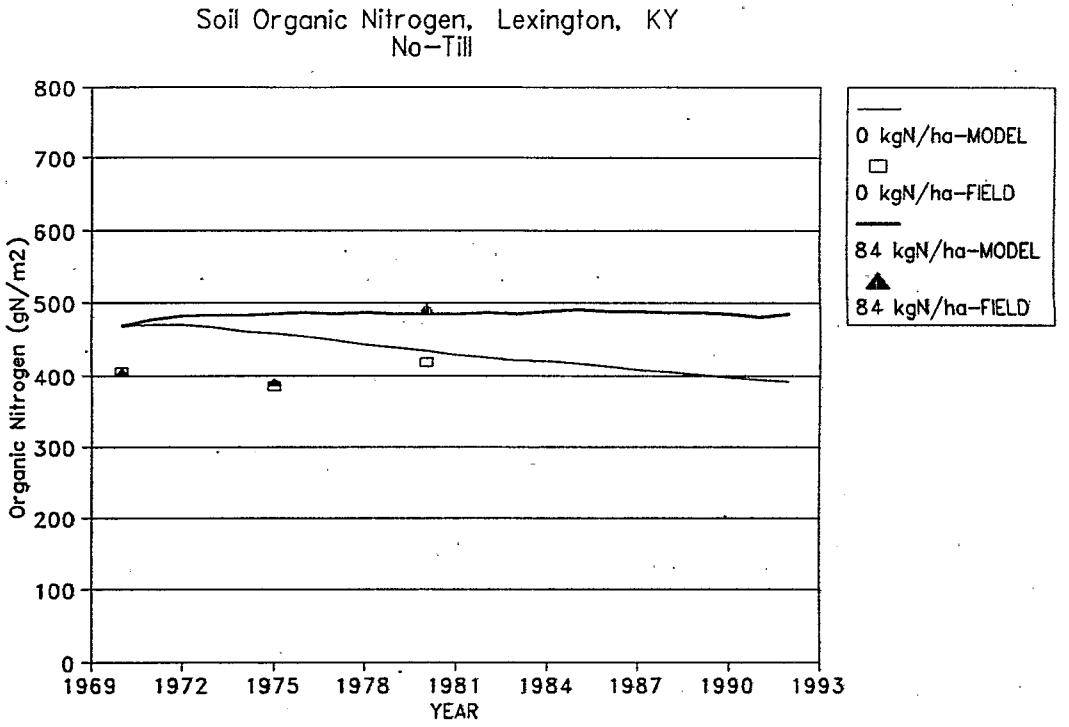
Grain Nitrogen Concentration and Nitrogen Uptake by Plants

Simulated grain nitrogen concentration compared reasonably well with the observed data (Figure B.9). The model simulated the lowest nitrogen concentrations for the unfertilized treatment as expected. Based on the literature reported values (Follet et al. 1991), the model predictions were in the range for the three fertilizer rates (84, 168, and 336 kg/ha).

The nitrogen uptake by plants increased with increasing N fertilizer rates (Figure B.9). The simulated values did not compare well with the observed data. In general, the model under estimated the nitrogen uptake by plants.

B.5.3 Comparison of Conventional Tillage and No-till Simulations

The simulated average grain yields corresponding to no-till were less than those of conventional tillage for all the fertilizer rates except for the non fertilizer case (Table B.7), which is due to the simulation of lower soil temperatures under the no-till system resulting in retarding crop germination and hence crop yield. This result was not evident for the non fertilizer case because the higher crop production parameters (crop production parameters of the highest fertilizer application which resulted in highest yield were used) offset the effect of soil temperature on crop germination. These predictions are in contrast to the field data. Blevins et al. (1986) reported that, at low N fertilizer rates, the 10-year average corn yield was higher for conventional tillage than for no-till. However, at moderate to high rates of N fertilization,



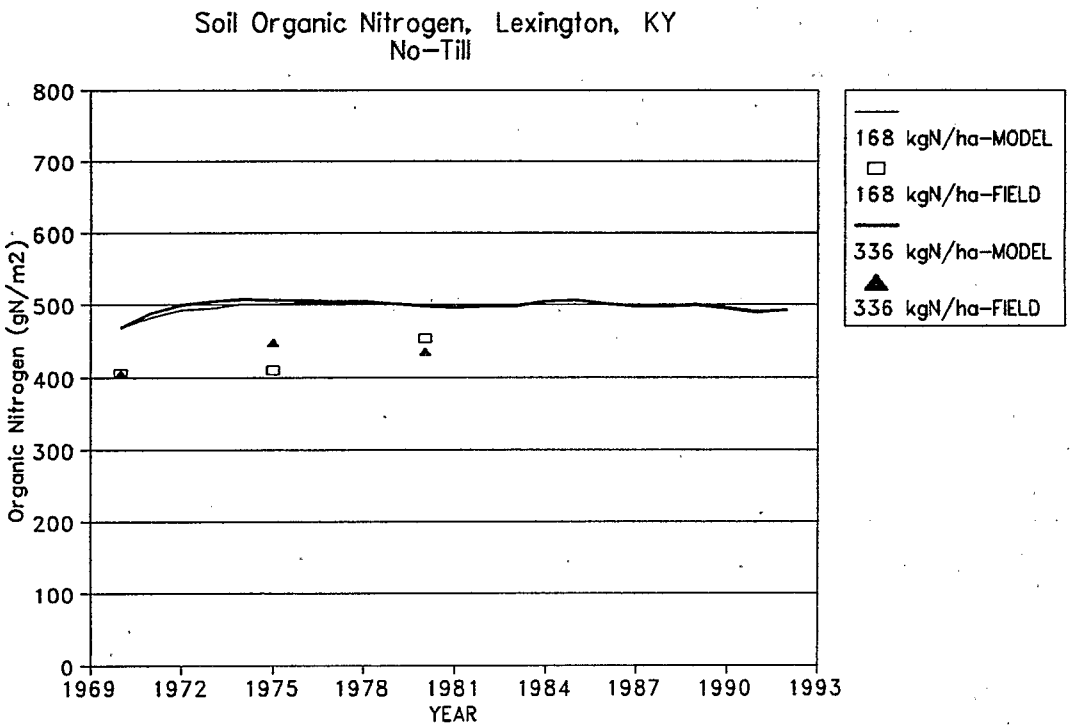


Figure B.8. Simulated and Measured Soil Organic Nitrogen at Different Nitrogen Fertilizer Additions.

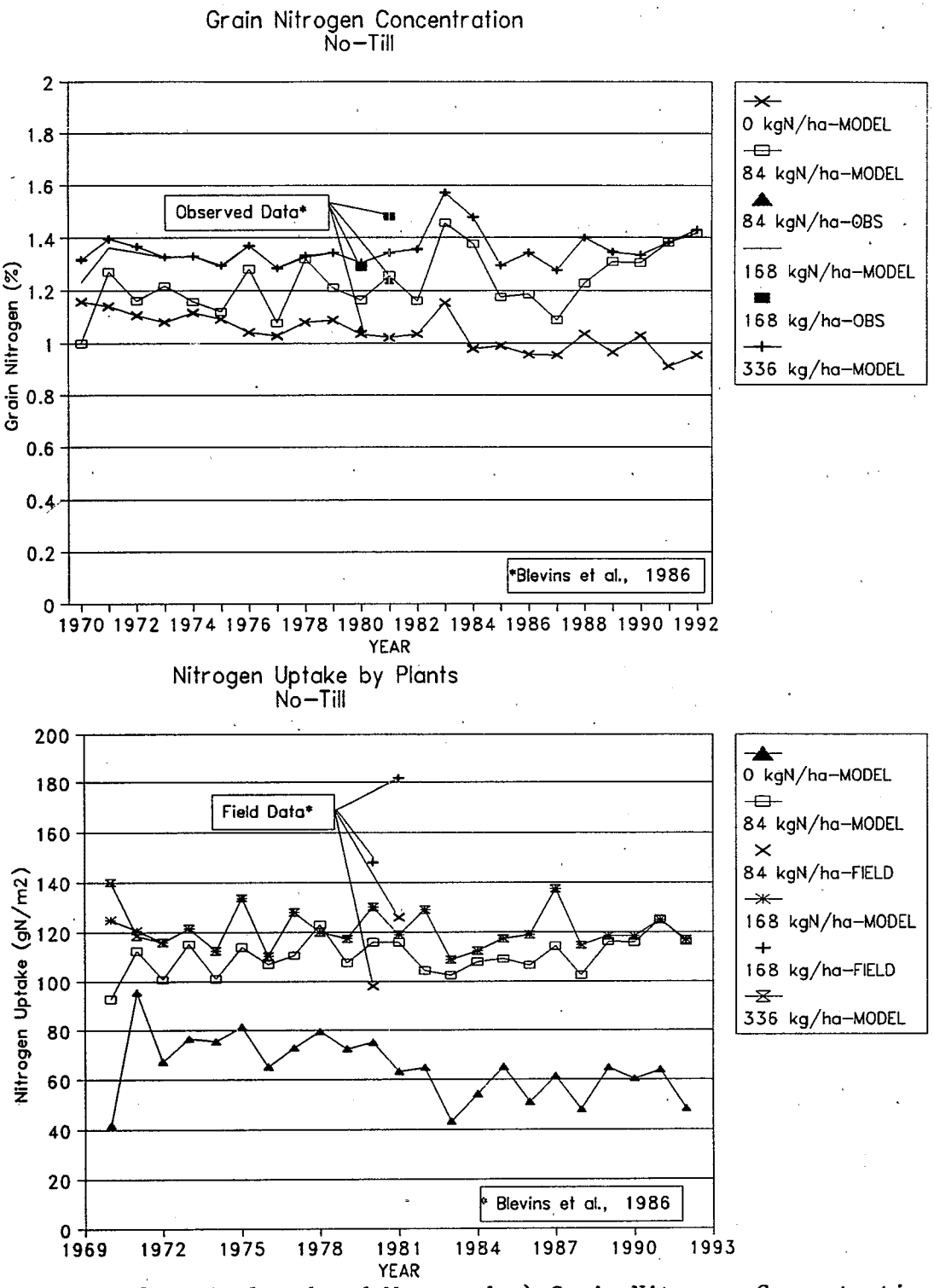


Figure B.9. Simulated and Measured a) Grain Nitrogen Concentration and b) Nitrogen Uptake by Plants, at Different Fertilizer Additions.

average corn yield was equal or higher for no-till. As reported by Hill et al. (1973), no-till causes an increase in corn yields by making water more readily available to the plants which is due to the low evaporation rate from the soil surface. On the other hand, in the conventional tillage system, the water stress resulting from high evaporation rate in the early growing period could reduce the yields. The model prediction which is quite opposite to the above criteria suggests that nutrients and other factors could control the yield levels apart from available water. However, since the predictions deviated by less than 10% (mostly) from the respective observed data, for both tillage types, the model is performing adequately in predicting the yield levels, and it should be noted that CENTURY model was not developed to predict yearly crop yields.

The organic carbon values for the no-till simulation were greater than those of conventional tillage for the fertilizer rates of zero and 84 kg/ha. For the high fertilizer rates, 168 and 336 kg/ha, the reverse was true. This fact is in contrast to the literature reports that the tillage operations associated with the conventional (tillage) treatment usually promote more rapid oxidation of organic matter (Blevins et al., 1977) thus resulting in lower organic carbon. As discussed before, lower soil temperature can limit crop production under a no-till system. Since the residue inputs, shoot and root, contribute directly to the surface and soil litter, respectively, a reduction in their quantity would have reduced the SOC levels at high fertilizer rates in the no-till treatment. The tillage parameters used for no-till result in lower transfer of root and shoot litter thus producing lower carbon inputs, and resulting in lower SOC than for conventional tillage.

The organic nitrogen values corresponding to no-till system were approximately less than those of conventional tillage for all the fertilizer rates except for the non fertilizer case. The more organic N in conventional tillage system could be due to the incorporation of surface residue by plowing.

The net carbon input into the soil for conventional tillage was greater than that of no-till for all the fertilizer rates. This could be due to the incorporation of surface residue by plowing which is associated with the conventional tillage system.

The difference between the available water for both tillage systems was minimum (Figure B.10). As described above, the availability of water under no-till should be higher than that under conventional tillage. Hence, the model needs to be improved to represent the relative variation in the soil temperature (or low evaporation rate) resulting from the residue cover on the surface so as to better simulate the water availability.

B.6 CONCLUSIONS

The following conclusions can be drawn from the simulation of Lexington field experiments involving two tillage scenarios, conventional tillage and no-till, with four fertilizer rates:

The CENTURY model predicted the corn grain yields reasonably well. At high fertilizer rates,

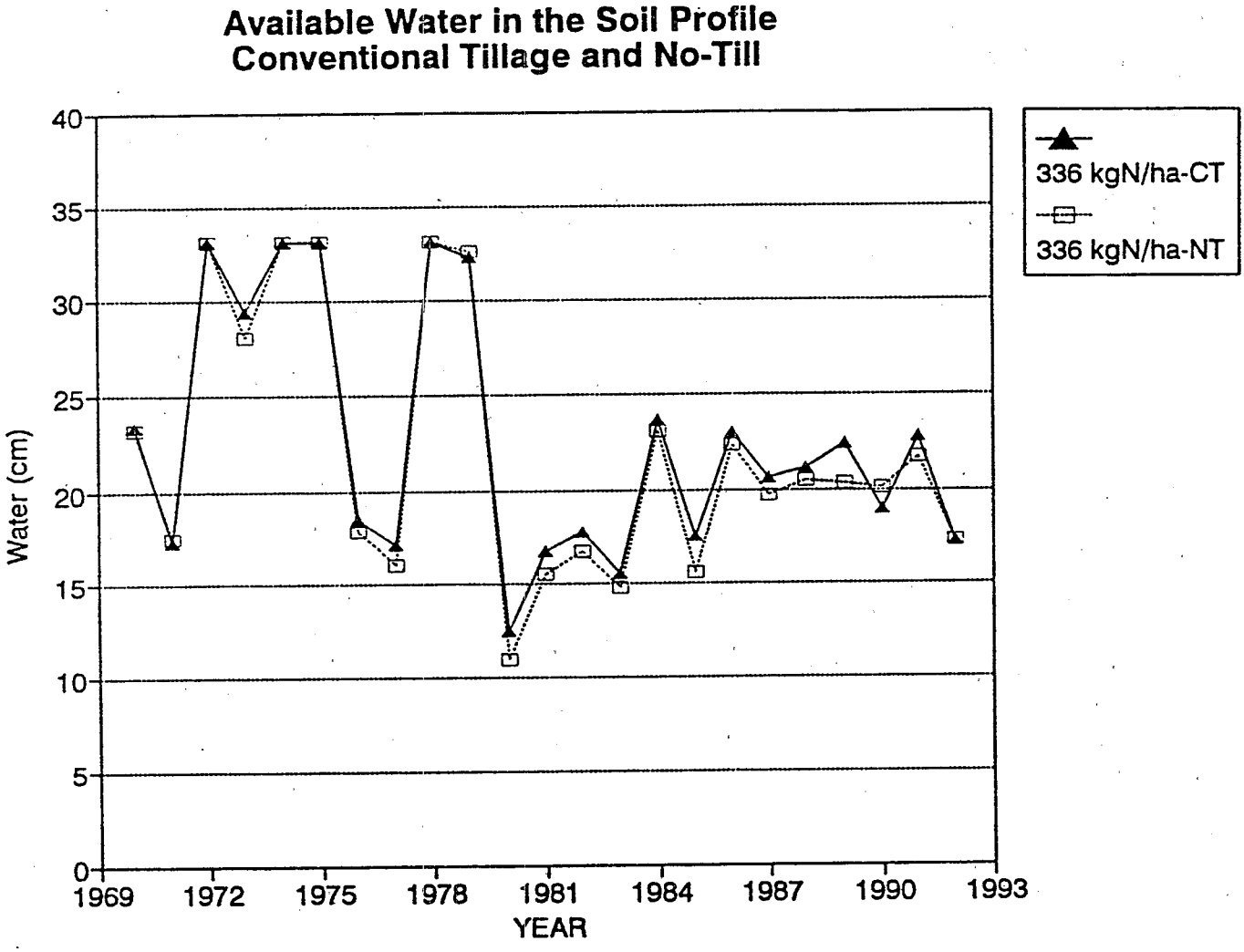


Figure B.10. Simulated Available Soil Water for Two Tillage Treatments.

the crop production parameter appears to limit the crop yield and at low fertilizer rates the nutrients (nitrogen) limit the crop production. In spite of the nutrient limitation on the crop production, the CENTURY model predictions, especially, 21-year average yields matched reasonably well with the field data.

In general, the organic C values predicted by the model adequately represented the dynamics of the organic matter in the soil. Even though they compared reasonably well with the measured data for both the tillage systems, the cultivation parameter values associated with each tillage practice should be reevaluated in order to better represent the impacts of tillage types on the soil organic matter dynamics. The results from the field testing of Sidney revealed similar findings (Appendix A).

The model predicted the organic N values within a reasonable degree of error. In fact, the lack of observed data further limited our ability to assess the accuracy of the model predictions. However, field testing of Sidney indicated that the model was able to predict organic nitrogen fairly close to the field data (Appendix A). Nevertheless, the fact that the model did not differentiate much between the tillage treatments, in both sites, suggests that the cultivation parameters and their effect on the decomposition rate of soil organic matter need to be further investigated and improved.

The grain nitrogen concentrations simulated by the model matched adequately with the observed values. In general, the predicted values were in the range reported by the researchers. The nitrogen uptake by the plants was reasonably predicted by the model for the conventional tillage system. However, the model under estimated the N uptake for no-till. As discussed above, further development in the parameter values associated with each tillage type and consequent improvement in the simulation of the soil organic matter dynamics could enhance the capability of the model to better predict the nitrogen uptake by plants.

Although the CENTURY model did a fairly good job in simulating the hydrology, the predictions did not differentiate much between the tillage treatments. The non-availability of the field data limited our ability to assess the model performance. However, the results from field testing of the model at Sidney site indicated similar observations. In addition, they further revealed that the model predicted differences between tillage treatments in some years were in the descending order of no-till, stubble mulch and plow. In light of the above discussions, we recommend that the hydrological parameter values be reestimated for different tillage types based on extensive field investigations.

Based on the preceding discussions, it is evident that CENTURY model can simulate soil organic matter dynamics adequately under various crop-tillage-management scenarios although it could benefit from improvements and modifications. Additionally, the testing results further confirm that the CENTURY model can be an excellent tool for assessing carbon sequestration potential of agroecosystems in the central United States.

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APPENDIX C

Tabulated Simulation Results by CD

C.1 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for the Study Region

C.2 Maximum, Minimum, and Average Percent Change in Total Soil Carbon for 1990-2030 by CD for the Status Quo Scenario

C.3 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for Crop Rotations with Cover Crops for the Study Region

C.4 Maximum, Minimum, and Average Percent Change in Total Soil Carbon for 1990-2030 by CD for Crop Rotations with Cover Crops

C.5 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for CRP and Dominant Crop Rotations for the Study Region

C.6 Percent Change in Soil Carbon from 1990-2030 for CRP Scenarios and Dominant Crop Rotation

Table C.1 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for the Study Region

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
221	239	CTFP	7344	7404	7985	8376	9032	9544	7.84%	4.89%	7.83%	5.66%	28.90%
221	239	RT	7344	7600	8359	8817	9616	10254	9.98%	5.47%	9.06%	6.63%	34.92%
221	239	NT	7344	7633	8559	9179	10087	10913	12.13%	7.24%	9.89%	8.18%	42.97%
221	350	CTFP	7344	7575	7335	7351	7483	7932	-3.16%	0.21%	1.79%	6.00%	4.71%
221	350	CTSP	7344	7575	7329	7257	7472	7795	-3.24%	-0.98%	2.96%	4.32%	2.90%
221	350	NT	7344	7599	7524	7630	8021	8458	-0.98%	1.40%	5.12%	5.44%	11.30%
222	239	CTFP	6654	6692	7049	7334	8009	8662	5.33%	4.04%	9.20%	8.15%	29.43%
222	239	RT	6654	6924	7448	7806	8602	9390	7.56%	4.80%	10.19%	9.16%	35.61%
222	239	NT	6654	6955	7691	8228	9125	10083	10.58%	6.98%	10.90%	10.49%	44.97%
222	350	CTFP	6654	6895	6539	6501	6587	7017	-5.16%	-0.58%	1.32%	6.52%	1.76%
222	350	CTSP	6654	6895	6539	6429	6574	6904	-5.16%	-1.68%	2.25%	5.01%	0.13%
222	350	NT	6654	6919	6735	6790	7107	7557	-2.65%	0.81%	4.66%	6.33%	9.22%
223	239	CTFP	6022	6044	6400	6673	7362	7865	5.89%	4.26%	10.32%	6.83%	30.12%
223	239	RT	6022	6251	6757	7069	7862	8482	8.09%	4.61%	11.21%	7.88%	35.69%
223	239	NT	6022	6278	6995	7517	8414	9209	11.42%	7.46%	11.93%	9.44%	46.68%
223	350	CTFP	6022	6225	5879	5860	5907	6228	-5.55%	-0.32%	0.80%	5.43%	0.04%
223	350	CTSP	6022	6225	5877	5812	5893	6107	-5.59%	-1.10%	1.39%	3.63%	-1.89%
223	350	NT	6022	6244	6053	6141	6387	6709	-3.05%	1.45%	4.00%	5.04%	7.44%
231	100	RT	5109	5370	6124	6569	7543	8395	14.04%	7.26%	14.82%	11.29%	56.33%
231	100	NT	5109	5397	6400	6964	8034	9008	18.58%	8.81%	15.36%	12.12%	66.90%
231	145	CTSP	5109	5361	5715	6144	6501	7132	6.60%	7.50%	5.81%	9.70%	33.03%
231	145	RT	5109	5370	5786	6255	6678	7366	7.74%	8.10%	6.76%	10.30%	37.16%
231	145	NT	5109	5397	5931	6483	6964	7729	9.89%	9.30%	7.41%	10.98%	43.20%
231	235	RT	5109	5389	6785	7653	9195	10507	25.90%	12.79%	20.14%	14.26%	94.97%
231	350	CTFP	5109	5366	5511	5702	6052	6691	2.70%	3.46%	6.13%	10.55%	24.69%
231	366	CTFP	5109	5366	5515	5669	6038	6648	2.77%	2.79%	6.50%	10.10%	23.89%
231	366	NT	5109	5387	5673	5842	6510	7253	5.30%	2.97%	11.43%	11.41%	34.63%
232	100	RT	5232	5575	6659	7300	8428	9501	19.44%	9.62%	15.45%	12.73%	70.42%
232	100	NT	5232	5609	6885	7607	8807	9978	22.74%	10.48%	15.77%	13.29%	77.89%
232	145	CTSP	5232	5569	6189	6662	6984	7794	11.13%	7.64%	4.83%	11.59%	39.95%
232	145	RT	5232	5576	6276	6798	7178	8057	12.55%	8.31%	5.58%	12.24%	44.49%
232	145	NT	5232	5610	6396	6986	7436	8342	14.01%	9.22%	6.44%	12.18%	48.69%
232	235	RT	5232	5597	7876	9228	11364	13556	40.71%	17.16%	23.14%	19.28%	142.20%
232	350	CTFP	5232	5579	5915	6085	6477	7221	6.02%	2.87%	6.44%	11.48%	29.43%
232	366	CTFP	5232	5579	5946	6098	6472	7338	6.57%	2.55%	6.13%	13.38%	31.52%
232	366	NT	5232	5609	6119	6313	6878	7752	9.09%	3.17%	8.94%	12.70%	38.20%
241	100	CTSP	5591	5942	6494	6800	7738	8293	9.28%	4.71%	13.79%	7.17%	39.56%
241	100	NT	5591	6002	6849	7288	8297	8969	14.11%	6.40%	13.84%	8.09%	49.43%
241	131	RT	5591	5961	6361	6587	7096	7828	6.71%	3.55%	7.72%	10.31%	31.32%
241	186	CTSP	5591	6058	6158	6242	6802	7383	1.65%	1.36%	8.97%	8.54%	21.87%
241	201	RT	5591	6072	6444	6586	7079	7862	6.12%	2.20%	7.48%	11.06%	29.47%
241	262	CTSP	5591	6079	6453	6631	7359	7778	6.15%	2.75%	10.97%	5.69%	27.94%
241	503	CTSP	5591	6109	6021	6098	6429	6918	-1.44%	1.27%	5.42%	7.60%	13.24%
241	508	CTSP	5591	6121	6089	6115	6375	6900	-0.52%	0.42%	4.25%	8.23%	12.72%
242	100	CTSP	4083	4397	4928	5160	5866	6311	12.07%	4.70%	13.68%	7.58%	43.52%
242	100	NT	4083	4460	5376	5824	6732	7371	20.53%	8.33%	15.59%	9.49%	65.26%
242	131	RT	4083	4416	4801	4955	5311	5908	8.71%	3.20%	7.18%	11.24%	33.78%
242	186	CTSP	4083	4498	4577	4654	5072	5565	1.75%	1.68%	8.98%	9.72%	23.72%
242	201	RT	4083	4512	4842	4988	5389	6121	7.31%	3.01%	8.03%	13.58%	35.66%
242	262	CTSP	4083	4516	4797	5014	5580	5970	6.22%	4.52%	11.28%	6.98%	32.19%
242	503	CTSP	4083	4559	4560	4763	5142	5611	0.02%	4.45%	7.95%	9.12%	23.07%
242	508	CTSP	4083	4576	4631	4763	5118	5494	1.20%	2.85%	7.45%	7.34%	20.06%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
251	100	NT	4085	4197	4956	5379	6206	6725	18.08%	8.53%	15.37%	8.36%	60.23%
251	144	CTSP	4085	4242	4447	4719	5183	5592	4.83%	6.11%	9.83%	7.89%	31.82%
251	145	CTSP	4085	4243	4514	4900	5095	5551	6.38%	8.55%	3.97%	8.94%	30.82%
251	186	CTSP	4085	4244	4309	4450	4828	5111	1.53%	3.27%	8.49%	5.86%	20.42%
251	186	RT	4085	4250	4361	4523	4941	5259	2.61%	3.71%	9.24%	6.43%	23.74%
251	186	NT	4085	4270	4617	4946	5486	5914	8.12%	7.12%	10.91%	7.80%	38.50%
251	366	CTSP	4085	4256	4436	4636	5020	5383	4.22%	4.50%	8.28%	7.23%	26.48%
251	366	RT	4085	4258	4459	4641	5063	5472	4.72%	4.08%	9.09%	8.07%	28.51%
252	100	NT	3927	4109	4977	5413	6304	6873	21.12%	8.76%	16.46%	9.02%	67.26%
252	144	CTSP	3927	4141	4637	5054	5703	6223	11.97%	8.99%	12.84%	9.11%	50.27%
252	145	CTSP	3927	4142	4665	5226	5607	6166	12.62%	12.02%	7.29%	9.96%	48.86%
252	186	CTSP	3927	4142	4418	4627	5171	5603	6.66%	4.73%	11.75%	8.35%	35.27%
252	186	RT	3927	4150	4488	4731	5320	5800	8.14%	5.41%	12.44%	9.02%	39.75%
252	186	NT	3927	4184	4752	5162	5865	6425	13.57%	8.62%	13.61%	9.54%	53.56%
252	366	CTSP	3927	4161	4705	5082	5705	6264	13.07%	8.01%	12.25%	9.79%	50.54%
252	366	RT	3927	4166	4614	4916	5574	6203	10.75%	6.54%	13.38%	11.28%	48.89%
253	100	NT	3276	3359	4110	4461	5225	5669	22.35%	8.54%	17.12%	8.49%	68.77%
253	144	CTSP	3276	3405	3589	3789	4193	4498	5.40%	5.57%	10.66%	7.27%	32.09%
253	145	CTSP	3276	3408	3623	3969	4149	4518	6.30%	9.55%	4.53%	8.89%	32.57%
253	186	CTSP	3276	3407	3476	3577	3908	4210	2.02%	2.90%	9.25%	7.72%	23.56%
253	186	RT	3276	3412	3532	3656	4020	4361	3.51%	3.51%	9.95%	8.48%	27.81%
253	186	NT	3276	3440	3818	4118	4640	5107	10.98%	7.85%	12.67%	10.06%	48.45%
253	366	CTSP	3276	3421	3573	3691	3990	4317	4.44%	3.30%	8.10%	8.19%	26.19%
253	366	RT	3276	3424	3591	3693	4034	4409	4.87%	2.84%	9.23%	9.29%	28.76%
261	100	CTSPD	3461	3726	3892	3993	4492	4771	4.45%	2.59%	12.49%	6.21%	28.04%
261	100	CTSPI	3461	3624	3822	3909	4383	4671	5.46%	2.27%	12.12%	6.57%	28.89%
261	100	RTD	3461	3731	3986	4123	4695	5028	6.83%	3.43%	13.87%	7.09%	34.76%
261	100	RTI	3461	3635	3945	4084	4640	4992	8.52%	3.52%	13.61%	7.58%	37.33%
261	100	NTD	3461	3736	4340	4643	5405	5826	16.16%	6.98%	16.41%	7.78%	55.94%
261	100	NTI	3461	3657	4312	4630	5369	5798	17.91%	7.37%	15.96%	7.99%	58.54%
261	145	CTSP	3461	3732	3987	4268	4464	4805	6.83%	7.04%	4.59%	7.63%	28.75%
261	215	RT	3461	3735	4308	4535	5220	5839	15.34%	5.26%	15.10%	11.85%	56.33%
261	280	RT	3461	3736	4619	5163	6117	6742	23.63%	11.77%	18.47%	10.21%	80.46%
261	366	CTSP	3461	3736	3959	4042	4397	4743	5.96%	2.09%	8.78%	7.86%	26.95%
262	100	CTSPD	3193	3460	3703	3816	4346	4695	7.02%	3.05%	13.88%	8.03%	35.69%
262	100	CTSPI	3193	3370	3635	3727	4251	4577	7.86%	2.53%	14.05%	7.66%	35.81%
262	100	RTD	3193	3465	3811	3958	4566	4958	9.98%	3.85%	15.36%	8.58%	43.08%
262	100	RTI	3193	3382	3773	3923	4542	4923	11.56%	3.97%	15.77%	8.38%	45.56%
262	100	NTD	3193	3498	4182	4525	5318	5832	19.55%	8.20%	17.52%	9.66%	66.72%
262	100	NTI	3193	3409	4166	4516	5317	5790	22.20%	8.40%	17.73%	8.89%	69.84%
262	145	CTSP	3193	3466	3805	4114	4336	4819	9.78%	8.12%	5.39%	11.13%	39.03%
262	215	RT	3193	3473	4273	4623	5480	6290	23.03%	8.19%	18.53%	14.78%	81.11%
262	280	RT	3193	3485	4585	5150	6298	7223	31.56%	12.32%	22.29%	14.68%	107.25%
262	366	CTSP	3193	3482	3777	3838	4268	4657	8.47%	1.61%	11.20%	9.11%	33.74%
271	100	NT	4256	4558	5815	6475	7730	8562	27.57%	11.34%	19.38%	10.76%	87.84%
271	138	CTSP	4256	4518	4952	5196	5917	6287	9.60%	4.92%	13.87%	6.25%	39.15%
271	186	CTSP	4256	4518	4877	5112	5716	6115	7.94%	4.81%	11.81%	6.98%	35.34%
271	186	RT	4256	4526	4939	5209	5866	6308	9.12%	5.46%	12.61%	7.53%	39.37%
271	186	NT	4256	4558	5195	5602	6370	6872	13.97%	7.83%	13.70%	7.88%	50.76%
271	201	RT	4256	4529	5150	5514	6010	6643	13.71%	7.06%	8.99%	10.53%	46.67%
271	243	CTSP	4256	4535	5472	6107	7074	7621	20.66%	11.60%	15.83%	7.73%	68.04%
271	366	CTSP	4256	4540	5023	5214	5726	6113	10.63%	3.80%	9.81%	6.75%	34.64%
272	100	NT	4289	4607	6043	6964	8364	9402	31.16%	15.24%	20.10%	12.41%	104.08%
272	138	CTSP	4289	4560	5056	5474	6300	6761	10.87%	8.26%	15.08%	7.31%	48.26%
272	186	CTSP	4289	4559	5029	5395	6076	6613	10.30%	7.27%	12.62%	8.83%	45.05%
272	186	RT	4289	4569	5109	5520	6256	6834	11.81%	8.04%	13.33%	9.23%	49.57%
272	186	NT	4289	4606	5364	5924	6769	7412	16.45%	10.43%	14.26%	9.49%	60.92%
272	201	RT	4289	4570	5231	5689	6180	6994	14.46%	8.75%	8.63%	13.17%	53.04%
272	243	CTSP	4289	4581	5546	6210	7194	7861	21.06%	11.97%	15.84%	9.27%	71.60%
272	366	CTSP	4289	4592	5132	5435	6088	6653	11.75%	5.90%	12.01%	9.28%	44.88%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
281	144	CTSP	4892	5007	5660	5983	6619	7175	13.04%	5.70%	10.63%	8.40%	43.29%
281	144	RT	4892	5007	5740	6082	6759	7366	14.63%	5.95%	11.13%	8.98%	47.11%
281	144	NT	4892	5007	5822	6276	6947	7545	16.27%	7.79%	10.69%	8.60%	50.68%
281	186	RT	4892	5007	5755	6092	6877	7449	14.93%	5.85%	12.88%	8.31%	48.77%
281	186	NT	4892	5007	5887	6349	7116	7692	17.57%	7.84%	12.08%	8.09%	53.62%
281	201	RT	4892	5007	5830	6247	6922	7626	16.43%	7.15%	10.80%	10.17%	52.30%
281	201	NT	4892	5007	5951	6444	7036	7712	18.85%	8.28%	9.18%	9.60%	54.02%
281	458	RT	4892	5007	5621	5863	6365	6861	12.26%	4.30%	8.56%	7.79%	37.02%
281	458	NT	4892	5007	5719	6084	6602	7063	14.22%	6.38%	8.51%	6.98%	41.06%
281	503	CTSP	4892	5007	5319	5524	5959	6381	6.23%	3.85%	7.87%	7.08%	27.44%
281	508	CTFP	4892	5007	5384	5606	5901	6628	7.52%	4.12%	5.26%	12.31%	32.37%
281	508	CTSP	4892	5007	5387	5477	5946	6377	7.58%	1.67%	8.56%	7.24%	27.36%
281	508	RT	4892	5007	5425	5519	6005	6447	8.34%	1.73%	8.80%	7.36%	28.75%
282	144	CTSP	4711	4909	5593	6019	6623	7196	13.93%	7.61%	10.03%	8.65%	46.58%
282	144	RT	4711	4909	5673	6123	6771	7396	15.56%	7.93%	10.58%	9.23%	50.66%
282	144	NT	4711	4910	5762	6333	6972	7582	17.35%	9.90%	10.09%	8.74%	54.41%
282	186	RT	4711	4909	5570	5890	6551	7094	13.46%	5.74%	11.22%	8.28%	44.51%
282	186	NT	4711	4910	5742	6178	6854	7397	16.94%	7.59%	10.94%	7.92%	50.65%
282	201	RT	4711	4909	5623	5999	6553	7255	14.54%	6.68%	9.23%	10.71%	47.78%
282	201	NT	4711	4910	5774	6207	6729	7375	17.59%	7.49%	8.40%	9.60%	50.20%
282	458	RT	4711	4909	5341	5479	5820	6217	8.80%	2.58%	6.22%	6.82%	26.64%
282	458	NT	4711	4909	5472	5744	6126	6478	11.46%	4.97%	6.65%	5.74%	31.96%
282	503	CTSP	4711	4910	5329	5716	6191	6748	8.53%	7.26%	8.31%	8.99%	37.43%
282	508	CTFP	4711	4910	5399	5791	6142	7039	9.95%	7.26%	6.06%	14.60%	43.36%
282	508	CTSP	4711	4910	5404	5678	6196	6722	10.06%	5.07%	9.12%	8.48%	36.90%
282	508	RT	4711	4910	5444	5733	6262	6797	10.87%	5.30%	9.22%	8.54%	38.43%
311	131	RT	4385	4501	5511	6165	6856	7710	22.43%	11.86%	11.20%	12.45%	71.29%
311	131	NT	4385	4503	5632	6394	7133	7986	25.07%	13.52%	11.55%	11.95%	77.34%
311	138	NT	4385	4503	5281	5915	6738	7218	17.27%	12.00%	13.91%	7.12%	60.29%
311	145	CTSP	4385	4495	5182	5903	6100	6828	15.28%	13.91%	3.33%	11.93%	51.90%
311	196	CTSP	4385	4496	5015	5370	5981	6452	11.54%	7.07%	11.37%	7.87%	43.50%
311	196	RT	4385	4501	5046	5402	6039	6520	12.10%	7.05%	11.79%	7.96%	44.85%
311	196	NT	4385	4503	5176	5614	6289	6791	14.94%	8.46%	12.02%	7.98%	50.81%
311	250	RT	4385	4503	6378	7521	8681	9860	41.63%	17.92%	15.42%	13.58%	118.96%
311	250	NT	4385	4503	6359	7640	8920	10285	41.21%	20.14%	16.75%	15.30%	128.40%
311	503	CTSP	4385	4503	4779	5126	5605	6071	6.12%	7.26%	9.34%	8.31%	34.82%
311	508	CTSP	4385	4503	4820	5106	5628	6072	7.03%	5.93%	10.22%	7.88%	34.84%
312	131	RT	3543	3606	4596	5234	5967	6925	27.45%	13.88%	14.00%	16.05%	92.04%
312	131	NT	3543	3629	4709	5445	6248	7221	29.76%	15.62%	14.74%	15.57%	98.98%
312	138	NT	3543	3629	4366	4982	5841	6380	20.30%	14.10%	17.24%	9.22%	75.80%
312	145	CTSP	3543	3596	4243	4916	5105	5883	17.99%	15.86%	3.84%	15.23%	63.59%
312	196	CTSP	3543	3596	4045	4441	5102	5504	12.48%	9.78%	14.88%	7.87%	53.05%
312	196	RT	3543	3605	4069	4472	5161	5602	12.87%	9.90%	15.40%	8.54%	55.39%
312	196	NT	3543	3628	4181	4656	5369	5862	15.24%	11.36%	15.31%	9.18%	61.57%
312	250	RT	3543	3625	5771	7290	8734	10095	59.20%	26.32%	19.80%	15.58%	178.48%
312	250	NT	3543	3634	5721	7233	8809	10400	57.42%	26.42%	21.78%	18.06%	186.18%
312	503	CTSP	3543	3622	3734	4013	4332	4819	3.09%	7.47%	7.94%	11.24%	33.04%
312	508	CTSP	3543	3629	3735	3961	4305	4733	2.92%	6.05%	8.68%	9.94%	30.42%
313	131	RT	3105	3129	3829	4230	4747	5415	22.37%	10.47%	12.22%	14.07%	73.05%
313	131	NT	3105	3149	3964	4477	5060	5758	25.88%	12.94%	13.02%	13.79%	82.85%
313	138	NT	3105	3149	3665	4073	4753	5166	16.38%	11.13%	16.69%	8.68%	64.05%
313	145	CTSP	3105	3121	3571	4048	4167	4736	14.41%	13.35%	2.93%	13.65%	51.74%
313	196	CTSP	3105	3121	3423	3649	4137	4470	9.67%	6.60%	13.37%	8.04%	43.22%
313	196	RT	3105	3129	3442	3665	4161	4519	10.00%	6.47%	13.53%	8.60%	44.42%
313	196	NT	3105	3149	3532	3799	4320	4750	12.16%	7.55%	13.71%	9.95%	50.84%
313	250	RT	3105	3147	4867	6040	7235	8413	54.65%	24.10%	19.78%	16.28%	167.33%
313	250	NT	3105	3158	4834	6025	7249	8526	53.07%	24.63%	20.31%	17.61%	169.98%
313	503	CTSP	3105	3146	3211	3381	3638	4026	2.06%	5.29%	7.60%	10.66%	27.97%
313	508	CTSP	3105	3150	3206	3331	3590	3902	1.77%	3.89%	7.77%	8.69%	23.87%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
314	131	RT	3780	3917	4930	5609	6302	7208	25.86%	13.77%	12.35%	14.37%	84.01%
314	131	NT	3780	3926	5063	5821	6594	7521	28.96%	14.97%	13.27%	14.05%	91.56%
314	138	NT	3780	3926	4677	5320	6179	6716	19.12%	13.74%	16.14%	8.69%	71.06%
314	145	CTSP	3780	3906	4578	5333	5605	6362	17.20%	16.49%	5.10%	13.50%	62.87%
314	196	CTSP	3780	3907	4381	4787	5477	5871	12.13%	9.26%	14.41%	7.19%	50.26%
314	196	RT	3780	3918	4408	4822	5555	5980	12.50%	9.39%	15.20%	7.65%	52.62%
314	196	NT	3780	3926	4518	4994	5742	6227	15.07%	10.53%	14.97%	8.44%	58.60%
314	250	RT	3780	3926	5662	6746	7837	9146	44.21%	19.14%	16.17%	16.70%	132.95%
314	250	NT	3780	3926	5685	6824	8036	9497	44.80%	20.03%	17.76%	18.18%	141.90%
314	503	CTSP	3780	3926	4121	4520	5015	5666	4.96%	9.68%	10.95%	12.98%	44.31%
314	508	CTSP	3780	3926	4159	4506	4963	5606	5.93%	8.34%	10.14%	12.95%	42.79%
321	125	CTSP	4171	4465	5155	5630	6535	7163	15.45%	9.21%	16.07%	9.60%	60.42%
321	125	RT	4171	4474	5225	5731	6775	7446	16.78%	9.68%	18.21%	9.90%	66.42%
321	125	NT	4171	4505	5394	5983	7028	7686	19.73%	10.91%	17.46%	9.36%	70.61%
321	131	CTSP	4171	4465	5366	5898	6592	7463	20.17%	9.91%	11.76%	13.21%	67.14%
321	131	NT	4171	4505	5681	6374	7253	8247	26.10%	12.19%	13.79%	13.70%	83.06%
321	186	CTSP	4171	4464	5050	5472	6216	6836	13.12%	8.35%	13.59%	9.97%	53.13%
321	186	RT	4171	4474	5123	5590	6384	7064	14.50%	9.11%	14.20%	10.65%	57.89%
321	186	NT	4171	4504	5354	5935	6810	7588	18.87%	10.85%	14.74%	11.42%	68.47%
321	203	CTSP	4171	4466	4910	5430	5900	6493	9.94%	10.59%	8.65%	10.05%	45.38%
321	203	RT	4171	4475	4958	5503	6008	6641	10.79%	10.99%	9.17%	10.53%	48.40%
322	125	CTSP	4345	4598	5349	5883	6681	7333	16.33%	9.98%	13.56%	9.75%	59.48%
322	125	RT	4345	4607	5384	5954	6822	7525	16.86%	10.58%	14.57%	10.30%	63.33%
322	125	NT	4345	4635	5499	6141	6994	7674	18.64%	11.67%	13.89%	9.72%	65.56%
322	131	CTSP	4345	4598	5529	6115	6748	7592	20.24%	10.59%	10.35%	12.50%	65.11%
322	131	NT	4345	4635	5761	6481	7227	8135	24.29%	12.49%	11.51%	12.56%	75.51%
322	186	CTSP	4345	4598	5242	5725	6385	6942	14.00%	9.21%	11.52%	8.72%	50.97%
322	186	RT	4345	4607	5307	5820	6532	7141	15.19%	9.66%	12.23%	9.32%	55.00%
322	186	NT	4345	4635	5487	6088	6836	7503	18.38%	10.95%	12.28%	9.75%	61.87%
322	203	CTSP	4345	4599	5080	5648	5990	6641	10.45%	11.18%	6.05%	10.86%	44.40%
322	203	RT	4345	4609	5112	5696	6079	6745	10.91%	11.42%	6.72%	10.95%	46.34%
323	125	CTSP	3925	4206	4917	5567	6535	7052	16.90%	13.21%	17.38%	7.91%	67.66%
323	125	RT	3925	4214	4960	5645	6663	7264	17.70%	13.81%	18.03%	9.01%	72.37%
323	125	NT	3925	4241	5081	5801	6783	7480	19.80%	14.17%	16.92%	10.27%	76.37%
323	131	CTSP	3925	4202	4985	5584	6172	6967	18.63%	12.01%	10.53%	12.88%	65.80%
323	131	NT	3925	4238	5235	5950	6686	7572	23.52%	13.65%	12.36%	13.25%	78.66%
323	186	CTSP	3925	4201	4709	5200	5832	6348	12.09%	10.42%	12.15%	8.84%	51.10%
323	186	RT	3925	4209	4773	5293	5972	6539	13.39%	10.89%	12.82%	9.49%	55.35%
323	186	NT	3925	4237	4977	5558	6296	6959	17.46%	11.67%	13.27%	10.53%	64.24%
323	203	CTSP	3925	4202	4619	5165	5576	6166	9.92%	11.82%	7.95%	10.58%	46.73%
323	203	RT	3925	4210	4654	5216	5657	6267	10.54%	12.07%	8.45%	10.78%	48.85%
341	144	CTSP	3294	3478	3620	3842	4316	4611	4.08%	6.13%	12.33%	6.83%	32.57%
341	144	RT	3294	3456	3667	3922	4447	4787	6.10%	6.95%	13.38%	7.64%	38.51%
341	144	NT	3294	3498	3795	4116	4683	5068	8.49%	8.45%	13.77%	8.22%	44.88%
341	186	CTFP	3294	3442	3528	3682	4077	4354	2.49%	4.36%	10.72%	6.79%	26.49%
341	186	NT	3294	3495	3911	4263	4824	5281	11.90%	9.00%	13.15%	9.47%	51.10%
341	232	CTSP	3294	3443	3514	3614	3992	4255	2.06%	2.84%	10.45%	6.58%	23.58%
341	232	RT	3294	3457	3531	3647	4011	4271	2.14%	3.28%	9.98%	6.48%	23.54%
342	144	CTSP	3502	3679	3940	4205	4727	5048	7.09%	6.72%	12.41%	6.79%	37.21%
342	144	RT	3502	3659	3986	4276	4847	5223	8.93%	7.27%	13.35%	7.75%	42.74%
342	144	NT	3502	3700	4105	4433	5073	5476	10.94%	7.99%	14.43%	7.94%	47.99%
342	186	CTFP	3502	3645	3797	3973	4290	4584	4.17%	4.63%	7.97%	6.85%	25.76%
342	186	NT	3502	3699	4194	4589	5060	5493	13.38%	9.41%	10.26%	8.55%	48.49%
342	232	CTSP	3502	3648	3882	3958	4290	4604	6.41%	1.95%	8.38%	7.31%	26.20%
342	232	RT	3502	3663	3898	3979	4324	4626	6.41%	2.07%	8.67%	6.98%	26.28%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
351	100	NT	4049	4346	5667	6467	7808	8859	30.39%	14.11%	20.73%	13.46%	103.84%
351	115	CTSP	4049	4295	4947	5419	6015	6746	15.18%	9.54%	10.99%	12.15%	57.06%
351	131	NT	4049	4347	5373	5972	6819	7770	23.60%	11.14%	14.18%	13.94%	78.74%
351	186	CTSP	4049	4294	4677	4962	5620	6195	8.91%	6.09%	13.26%	10.23%	44.27%
351	186	RT	4049	4305	4754	5076	5789	6410	10.42%	6.77%	14.04%	10.72%	48.89%
351	186	NT	4049	4346	5032	5531	6352	7066	15.78%	9.91%	14.84%	11.24%	62.58%
351	201	RT	4049	4306	4945	5351	5967	6825	14.83%	8.21%	11.51%	14.37%	58.49%
351	366	CTSP	4049	4316	4793	5237	6094	6724	11.05%	9.26%	16.36%	10.33%	55.79%
352	100	NT	4845	5173	6706	7682	9100	10443	29.63%	14.55%	18.45%	14.75%	101.87%
352	115	CTSP	4845	5119	5958	6554	7212	8177	16.38%	10.00%	10.03%	13.38%	59.73%
352	131	NT	4845	5174	6333	7048	7869	8989	22.40%	11.29%	11.64%	14.23%	73.73%
352	186	CTSP	4845	5118	5654	6053	6769	7476	10.47%	7.05%	11.82%	10.44%	46.07%
352	186	RT	4845	5132	5719	6160	6928	7698	11.43%	7.71%	12.46%	11.11%	49.99%
352	186	NT	4845	5172	5940	6496	7290	8124	14.84%	9.36%	12.22%	11.44%	57.07%
352	201	RT	4845	5133	5918	6353	6975	7998	15.29%	7.35%	9.79%	14.66%	55.81%
352	366	CTSP	4845	5146	5626	5978	6869	7540	9.32%	6.25%	14.90%	9.76%	46.52%
353	100	NT	4072	4336	5584	6394	7646	8604	28.78%	14.50%	19.58%	12.52%	98.43%
353	115	CTSP	4072	4285	4965	5482	6037	6824	15.86%	10.41%	10.12%	13.03%	59.25%
353	131	NT	4072	4337	5244	5818	6523	7362	20.91%	10.94%	12.11%	12.86%	69.74%
353	186	CTSP	4072	4285	4651	4951	5548	6050	8.54%	6.45%	12.05%	9.04%	41.19%
353	186	RT	4072	4299	4701	5031	5672	6220	9.35%	7.01%	12.74%	9.66%	44.68%
353	186	NT	4072	4335	4900	5330	6007	6616	13.03%	8.77%	12.70%	10.13%	52.61%
353	201	RT	4072	4300	4856	5093	5559	6306	12.93%	4.88%	9.14%	13.43%	46.65%
353	366	CTSP	4072	4299	4575	4850	5597	6024	6.42%	6.01%	15.40%	7.62%	40.12%
391	131	CTSP	5201	5217	5563	5783	6108	6532	6.63%	3.95%	5.61%	6.94%	25.20%
391	131	RT	5201	5227	5644	5906	6297	6775	7.97%	4.64%	6.62%	7.59%	29.61%
391	131	NT	5201	5247	5858	6268	6754	7293	11.64%	6.99%	7.75%	7.98%	38.99%
391	186	CTSP	5201	5244	5566	5758	6200	6726	6.14%	3.44%	7.67%	8.48%	28.26%
391	186	RT	5201	5254	5625	5849	6326	6894	7.06%	3.98%	8.15%	8.97%	31.21%
391	186	NT	5201	5278	5868	6263	6831	7490	11.17%	6.73%	9.06%	9.64%	41.90%
391	189	CTSP	5201	5244	5773	5998	6466	7142	10.08%	3.89%	7.80%	10.45%	36.19%
391	201	CTFP	5201	5244	5666	5911	6310	6830	8.04%	4.32%	6.75%	8.24%	30.24%
391	243	CTSP	5201	5255	5843	6227	6922	7569	11.18%	6.57%	11.16%	9.34%	44.03%
391	350	CTSP	5201	5259	5713	5998	6521	7052	8.63%	4.98%	8.71%	8.14%	34.09%
391	366	CTSP	5201	5259	5770	6030	6550	7138	9.71%	4.50%	8.62%	8.97%	35.72%
392	131	CTSP	4868	4968	5374	5584	5971	6460	8.17%	3.90%	6.93%	8.18%	30.03%
392	131	RT	4868	4979	5470	5732	6172	6717	9.86%	4.78%	7.67%	8.83%	34.90%
392	131	NT	4868	5004	5685	6104	6633	7249	13.60%	7.37%	8.66%	9.28%	44.86%
392	186	CTSP	4868	5045	5435	5669	6207	6903	7.73%	4.30%	9.49%	11.21%	36.82%
392	186	RT	4868	5050	5500	5764	6342	7093	8.91%	4.79%	10.02%	11.84%	40.45%
392	186	NT	4868	5076	5758	6188	6860	7727	13.43%	7.46%	10.85%	12.63%	52.22%
392	189	CTSP	4868	5046	5610	5747	6257	7027	11.17%	2.44%	8.87%	12.30%	39.25%
392	201	CTFP	4868	5044	5420	5659	6152	6852	7.45%	4.40%	8.71%	11.37%	35.84%
392	243	CTSP	4868	5065	5746	6358	7206	8040	13.44%	10.65%	13.33%	11.57%	58.73%
392	350	CTSP	4868	5044	5322	5630	6075	6837	5.51%	5.78%	7.90%	12.54%	35.54%
392	366	CTSP	4868	5044	5344	5655	6092	6890	5.94%	5.81%	7.72%	13.09%	36.59%
393	131	CTSP	4779	5036	5558	5832	6245	6813	10.36%	4.92%	7.08%	9.09%	35.28%
393	131	RT	4779	5049	5670	5993	6475	7117	12.29%	5.69%	8.04%	9.91%	40.95%
393	131	NT	4779	5077	5889	6353	6930	7596	15.99%	7.87%	9.08%	9.61%	49.61%
393	186	CTSP	4779	5089	5614	5856	6586	7422	10.31%	4.31%	12.46%	12.69%	45.84%
393	186	RT	4779	5096	5691	5975	6764	7641	11.67%	4.99%	13.20%	12.96%	49.94%
393	186	NT	4779	5129	5974	6393	7337	8286	16.47%	7.01%	14.76%	12.93%	61.55%
393	189	CTSP	4779	5089	5689	5850	6461	7402	11.79%	2.83%	10.44%	14.56%	45.45%
393	201	CTFP	4779	5089	5550	5784	6300	7157	9.05%	4.21%	8.92%	13.60%	40.63%
393	243	CTSP	4779	5113	6053	6726	7918	9029	18.38%	11.11%	17.72%	14.03%	76.58%
393	350	CTSP	4779	5089	5309	5626	6163	6876	4.32%	5.97%	9.54%	11.56%	35.11%
393	366	CTSP	4779	5089	5325	5663	6143	7012	4.63%	6.34%	8.47%	14.14%	37.78%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
401	100	CTSP	6396	6695	7225	7540	8406	8935	7.91%	4.35%	11.48%	6.29%	33.45%
401	100	RT	6396	6711	7380	7780	8771	9401	9.96%	5.42%	12.73%	7.18%	40.08%
401	186	CTFP	6396	6742	6704	6784	7232	7684	-0.56%	1.19%	6.60%	6.25%	13.97%
401	186	NT	6396	6795	7125	7423	8007	8622	4.85%	4.18%	7.86%	7.68%	26.88%
401	246	CTSP	6396	6775	7574	8220	9475	10346	11.79%	8.52%	15.26%	9.19%	52.70%
401	246	NT	6396	6827	7704	8411	9709	10771	12.84%	9.17%	15.43%	10.93%	57.77%
401	280	CTSP	6396	6777	8026	8947	10232	11454	18.42%	11.47%	14.36%	11.94%	69.01%
401	280	NT	6396	6828	8190	9184	10645	12128	19.94%	12.13%	15.90%	13.93%	77.62%
401	366	CTFP	6396	6761	6807	7018	7364	8052	0.68%	3.09%	4.93%	9.34%	19.09%
401	366	NT	6396	6792	6976	7171	7784	8344	2.70%	2.79%	8.54%	7.19%	22.85%
401	503	CTFP	6396	6720	6546	6795	6964	7687	-2.58%	3.80%	2.48%	10.38%	14.38%
402	100	CTSP	6241	6590	7351	7789	8708	9357	11.54%	5.95%	11.79%	7.45%	41.98%
402	100	RT	6241	6606	7523	8062	9149	9903	13.88%	7.16%	13.48%	8.24%	49.90%
402	186	CTFP	6241	6667	6774	6903	7374	7911	1.60%	1.90%	6.82%	7.28%	18.65%
402	186	NT	6241	6722	7196	7553	8181	8904	7.05%	4.96%	8.31%	8.83%	32.46%
402	246	CTSP	6241	6688	7572	8214	9440	10355	13.21%	8.47%	14.92%	9.69%	54.82%
402	246	NT	6241	6742	7687	8412	9683	10800	14.01%	9.43%	15.10%	11.53%	60.18%
402	280	CTSP	6241	6687	7928	8834	10053	11241	18.55%	11.42%	13.79%	11.81%	68.10%
402	280	NT	6241	6742	8075	9084	10466	11980	19.77%	12.49%	15.21%	14.46%	77.69%
402	366	CTFP	6241	6674	6756	6889	7206	7974	1.22%	1.96%	4.60%	10.65%	19.47%
402	366	NT	6241	6709	6913	7050	7600	8189	3.04%	1.98%	7.80%	7.75%	22.05%
402	503	CTFP	6241	6608	6393	6595	6712	7403	-3.25%	3.15%	1.77%	10.29%	12.03%
403	100	CTSP	5565	5953	6677	7037	8045	8705	12.16%	5.39%	14.32%	8.20%	46.22%
403	100	RT	5565	5972	6867	7323	8499	9294	14.98%	6.64%	16.05%	9.35%	55.62%
403	186	CTFP	5565	6074	6312	6413	6968	7597	3.91%	1.60%	8.65%	9.02%	25.07%
403	186	NT	5565	6135	6769	7120	7883	8672	10.33%	5.18%	10.71%	10.00%	41.35%
403	246	CTSP	5565	6107	7093	7637	8984	10030	16.14%	7.66%	17.63%	11.64%	64.23%
403	246	NT	5565	6170	7228	7935	9295	10465	17.14%	9.78%	17.13%	12.58%	69.61%
403	280	CTSP	5565	6102	7443	8138	9362	10632	21.97%	9.33%	15.04%	13.56%	74.23%
403	280	NT	5565	6164	7611	8436	9819	11360	23.47%	10.83%	16.39%	15.69%	84.29%
403	366	CTFP	5565	6087	6221	6347	6796	7682	2.20%	2.02%	7.07%	13.03%	26.20%
403	366	NT	5565	6132	6371	6604	7166	7863	3.89%	3.65%	8.50%	9.72%	28.22%
403	503	CTFP	5565	5988	5731	5948	6114	6851	-4.29%	3.78%	2.79%	12.05%	14.41%
411	100	CTSP	4972	5244	6257	6849	7931	8899	19.31%	9.46%	15.79%	12.20%	69.69%
411	100	RT	4972	5252	6411	7077	8294	9410	22.06%	10.38%	17.19%	13.45%	79.16%
411	115	CTSP	4972	5245	6000	6458	7014	7932	14.39%	7.63%	8.60%	13.08%	51.22%
411	138	CTSP	4972	5244	5640	5894	6627	7114	7.55%	4.50%	12.43%	7.34%	35.65%
411	138	RT	4972	5252	5705	5998	6785	7316	8.62%	5.13%	13.12%	7.82%	39.29%
411	186	CTFP	4972	5244	5615	5835	6387	6991	7.07%	3.91%	9.46%	9.45%	33.31%
411	186	CTSP	4972	5244	5676	5927	6533	7204	8.23%	4.42%	10.22%	10.27%	37.37%
411	186	RT	4972	5252	5759	6049	6706	7429	9.65%	5.03%	10.86%	10.78%	41.45%
411	186	NT	4972	5290	6056	6497	7265	8072	14.48%	7.28%	11.82%	11.10%	52.58%
411	243	CTSP	4972	5272	6307	6972	8104	9176	19.63%	10.54%	16.23%	13.22%	74.05%
411	503	CTSP	4972	5314	5524	5968	6506	7360	3.95%	8.03%	9.01%	13.12%	38.50%
411	508	CTFP	4972	5328	5566	5985	6441	7456	4.46%	7.52%	7.61%	15.75%	39.93%
412	100	CTSP	4566	4804	5681	6137	7104	7951	18.25%	8.02%	15.75%	11.92%	65.50%
412	100	RT	4566	4815	5822	6340	7444	8398	20.91%	8.89%	17.41%	12.81%	74.41%
412	115	CTSP	4566	4805	5468	5742	6247	6985	13.79%	5.01%	8.79%	11.81%	45.36%
412	138	CTSP	4566	4805	5241	5471	6142	6731	9.07%	4.38%	12.26%	9.58%	40.08%
412	138	RT	4566	4816	5304	5568	6300	6929	10.13%	4.97%	13.14%	9.98%	43.87%
412	186	CTFP	4566	4804	5091	5245	5753	6267	5.97%	3.02%	9.68%	8.93%	30.45%
412	186	CTSP	4566	4804	5151	5335	5887	6445	7.22%	3.57%	10.34%	9.47%	34.15%
412	186	RT	4566	4815	5224	5441	6042	6647	8.49%	4.15%	11.04%	10.01%	38.04%
412	186	NT	4566	4850	5495	5847	6542	7220	13.29%	6.40%	11.88%	10.36%	48.86%
412	243	CTSP	4566	4822	5999	6488	7721	8647	24.40%	8.15%	19.00%	11.99%	79.32%
412	503	CTSP	4566	4849	5013	5219	5681	6180	3.38%	4.10%	8.85%	8.78%	27.44%
412	508	CTFP	4566	4859	5051	5273	5575	6400	3.95%	4.39%	5.72%	14.79%	31.71%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
413	100	CTSP	4677	4967	5933	6559	7510	8442	19.44%	10.55%	14.49%	12.41%	69.96%
413	100	RT	4677	4979	6098	6804	7913	9012	22.47%	11.57%	16.29%	13.88%	81.00%
413	115	CTSP	4677	4969	5693	6244	6740	7590	14.57%	9.67%	7.94%	12.61%	52.74%
413	138	CTSP	4677	4968	5355	5658	6333	6741	7.78%	5.65%	11.93%	6.44%	35.68%
413	138	RT	4677	4979	5413	5768	6513	6958	8.71%	6.55%	12.91%	6.83%	39.74%
413	186	CTFP	4677	4966	5123	5286	5493	5790	3.16%	3.18%	3.91%	5.40%	16.59%
413	186	CTSP	4677	4965	5193	5390	5634	5980	4.59%	3.79%	4.52%	6.14%	20.44%
413	186	RT	4677	4976	5257	5491	5758	6133	5.64%	4.45%	4.86%	6.51%	23.25%
413	186	NT	4677	5018	5553	5958	6356	6815	10.66%	7.29%	6.68%	7.22%	35.81%
413	243	CTSP	4677	4988	5981	6588	7606	8592	19.90%	10.14%	15.45%	12.96%	72.25%
413	503	CTSP	4677	5041	5216	5733	6341	7134	3.47%	9.91%	10.60%	12.50%	41.51%
413	508	CTFP	4677	5054	5230	5746	6233	7114	3.48%	9.86%	8.47%	14.13%	40.75%
414	100	CTSP	4856	5142	6011	6463	7554	8593	16.90%	7.51%	16.88%	13.75%	67.11%
414	100	RT	4856	5154	6150	6678	7908	9093	19.32%	8.58%	18.41%	14.98%	76.42%
414	115	CTSP	4856	5143	5818	6181	6781	7733	13.12%	6.23%	9.70%	14.03%	50.35%
414	138	CTSP	4856	5142	5558	5873	6713	7310	8.09%	5.66%	14.30%	8.89%	42.16%
414	138	RT	4856	5154	5612	5969	6873	7499	8.88%	6.36%	15.14%	9.10%	45.49%
414	186	CTFP	4856	5142	5399	5537	6150	6818	4.99%	2.55%	11.07%	10.86%	32.59%
414	186	CTSP	4856	5142	5476	5658	6330	7062	6.49%	3.32%	11.87%	11.56%	37.33%
414	186	RT	4856	5154	5547	5756	6477	7270	7.62%	3.76%	12.52%	12.24%	41.05%
414	186	NT	4856	5190	5815	6150	6978	7836	12.04%	5.76%	13.46%	12.29%	50.98%
414	243	CTSP	4856	5169	6311	6868	8143	9239	22.09%	8.82%	18.56%	13.45%	78.73%
414	503	CTSP	4856	5206	5453	5791	6440	7148	4.74%	6.19%	11.20%	10.99%	37.30%
414	508	CTFP	4856	5216	5472	5872	6368	7509	4.90%	7.30%	8.44%	17.91%	43.96%
415	100	CTSP	4649	4846	5804	6507	7472	8499	19.76%	12.11%	14.83%	13.74%	75.38%
415	100	RT	4649	4860	5941	6738	7844	9041	22.24%	13.41%	16.41%	15.26%	86.02%
415	115	CTSP	4649	4847	5560	6105	6584	7529	14.71%	9.80%	7.84%	14.35%	55.33%
415	138	CTSP	4649	4847	5135	5584	6243	6651	5.94%	8.74%	11.80%	6.53%	37.21%
415	138	RT	4649	4860	5179	5673	6394	6825	6.56%	9.53%	12.70%	6.74%	40.43%
415	186	CTFP	4649	4847	5128	5419	5919	6485	5.79%	5.67%	9.22%	9.56%	33.79%
415	186	CTSP	4649	4846	5210	5554	6119	6752	7.51%	6.60%	10.17%	10.34%	39.33%
415	186	RT	4649	4860	5280	5662	6281	6971	8.64%	7.23%	10.93%	10.98%	43.43%
415	186	NT	4649	4898	5548	6075	6771	7543	13.27%	9.49%	11.45%	11.40%	54.00%
415	243	CTSP	4649	4860	5842	6532	7530	8480	20.20%	11.81%	15.27%	12.61%	74.48%
415	503	CTSP	4649	4900	5080	5593	6112	6783	3.67%	10.09%	9.27%	10.97%	38.42%
415	508	CTFP	4649	4912	5095	5651	6083	7027	3.72%	10.91%	7.64%	15.51%	43.05%
416	100	CTSP	4946	5143	6196	6950	7942	8912	20.47%	12.16%	14.27%	12.21%	73.28%
416	100	RT	4946	5159	6328	7186	8308	9387	22.65%	13.55%	15.61%	12.98%	81.95%
416	115	CTSP	4946	5145	5972	6551	7147	8122	16.07%	9.69%	9.09%	13.64%	57.86%
416	138	CTSP	4946	5144	5633	6176	6879	7373	9.50%	9.63%	11.38%	7.18%	43.33%
416	138	RT	4946	5159	5676	6267	7028	7547	10.02%	10.41%	12.14%	7.38%	46.28%
416	186	CTFP	4946	5145	5498	5818	6328	6877	6.86%	5.82%	8.76%	8.67%	33.66%
416	186	CTSP	4946	5144	5592	5985	6561	7177	8.70%	7.02%	9.62%	9.38%	39.52%
416	186	RT	4946	5159	5663	6087	6608	7210	9.76%	7.48%	8.55%	9.11%	39.75%
416	186	NT	4946	5196	5942	6489	7155	7907	14.35%	9.20%	10.26%	10.51%	52.17%
416	243	CTSP	4946	5162	6359	7134	8377	9474	23.18%	12.18%	17.42%	13.09%	83.53%
416	503	CTSP	4946	5205	5515	6000	6715	7472	5.95%	8.79%	11.91%	11.27%	43.55%
416	508	CTFP	4946	5217	5527	6223	6665	7583	5.94%	12.59%	7.10%	13.77%	45.35%
421	100	CTSP	4631	4870	5670	6058	6930	7506	16.42%	6.84%	14.39%	8.31%	54.12%
421	145	CTSP	4631	4902	5492	6023	6405	7253	12.03%	9.66%	6.34%	13.23%	47.96%
421	186	CTSP	4631	4904	5317	5607	6248	6914	8.42%	5.45%	11.43%	10.65%	40.98%
421	186	RT	4631	4918	5383	5700	6379	7103	9.45%	5.88%	11.91%	11.34%	44.42%
421	186	NT	4631	4954	5632	6077	6840	7647	13.68%	7.90%	12.55%	11.79%	54.36%
421	201	RT	4631	4918	5512	5808	6431	7342	12.07%	5.37%	10.72%	14.16%	49.28%
421	244	CTSP	4631	4922	6060	6739	7402	8570	23.12%	11.20%	9.83%	15.77%	74.11%
421	262	CTSP	4631	4924	5672	6076	6987	7688	15.19%	7.12%	14.99%	10.03%	56.13%
421	503	CTSP	4631	4958	5167	5470	6001	6665	4.21%	5.86%	9.70%	11.06%	34.42%
421	508	CTSP	4631	4969	5259	5490	6022	6678	5.83%	4.39%	9.69%	10.89%	34.39%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
422	100	CTSP	4419	4654	5569	5999	6973	7636	19.66%	7.72%	16.23%	9.50%	64.07%
422	145	CTSP	4419	4685	5270	5804	6302	7101	12.48%	10.13%	8.58%	12.67%	51.56%
422	186	CTSP	4419	4685	5141	5452	6237	6921	9.73%	6.04%	14.39%	10.96%	47.72%
422	186	RT	4419	4700	5203	5539	6368	7114	10.70%	6.45%	14.96%	11.71%	51.36%
422	186	NT	4419	4741	5456	5895	6791	7624	15.08%	8.04%	15.19%	12.26%	60.80%
422	201	RT	4419	4700	5340	5601	6375	7246	13.61%	4.88%	13.81%	13.66%	54.17%
422	244	CTSP	4419	4696	5754	6371	7157	8200	22.52%	10.72%	12.33%	14.57%	74.61%
422	262	CTSP	4419	4696	5312	5686	6744	7202	13.11%	7.04%	18.60%	6.79%	53.36%
422	503	CTSP	4419	4731	4715	4898	5512	6002	-0.33%	3.88%	12.53%	8.88%	26.86%
422	508	CTSP	4419	4740	4781	4929	5538	5969	0.86%	3.09%	12.35%	7.78%	25.92%
431	100	CTSP	4522	4752	5673	6111	7044	7677	19.38%	7.72%	15.26%	8.98%	61.55%
431	131	CTSP	4522	4752	5351	5671	6111	6746	12.60%	5.98%	7.75%	10.39%	41.96%
431	131	NT	4522	4799	5575	6000	6527	7228	16.17%	7.62%	8.78%	10.74%	50.61%
431	186	RT	4522	4792	5247	5612	6413	7095	9.49%	6.95%	14.27%	10.63%	48.05%
431	186	NT	4522	4831	5463	5935	6791	7552	13.08%	8.63%	14.42%	11.20%	56.32%
431	201	CTSP	4522	4779	5382	5686	6235	7009	12.61%	5.64%	9.65%	12.41%	46.66%
431	201	RT	4522	4793	5452	5766	6369	7153	13.74%	5.75%	10.45%	12.30%	49.23%
431	201	NT	4522	4832	5569	5923	6541	7311	15.25%	6.35%	10.43%	11.77%	51.30%
431	262	CTSP	4522	4790	5411	5962	7209	7692	12.96%	10.18%	20.91%	6.69%	60.58%
431	503	CTSP	4522	4824	4935	5318	6094	6732	2.30%	7.76%	14.59%	10.46%	39.55%
431	508	CTFP	4522	4833	4968	5457	6032	6667	2.79%	9.84%	10.53%	10.52%	37.94%
432	100	CTSP	3984	4184	4962	5319	6155	6688	18.59%	7.19%	15.71%	8.65%	59.84%
432	131	CTSP	3984	4184	4710	4993	5418	5974	12.57%	6.00%	8.51%	10.26%	42.78%
432	131	NT	3984	4229	4950	5345	5863	6479	17.04%	7.97%	9.69%	10.50%	53.20%
432	186	RT	3984	4228	4692	5007	5782	6354	10.97%	6.71%	15.47%	9.89%	50.28%
432	186	NT	3984	4265	4897	5320	6146	6783	14.81%	8.63%	15.52%	10.36%	59.03%
432	201	CTSP	3984	4216	4830	5111	5706	6453	14.56%	5.81%	11.64%	13.09%	53.05%
432	201	RT	3984	4229	4889	5180	5842	6610	15.60%	5.95%	12.77%	13.14%	56.30%
432	201	NT	3984	4265	5006	5353	6022	6773	17.37%	6.93%	12.49%	12.47%	58.80%
432	262	CTSP	3984	4232	4879	5255	6382	6789	15.28%	7.70%	21.44%	6.37%	60.42%
432	503	CTSP	3984	4257	4385	4670	5290	5786	3.00%	6.49%	13.27%	9.37%	35.91%
432	508	CTFP	3984	4271	4411	4760	5237	5819	3.27%	7.91%	10.02%	11.11%	36.24%
433	100	CTSP	3359	3615	4308	4634	5388	5821	19.17%	7.56%	16.27%	8.03%	61.02%
433	131	CTSP	3359	3615	4073	4257	4641	5156	12.66%	4.51%	9.02%	11.09%	42.62%
433	131	NT	3359	3655	4279	4579	4995	5542	17.07%	7.01%	9.08%	10.95%	51.62%
433	186	RT	3359	3650	3971	4262	4931	5413	8.79%	7.32%	15.69%	9.77%	48.30%
433	186	NT	3359	3676	4138	4528	5215	5778	12.56%	9.42%	15.17%	10.79%	57.18%
433	201	CTSP	3359	3605	4123	4372	4856	5431	14.36%	6.03%	11.07%	11.84%	50.65%
433	201	RT	3359	3617	4172	4433	4983	5575	15.34%	6.25%	12.40%	11.88%	54.13%
433	201	NT	3359	3679	4315	4652	5190	5786	17.28%	7.80%	11.56%	11.48%	57.27%
433	262	CTSP	3359	3660	4136	4455	5228	5566	13.00%	7.71%	17.35%	6.46%	52.07%
433	503	CTSP	3359	3652	3660	3819	4258	4589	0.21%	4.34%	11.49%	7.77%	25.65%
433	508	CTFP	3359	3666	3684	3892	4146	4469	0.49%	5.64%	6.52%	7.79%	21.90%
441	186	CTFP	3702	3874	3922	3937	4329	4580	1.23%	0.38%	9.95%	5.79%	18.22%
441	186	CTSP	3702	3874	4007	4078	4511	4806	3.43%	1.77%	10.61%	6.53%	24.05%
441	186	NT	3702	3905	4150	4323	4756	5093	6.27%	4.16%	10.01%	7.08%	30.42%
441	218	NT	3702	3931	4424	4890	5419	6000	12.54%	10.53%	10.81%	10.72%	52.63%
441	366	CTFP	3702	3921	3901	4042	4266	4564	-0.51%	3.61%	5.54%	6.98%	16.39%
441	366	RT	3702	3922	3841	3865	4185	4395	-2.06%	0.62%	8.27%	5.01%	12.06%
441	416	CTFP	3702	3897	3997	4116	4469	4808	2.56%	2.97%	8.57%	7.58%	23.37%
441	416	NT	3702	3931	4269	4535	4943	5422	8.59%	6.23%	8.99%	9.69%	37.92%
441	458	CTFP	3702	3867	3846	3891	4073	4386	-0.54%	1.17%	4.67%	7.68%	13.42%
441	459	RT	3702	3873	4190	4336	4625	5028	8.18%	3.48%	6.66%	8.71%	29.82%
441	459	NT	3702	3909	4238	4436	4665	5074	8.41%	4.67%	5.16%	8.76%	29.80%
441	503	CTSP	3702	3916	3752	3824	4068	4397	-4.18%	1.91%	6.38%	8.08%	12.28%
441	508	CTFP	3702	3923	3758	3903	3922	4404	-4.20%	3.85%	0.48%	12.28%	12.26%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
442	186	CTFP	2761	2950	3175	3310	3734	3973	7.62%	4.25%	12.80%	6.40%	34.67%
442	186	CTSP	2761	2949	3249	3428	3891	4180	10.17%	5.50%	13.50%	7.42%	41.74%
442	186	NT	2761	2983	3445	3731	4238	4589	15.48%	8.30%	13.58%	8.28%	53.83%
442	218	NT	2761	3022	3802	4461	5223	6060	25.81%	17.33%	17.08%	16.02%	100.52%
442	366	CTFP	2761	2995	3014	3084	3340	3575	0.63%	2.32%	8.30%	7.03%	19.36%
442	366	RT	2761	2997	2938	2912	3251	3373	-1.96%	-0.88%	11.64%	3.75%	12.54%
442	416	CTFP	2761	2986	3235	3281	3641	4051	8.33%	1.42%	10.97%	11.26%	35.66%
442	416	NT	2761	3023	3547	3744	4188	4757	17.33%	5.55%	11.85%	13.58%	57.36%
442	458	CTFP	2761	2935	2888	2886	3067	3263	-1.60%	-0.06%	6.27%	6.39%	11.17%
442	459	RT	2761	2942	3304	3401	3762	4163	12.30%	2.93%	10.61%	10.65%	41.50%
442	459	NT	2761	2978	3366	3551	3852	4274	13.02%	5.49%	8.47%	10.95%	43.51%
442	503	CTSP	2761	2971	2843	2865	3124	3308	-4.30%	0.77%	9.04%	5.88%	11.34%
442	508	CTFP	2761	2978	2840	2895	2912	3223	-4.63%	1.93%	0.58%	10.67%	8.22%
443	186	CTFP	2477	2652	2851	2963	3305	3528	7.50%	3.92%	11.54%	6.74%	33.03%
443	186	CTSP	2477	2651	2918	3078	3458	3730	10.07%	5.48%	12.34%	7.86%	40.70%
443	186	NT	2477	2681	3115	3371	3811	4122	16.18%	8.21%	13.05%	8.16%	53.74%
443	218	NT	2477	2713	3476	4047	4720	5254	28.12%	16.42%	16.62%	11.31%	93.66%
443	366	CTFP	2477	2689	2844	2998	3214	3497	5.76%	5.41%	7.20%	8.80%	30.04%
443	366	RT	2477	2690	2757	2816	3124	3201	2.49%	2.14%	10.93%	2.46%	18.99%
443	416	CTFP	2477	2682	2934	2959	3301	3626	9.39%	0.85%	11.55%	9.84%	35.19%
443	416	NT	2477	2713	3222	3394	3845	4303	18.76%	5.33%	13.28%	11.91%	58.60%
443	458	CTFP	2477	2635	2687	2690	2899	3051	1.97%	0.11%	7.76%	5.24%	15.78%
443	459	RT	2477	2640	3060	3206	3544	3915	15.90%	4.77%	10.54%	10.46%	48.29%
443	459	NT	2477	2670	3128	3362	3657	4056	17.15%	7.48%	8.77%	10.91%	51.91%
443	503	CTSP	2477	2675	2698	2819	3118	3303	0.85%	4.48%	10.60%	5.93%	23.47%
443	508	CTFP	2477	2683	2707	2852	2939	3239	0.89%	5.35%	3.05%	10.20%	20.72%
444	186	CTFP	2454	2610	2921	3101	3544	3791	11.91%	6.16%	14.28%	6.96%	45.24%
444	186	CTSP	2454	2610	2992	3222	3710	4008	14.63%	7.68%	15.14%	8.03%	53.56%
444	186	NT	2454	2636	3154	3469	3995	4359	19.65%	9.98%	15.16%	9.11%	65.36%
444	218	NT	2454	2660	3541	4331	5241	6034	33.12%	22.31%	21.01%	15.13%	126.84%
444	366	CTFP	2454	2642	2770	2871	3087	3379	4.84%	3.64%	7.52%	9.45%	27.89%
444	366	RT	2454	2643	2669	2684	2972	3111	0.98%	0.56%	10.73%	4.67%	17.70%
444	416	CTFP	2454	2632	2993	3056	3390	3846	13.71%	2.10%	10.92%	13.45%	46.12%
444	416	NT	2454	2660	3253	3451	3865	4470	22.29%	6.08%	11.99%	15.65%	68.04%
444	458	CTFP	2454	2594	2640	2691	2871	3096	1.77%	1.93%	6.68%	7.83%	19.35%
444	459	RT	2454	2600	3110	3303	3764	4267	19.61%	6.20%	13.95%	13.36%	64.11%
444	459	NT	2454	2627	3141	3411	3814	4347	19.56%	8.59%	11.81%	13.97%	65.47%
444	503	CTSP	2454	2611	2556	2591	2833	3008	-2.10%	1.36%	9.34%	6.17%	15.20%
444	508	CTFP	2454	2617	2558	2606	2687	2963	-2.25%	1.87%	3.10%	10.27%	13.22%
471	2	CTSP	3746	3779	4853	5316	6379	7347	28.42%	9.54%	19.99%	15.17%	94.41%
471	2	RT	3746	3780	4910	5396	6508	7525	29.89%	9.89%	20.60%	15.62%	99.07%
471	100	NT	3746	3787	5048	5626	6856	7754	33.29%	11.45%	21.86%	13.09%	104.75%
471	125	CTSP	3746	3769	4610	4991	5678	6044	22.31%	8.26%	13.76%	6.44%	60.36%
471	145	CTFP	3746	3774	4558	4887	5375	5924	20.77%	7.21%	9.98%	10.21%	56.96%
471	215	CTSP	3746	3769	4919	5610	6690	7782	30.51%	14.04%	19.25%	16.32%	106.47%
471	215	RT	3746	3776	4968	5703	6872	8045	31.56%	14.79%	20.49%	17.06%	113.05%
471	215	NT	3746	3785	5205	6061	7433	8817	37.51%	16.44%	22.63%	18.61%	132.94%
471	262	CTFP	3746	3778	4456	4783	5662	6165	17.94%	7.33%	18.37%	8.88%	63.18%
471	463	CTSP	3746	3714	3907	3963	4186	4309	5.19%	1.43%	5.62%	2.93%	16.02%
471	463	RT	3746	3714	4442	4768	5536	6107	19.60%	7.33%	16.10%	10.31%	64.43%
471	508	CTFP	3746	3782	4158	4352	4697	5226	9.94%	4.66%	7.92%	11.26%	38.18%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
472	2	CTSP	4227	4344	5794	6357	7519	8892	33.37%	9.71%	18.27%	18.26%	104.69%
472	2	RT	4227	4345	5867	6449	7645	9110	35.02%	9.91%	18.54%	19.16%	109.66%
472	100	NT	4227	4348	6170	7016	8837	10650	41.90%	13.71%	25.95%	20.51%	144.94%
472	125	CTSP	4227	4330	5299	5920	7005	7846	22.37%	11.71%	18.32%	12.00%	81.20%
472	145	CTFP	4227	4332	5311	5905	6547	7694	22.59%	11.18%	10.87%	17.51%	77.60%
472	215	CTSP	4227	4330	5845	6650	8100	9835	34.98%	13.77%	21.80%	21.41%	127.13%
472	215	RT	4227	4337	5920	6751	8305	10177	36.49%	14.03%	23.01%	22.54%	134.65%
472	215	NT	4227	4348	6046	6957	8604	10741	39.05%	15.06%	23.67%	24.83%	147.03%
472	262	CTFP	4227	4337	5156	5583	6601	7463	18.88%	8.28%	18.23%	13.05%	72.07%
472	463	CTSP	4227	4295	4576	4560	4812	5038	6.54%	-0.34%	5.52%	4.69%	17.29%
472	463	RT	4227	4295	5129	5351	6100	6891	19.41%	4.32%	13.99%	12.96%	60.44%
472	508	CTFP	4227	4340	4704	5005	5255	6178	8.38%	6.39%	4.99%	17.56%	42.35%
473	2	CTSP	3895	3971	5046	5594	6327	7277	27.07%	10.86%	13.10%	15.01%	83.25%
473	2	RT	3895	3977	5117	5713	6470	7508	28.66%	11.64%	13.25%	16.04%	88.78%
473	100	NT	3895	3976	5435	6156	7504	8698	36.69%	13.26%	21.89%	15.91%	118.76%
473	125	CTSP	3895	3958	4921	5555	6397	7265	24.33%	12.88%	15.15%	13.56%	83.55%
473	145	CTFP	3895	3965	4918	5618	6258	7215	24.03%	14.23%	11.39%	15.29%	81.96%
473	215	CTSP	3895	3956	5157	5868	6859	7948	30.35%	13.78%	16.88%	15.87%	100.91%
473	215	RT	3895	3967	5232	5993	7091	8317	31.88%	14.54%	18.32%	17.28%	109.65%
473	215	NT	3895	3975	5428	6311	7524	9106	36.55%	16.26%	19.22%	21.02%	129.08%
473	262	CTFP	3895	3975	5020	5630	6625	7597	26.28%	12.15%	17.67%	14.67%	91.11%
473	463	CTSP	3895	3917	4128	4133	4345	4511	5.38%	0.12%	5.12%	3.82%	15.16%
473	463	RT	3895	3917	4479	4649	5219	5758	14.34%	3.79%	12.26%	10.32%	47.00%
473	508	CTFP	3895	3977	4700	5289	5674	7133	18.17%	12.53%	7.27%	25.71%	79.35%
474	2	CTSP	3166	3279	4632	5478	6407	7865	41.26%	18.26%	16.95%	22.75%	139.85%
474	2	RT	3166	3282	4698	5582	6542	8070	43.14%	18.81%	17.19%	23.35%	145.88%
474	100	NT	3166	3288	5350	6666	8787	10755	62.71%	24.59%	31.81%	22.39%	227.09%
474	125	CTSP	3166	3277	4287	5145	6345	7376	30.82%	20.01%	23.32%	16.24%	125.08%
474	145	CTFP	3166	3280	4258	5120	5739	6799	29.81%	20.24%	12.08%	18.47%	107.28%
474	215	CTSP	3166	3274	4725	5946	7097	8821	44.31%	25.84%	19.35%	24.29%	169.42%
474	215	RT	3166	3280	4798	6085	7340	9181	46.28%	26.82%	20.62%	25.08%	179.90%
474	215	NT	3166	3285	4948	6423	7829	10002	50.62%	29.81%	21.89%	27.75%	204.47%
474	262	CTFP	3166	3281	4039	4584	5530	6516	23.10%	13.49%	20.63%	17.83%	98.59%
474	463	CTSP	3166	3219	3388	3430	3620	3708	5.25%	1.23%	5.53%	2.43%	15.19%
474	463	RT	3166	3219	3960	4309	5416	6207	23.01%	8.81%	25.69%	14.60%	92.82%
474	508	CTFP	3166	3287	3592	4005	4196	5162	9.27%	11.49%	4.76%	23.02%	57.04%
475	2	CTSP	3650	3753	4749	5348	5969	6781	26.53%	12.61%	11.61%	13.60%	80.68%
475	2	RT	3650	3758	4805	5434	6082	6954	27.86%	13.09%	11.92%	14.33%	85.04%
475	100	NT	3650	3762	5463	6399	7853	9160	45.21%	17.13%	22.72%	16.64%	143.48%
475	125	CTSP	3650	3745	4792	5529	6449	7347	27.95%	15.37%	16.63%	13.92%	96.18%
475	145	CTFP	3650	3749	4846	5608	6346	7216	29.26%	15.72%	13.15%	13.70%	92.47%
475	215	CTSP	3650	3745	4938	5831	6645	7734	31.85%	18.08%	13.95%	16.38%	106.51%
475	215	RT	3650	3754	5004	5948	6847	8069	33.29%	18.86%	15.11%	17.84%	114.94%
475	215	NT	3650	3762	5185	6273	7302	8762	37.82%	20.98%	16.40%	19.99%	132.90%
475	262	CTFP	3650	3758	4821	5515	6595	7490	28.28%	14.39%	19.58%	13.57%	99.30%
475	463	CTSP	3650	3691	3866	3904	4124	4189	4.74%	0.98%	5.63%	1.57%	13.49%
475	463	RT	3650	3691	4127	4308	4917	5290	11.81%	4.38%	14.13%	7.58%	43.32%
475	508	CTFP	3650	3774	4573	5296	5714	7058	21.17%	15.81%	7.89%	23.52%	87.01%
531	4	CTSP	3424	3475	4090	4370	4652	5484	17.69%	6.84%	6.45%	17.88%	57.81%
531	4	RT	3424	3477	4121	4403	4700	5571	18.52%	6.84%	6.74%	18.53%	60.22%
531	100	CTSP	3424	3424	4215	4684	5374	5863	23.10%	11.12%	14.73%	9.09%	71.23%
531	100	RT	3424	3429	4292	4813	5573	6123	25.16%	12.13%	15.79%	9.86%	78.56%
531	100	NT	3424	3438	4421	5031	5892	6530	28.59%	13.79%	17.11%	10.82%	89.93%
531	244	CTSP	3424	3429	3883	4230	4456	4907	13.24%	8.93%	5.34%	10.12%	43.10%
531	463	CTSP	3424	3418	3536	3582	3758	3865	3.45%	1.30%	4.91%	2.84%	13.07%
531	463	RT	3424	3418	3543	3594	3772	3885	3.65%	1.43%	4.95%	2.99%	13.66%
531	503	CTFP	3424	3489	3859	4213	4638	5446	10.60%	9.17%	10.08%	17.42%	56.09%
531	508	CTSP	3424	3491	3892	4213	4613	5274	11.48%	8.24%	9.49%	14.32%	51.07%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
532	4	CTSP	2956	3042	3556	3867	4039	4720	16.89%	8.74%	4.44%	16.86%	55.16%
532	4	RT	2956	3044	3575	3888	4068	4784	17.44%	8.75%	4.62%	17.60%	57.16%
532	100	CTSP	2956	3003	3754	4169	4794	5187	25.00%	11.05%	14.99%	8.19%	72.72%
532	100	RT	2956	3008	3796	4252	4937	5382	26.19%	12.01%	16.11%	9.01%	78.92%
532	100	NT	2956	3013	3899	4448	5233	5722	29.40%	14.08%	17.64%	9.34%	89.91%
532	244	CTSP	2956	3011	3579	4018	4253	4760	18.86%	12.26%	5.84%	11.92%	58.08%
532	463	CTSP	2956	2994	3176	3231	3340	3418	6.07%	1.73%	3.37%	2.33%	14.16%
532	463	RT	2956	2994	3181	3237	3348	3432	6.24%	1.76%	3.42%	2.50%	14.62%
532	503	CTFP	2956	3073	3594	4127	4767	5480	16.95%	14.83%	15.50%	14.95%	78.32%
532	508	CTSP	2956	3077	3633	4091	4782	5495	18.06%	12.60%	16.89%	14.91%	78.58%
533	4	CTSP	2943	3000	3389	3563	3669	4192	12.96%	5.13%	2.97%	14.25%	39.73%
533	4	RT	2943	3001	3400	3578	3690	4237	13.29%	5.23%	3.13%	14.82%	41.18%
533	100	CTSP	2943	2979	3988	4503	5250	5711	33.87%	12.91%	16.58%	8.78%	91.70%
533	100	RT	2943	2983	4021	4591	5413	5930	34.79%	14.17%	17.90%	9.55%	98.79%
533	100	NT	2943	2988	4103	4759	5686	6302	37.31%	15.98%	19.47%	10.83%	110.91%
533	244	CTSP	2943	2983	3907	4596	4895	5591	30.97%	17.63%	6.50%	14.21%	87.42%
533	463	CTSP	2943	2963	3083	3084	3160	3291	4.04%	0.03%	2.46%	4.14%	11.06%
533	463	RT	2943	2963	3086	3090	3166	3301	4.15%	0.12%	2.45%	4.26%	11.40%
533	503	CTFP	2943	3032	3674	4239	4919	5894	21.17%	15.37%	16.04%	19.82%	94.39%
533	508	CTSP	2943	3038	3693	4183	4853	5693	21.56%	13.26%	16.01%	17.30%	87.39%
561	100	NT	3438	3815	5668	6911	8713	10717	48.57%	21.93%	26.07%	23.00%	180.91%
561	131	CTSP	3438	3714	4338	4641	5034	5628	16.80%	6.98%	8.46%	11.79%	51.53%
561	131	RT	3438	3730	4441	4809	5262	5946	19.06%	8.28%	9.41%	12.99%	59.41%
561	131	NT	3438	3767	4698	5237	5848	6546	24.71%	11.47%	11.66%	11.93%	73.77%
561	145	CTSP	3438	3762	4461	5075	5248	6055	18.58%	13.76%	3.40%	15.37%	60.95%
561	145	RT	3438	3776	4525	5218	5472	6350	19.83%	15.31%	4.86%	16.04%	68.16%
561	186	CTSP	3438	3758	4425	4882	5575	6465	17.74%	10.32%	14.19%	15.96%	72.03%
561	201	RT	3438	3771	4490	4818	5381	6349	19.06%	7.30%	11.68%	17.98%	68.36%
561	246	CTSP	3438	3777	4649	5197	6367	7368	23.08%	11.78%	22.51%	15.72%	95.07%
561	246	RT	3438	3792	4825	5478	6648	7660	27.24%	13.53%	21.35%	15.22%	102.00%
561	262	CTSP	3438	3713	3874	4077	4428	4725	4.33%	5.24%	8.60%	6.70%	27.25%
561	366	CTSP	3438	3827	4016	4228	4511	5026	4.93%	5.27%	6.69%	11.41%	31.33%
562	100	NT	3931	4355	6128	7437	9364	11661	40.71%	21.36%	25.91%	24.53%	167.76%
562	131	CTSP	3931	4251	5026	5424	5937	6660	18.23%	7.91%	9.45%	12.17%	56.66%
562	131	RT	3931	4266	5116	5575	6186	7000	19.92%	8.97%	10.95%	13.15%	64.08%
562	131	NT	3931	4312	5270	5850	6568	7320	22.21%	11.00%	12.27%	11.44%	69.75%
562	145	CTSP	3931	4294	5015	5752	5986	6950	16.79%	14.69%	4.06%	16.10%	61.85%
562	145	RT	3931	4308	5070	5872	6191	7197	17.68%	15.81%	5.43%	16.24%	67.06%
562	186	CTSP	3931	4289	4964	5507	6290	7408	15.73%	10.93%	14.21%	17.77%	72.72%
562	201	RT	3931	4303	5058	5472	6068	7223	17.54%	8.18%	10.89%	19.03%	67.85%
562	246	CTSP	3931	4309	5185	5816	7267	8473	20.32%	12.16%	24.94%	16.59%	96.63%
562	246	RT	3931	4323	5358	6113	7557	8778	23.94%	14.09%	23.62%	16.15%	103.05%
562	262	CTSP	3931	4266	4466	4688	5143	5520	4.68%	4.97%	9.70%	7.33%	29.39%
562	366	CTSP	3931	4359	4548	4755	5159	5710	4.33%	4.55%	8.49%	10.68%	30.99%
571	125	RT	4204	4508	5384	5888	6827	7786	19.43%	9.36%	15.94%	14.04%	72.71%
571	131	CTSP	4204	4439	5066	5368	5764	6354	14.12%	5.96%	7.37%	10.23%	43.14%
571	131	RT	4204	4455	5193	5559	6034	6704	16.56%	7.04%	8.54%	11.10%	50.48%
571	131	NT	4204	4495	5422	5953	6531	7240	20.62%	9.79%	9.70%	10.85%	61.06%
571	138	RT	4204	4508	5249	5671	6554	7191	16.43%	8.03%	15.57%	9.71%	59.51%
571	186	CTFP	4204	4495	5093	5452	6063	6876	13.30%	7.04%	11.20%	13.40%	52.96%
571	186	RT	4204	4507	5279	5730	6467	7420	17.12%	8.54%	12.86%	14.73%	64.63%
571	218	CTFP	4204	4494	5057	5397	6069	6859	12.52%	6.72%	12.45%	13.01%	52.62%
571	218	RT	4204	4507	5280	5741	6550	7540	17.15%	8.73%	14.09%	15.11%	67.29%
571	339	CTSP	4204	4570	5014	5654	6276	6761	9.71%	12.76%	11.00%	7.72%	47.94%
571	339	RT	4204	4576	5052	5661	6311	6844	10.40%	12.05%	11.48%	8.44%	49.56%
571	350	CTSP	4204	4567	4869	5419	5877	6509	6.61%	11.29%	8.45%	10.75%	42.52%
571	366	CTSP	4204	4567	4979	5512	6045	6807	9.02%	10.70%	9.66%	12.60%	49.04%
571	508	CTFP	4204	4587	4892	5498	5771	6822	6.64%	12.38%	4.96%	18.21%	48.72%
571	508	CTSP	4204	4587	4910	5534	6172	6960	7.04%	12.70%	11.52%	12.76%	51.73%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
572	125	RT	3822	4147	4735	5357	6305	7273	14.17%	13.13%	17.69%	15.35%	75.37%
572	131	CTSP	3822	4044	4664	4960	5350	5939	15.33%	6.34%	7.86%	11.00%	46.85%
572	131	RT	3822	4061	4777	5133	5592	6261	17.63%	7.45%	8.94%	11.96%	54.17%
572	131	NT	3822	4102	5018	5497	6066	6728	22.33%	9.54%	10.35%	10.91%	64.01%
572	138	RT	3822	4147	4592	5190	7055	8412	10.73%	13.02%	35.93%	19.23%	102.84%
572	186	CTFP	3822	4133	4536	4916	5564	6452	9.75%	8.37%	13.18%	15.95%	56.10%
572	186	RT	3822	4144	4702	5202	5993	7049	13.46%	10.63%	15.20%	17.62%	70.10%
572	218	CTFP	3822	4132	4639	4979	5689	6706	12.27%	7.32%	14.25%	17.87%	62.29%
572	218	RT	3822	4143	4838	5316	6190	7391	16.77%	9.88%	16.44%	19.40%	78.39%
572	339	CTSP	3822	4188	4479	4959	5689	6044	6.94%	10.71%	14.72%	6.24%	44.31%
572	339	RT	3822	4196	4517	5025	5769	6168	7.65%	11.24%	14.80%	6.91%	46.99%
572	350	CTSP	3822	4200	4379	4826	5303	5873	4.26%	10.20%	9.88%	10.74%	39.83%
572	366	CTSP	3822	4200	4463	4963	5488	6189	6.26%	11.20%	10.57%	12.77%	47.35%
572	508	CTFP	3822	4215	4381	4858	5283	6402	3.93%	10.88%	8.74%	21.18%	51.88%
572	508	CTSP	3822	4215	4396	4882	5323	6139	4.29%	11.05%	9.03%	15.32%	45.64%
573	125	RT	3085	3415	3861	4279	4983	5638	13.06%	10.82%	16.45%	13.14%	65.09%
573	131	CTSP	3085	3330	3902	4170	4456	4936	17.17%	6.86%	6.85%	10.77%	48.22%
573	131	RT	3085	3342	4001	4319	4655	5200	19.71%	7.94%	7.77%	11.70%	55.59%
573	131	NT	3085	3385	4265	4708	5171	5726	25.99%	10.38%	9.83%	10.73%	69.15%
573	138	RT	3085	3415	3787	4204	5014	5455	10.89%	11.01%	19.26%	8.79%	59.73%
573	186	CTFP	3085	3406	3793	4131	4675	5345	11.36%	8.91%	13.16%	14.33%	56.92%
573	186	RT	3085	3384	3836	4227	4854	5672	13.35%	10.19%	14.83%	16.85%	67.61%
573	218	CTFP	3085	3404	3920	4206	4825	5652	15.15%	7.29%	14.71%	17.13%	66.03%
573	218	RT	3085	3414	4091	4484	5237	6219	19.83%	9.60%	16.79%	18.75%	82.16%
573	339	CTSP	3085	3427	3595	3882	4467	4583	4.90%	7.98%	15.06%	2.59%	33.73%
573	339	RT	3085	3429	3628	3937	4552	4698	5.80%	8.51%	15.62%	3.20%	37.00%
573	350	CTSP	3085	3496	3469	3737	4125	4357	-0.77%	7.72%	10.38%	5.62%	24.62%
573	366	CTSP	3085	3496	3497	3735	4109	4388	0.02%	6.80%	10.01%	6.78%	25.51%
573	508	CTFP	3085	3449	3507	3728	4023	4722	1.68%	6.30%	7.91%	17.37%	36.90%
573	508	CTSP	3085	3449	3513	3722	4020	4497	1.85%	5.94%	8.00%	11.86%	30.38%
581	100	RT	2358	2354	2703	2927	3408	3676	14.82%	8.28%	16.43%	7.86%	56.15%
581	100	NT	2358	2363	2836	3118	3643	3952	20.01%	9.94%	16.83%	8.48%	67.24%
581	186	CTSP	2358	2349	2689	2900	3331	3613	14.47%	7.84%	14.86%	8.46%	53.81%
581	186	RT	2358	2354	2717	2941	3402	3702	15.42%	8.24%	15.67%	8.81%	57.26%
581	186	NT	2358	2363	2840	3140	3666	4020	20.18%	10.56%	16.75%	9.65%	70.12%
581	218	CTFP	2358	2350	2498	2597	2892	3113	6.29%	3.96%	11.35%	7.64%	32.46%
581	218	RT	2358	2354	2533	2649	2959	3201	7.60%	4.57%	11.70%	8.17%	35.98%
581	218	NT	2358	2363	2612	2768	3090	3336	10.53%	5.97%	11.63%	7.96%	41.17%
581	262	CTSP	2358	2380	2558	2756	3088	3281	7.47%	7.74%	12.04%	6.25%	37.85%
581	463	RT	2358	2343	2165	2023	2031	2032	-7.59%	-6.55%	0.39%	0.04%	-13.27%
581	490	RT	2358	2351	2411	2427	2632	2809	2.55%	0.66%	8.44%	6.72%	19.48%
581	503	CTFP	2358	2357	2252	2353	2363	2489	-4.45%	4.48%	0.42%	5.33%	5.60%
581	508	CTFP	2358	2421	2497	2650	2719	3110	3.13%	6.12%	2.60%	14.38%	28.45%
581	508	CTSP	2358	2421	2495	2641	2795	3081	3.05%	5.85%	5.83%	10.23%	27.26%
582	100	RT	4777	4996	6935	8103	10165	11164	38.81%	16.84%	25.44%	9.82%	123.45%
582	100	NT	4777	5012	6739	7709	9838	11608	34.45%	14.39%	27.61%	17.99%	131.60%
582	186	CTSP	4777	4986	5616	6020	6827	7446	12.63%	7.19%	13.40%	9.06%	49.33%
582	186	RT	4777	4995	5631	6099	6992	7677	12.73%	8.31%	14.64%	9.79%	53.69%
582	186	NT	4777	5012	5739	6183	7088	7674	14.50%	7.73%	14.63%	8.26%	53.11%
582	218	CTFP	4777	4987	5976	6603	7720	8630	19.83%	10.49%	16.91%	11.78%	73.04%
582	218	RT	4777	4995	6076	6796	8024	8998	21.64%	11.84%	18.06%	12.13%	80.14%
582	218	NT	4777	5012	5964	6517	8013	9491	18.99%	9.27%	22.95%	18.44%	89.36%
582	262	CTSP	4777	4994	5152	5473	6193	6559	3.16%	6.23%	13.15%	5.90%	31.33%
582	463	RT	4777	4899	4620	4314	4472	4586	-5.69%	-6.62%	3.66%	2.54%	-6.38%
582	490	RT	4777	4931	5431	5835	6720	7491	10.13%	7.43%	15.16%	11.47%	51.91%
582	503	CTFP	4777	4970	4859	5265	5521	6005	-2.23%	8.35%	4.86%	8.76%	20.82%
582	508	CTFP	4777	5079	5431	5870	6437	7446	6.93%	8.08%	9.65%	15.67%	46.60%
582	508	CTSP	4777	5077	5426	5849	6555	7425	6.87%	7.79%	12.07%	13.27%	46.24%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
583	100	RT	4626	4786	6152	7006	8404	9191	28.54%	13.88%	19.95%	9.36%	92.03%
583	100	NT	4626	4803	6026	6819	8303	9417	25.46%	13.15%	21.76%	13.41%	96.06%
583	186	CTSP	4626	4775	5113	5343	5988	6504	7.07%	4.49%	12.07%	8.61%	36.20%
583	186	RT	4626	4785	5176	5454	6110	6678	8.17%	5.37%	12.02%	9.29%	39.56%
583	186	NT	4626	4803	5262	5594	6277	6804	9.55%	6.30%	12.20%	8.39%	41.66%
583	218	CTFP	4626	4777	5394	5767	6551	7263	12.91%	6.91%	13.59%	10.86%	52.04%
583	218	RT	4626	4785	5496	5958	6825	7615	14.85%	8.40%	14.55%	11.57%	59.14%
583	218	NT	4626	4803	5429	5841	6671	7604	13.03%	7.58%	14.20%	13.98%	58.31%
583	262	CTSP	4626	4794	5019	5333	5992	6355	4.69%	6.25%	12.35%	6.05%	32.56%
583	463	RT	4626	4727	4269	3880	3895	3987	-9.68%	-9.11%	0.38%	2.36%	-15.65%
583	490	RT	4626	4763	4935	5124	5721	6255	3.61%	3.82%	11.65%	9.33%	31.32%
583	503	CTFP	4626	4774	4393	4596	4791	5193	-7.98%	4.62%	4.24%	8.39%	8.77%
583	508	CTFP	4626	4903	5153	5489	6038	6943	5.09%	6.52%	10.00%	14.98%	41.60%
583	508	CTSP	4626	4903	5143	5456	6200	6907	4.89%	6.08%	13.63%	11.40%	40.87%
584	100	RT	4496	4485	6281	7279	8851	9839	40.04%	15.88%	21.59%	11.16%	119.37%
584	100	NT	4496	4515	6196	7028	8880	10391	37.23%	13.42%	26.35%	17.01%	130.14%
584	186	CTSP	4496	4477	5097	5425	6189	6702	13.84%	6.43%	14.08%	8.28%	49.69%
584	186	RT	4496	4485	5154	5539	6321	6896	14.91%	7.46%	14.11%	9.09%	53.75%
584	186	NT	4496	4514	5244	5653	6395	6991	16.17%	7.79%	13.12%	9.31%	54.87%
584	218	CTFP	4496	4477	5260	5776	6673	7375	17.48%	9.80%	15.52%	10.52%	64.73%
584	218	RT	4496	4485	5370	5999	6973	7766	19.73%	11.71%	16.23%	11.37%	73.15%
584	218	NT	4496	4514	5359	5874	6811	7912	18.71%	9.61%	15.95%	16.16%	75.27%
584	262	CTSP	4496	4490	4717	5063	5724	6065	5.05%	7.33%	13.05%	5.95%	35.07%
584	463	RT	4496	4418	3994	3691	3698	3739	-9.59%	-7.58%	0.18%	1.10%	-15.36%
584	490	RT	4496	4450	4581	4796	5375	5783	2.94%	4.69%	12.07%	7.59%	29.95%
584	503	CTFP	4496	4482	4408	4917	5089	5523	-1.65%	11.54%	3.49%	8.52%	23.22%
584	508	CTFP	4496	4576	4743	5083	5563	6334	3.64%	7.16%	9.44%	13.85%	38.41%
584	508	CTSP	4496	4576	4752	5034	5670	6199	3.84%	5.93%	12.63%	9.32%	35.46%
591	100	CTSP	4635	5054	5886	6301	7267	7846	16.46%	7.05%	15.33%	7.96%	55.24%
591	100	RT	4635	5076	6067	6613	7762	8474	19.52%	8.99%	17.37%	9.17%	66.94%
591	100	NT	4635	5150	6294	6886	8008	8823	22.21%	9.40%	16.29%	10.17%	71.32%
591	186	CTFP	4635	5132	5541	5853	6630	7475	7.96%	5.63%	13.27%	12.74%	45.65%
591	186	RT	4635	5148	5712	6183	7150	8181	10.95%	8.24%	15.63%	14.41%	58.91%
591	244	CTSP	4635	5170	6328	7251	8138	9636	22.39%	14.58%	12.23%	18.40%	86.38%
591	339	CTFP	4635	5185	5215	5441	6137	6375	0.57%	4.33%	12.79%	3.87%	22.95%
591	490	RT	4635	5043	4823	4796	5121	5434	-4.36%	-0.55%	6.77%	6.11%	7.75%
591	508	CTSP	4635	5210	5081	5131	5505	5895	-2.47%	0.98%	7.28%	7.08%	13.14%
592	100	CTSP	3891	4179	4987	5360	6176	6739	19.33%	7.47%	15.22%	9.11%	61.25%
592	100	RT	3891	4194	5127	5579	6536	7232	22.24%	8.81%	17.15%	10.64%	72.43%
592	100	NT	3891	4247	5330	5834	6833	7469	25.50%	9.45%	17.12%	9.30%	75.86%
592	186	CTFP	3891	4265	4453	4699	5278	5789	4.40%	5.52%	12.32%	9.68%	35.73%
592	186	RT	3891	4276	4567	4919	5604	6243	6.80%	7.70%	13.92%	11.40%	46.00%
592	244	CTSP	3891	4291	5300	6122	6559	7617	23.51%	15.50%	7.13%	16.13%	77.51%
592	339	CTFP	3891	4304	4249	4484	5091	5343	-1.27%	5.53%	13.53%	4.94%	24.14%
592	490	RT	3891	4151	4027	3983	4164	4342	-2.98%	-1.09%	4.54%	4.27%	4.60%
592	508	CTSP	3891	4321	4243	4396	4836	5258	-1.80%	3.60%	10.00%	8.72%	21.68%
601	131	CTSP	4176	4234	4724	4977	5349	5874	11.57%	5.35%	7.47%	9.81%	38.73%
601	131	NT	4176	4280	5032	5428	5937	6564	17.57%	7.86%	9.37%	10.56%	53.36%
601	186	CTSP	4176	4297	4653	5017	5568	6171	8.28%	7.82%	10.98%	10.82%	43.61%
601	186	RT	4176	4308	4716	5121	5717	6381	9.47%	8.58%	11.63%	11.61%	48.11%
601	186	NT	4176	4342	4965	5500	6163	6913	14.34%	10.77%	12.05%	12.16%	59.21%
601	201	CTSP	4176	4298	4699	5021	5274	6018	9.32%	6.85%	5.03%	14.10%	40.01%
601	201	RT	4176	4310	4755	5098	5399	6208	10.32%	7.21%	5.90%	14.98%	44.03%
601	201	NT	4176	4343	4945	5362	5731	6546	13.86%	8.43%	6.88%	14.22%	50.72%
601	503	CTSP	4176	4354	4442	4794	5257	5759	2.02%	7.92%	9.65%	9.54%	32.26%
601	508	CTFP	4176	4367	4494	4930	5171	6080	2.90%	9.70%	4.88%	17.57%	39.22%
601	508	RT	4176	4366	4533	4866	5335	5945	3.82%	7.34%	9.63%	11.43%	36.16%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
602	131	CTSP	3614	3584	4388	4742	5306	5959	22.43%	8.06%	11.89%	12.30%	66.26%
602	131	NT	3614	3603	4528	4931	5561	6215	25.67%	8.90%	12.77%	11.76%	72.49%
602	186	CTSP	3614	3603	4195	4599	5312	5980	16.43%	9.63%	15.50%	12.57%	65.97%
602	186	RT	3614	3610	4239	4675	5429	6159	17.42%	10.28%	16.12%	13.44%	70.60%
602	186	NT	3614	3625	4363	4851	5618	6425	20.35%	11.18%	15.81%	14.36%	77.24%
602	201	CTSP	3614	3604	4252	4662	5275	6058	17.98%	9.64%	13.14%	14.84%	68.09%
602	201	RT	3614	3611	4287	4710	5378	6224	18.72%	9.86%	14.18%	15.73%	72.36%
602	201	NT	3614	3626	4361	4828	5482	6322	20.27%	10.70%	13.54%	15.32%	74.35%
602	503	CTSP	3614	3623	3646	3846	4205	4567	0.63%	5.48%	9.33%	8.60%	26.05%
602	508	CTFP	3614	3625	3648	3891	4110	4639	0.63%	6.66%	5.62%	12.87%	27.97%
602	508	RT	3614	3626	3659	3833	4133	4460	0.91%	4.75%	7.82%	7.91%	23.00%
603	131	CTSP	3268	3266	4002	4331	4796	5394	22.53%	8.22%	10.73%	12.46%	65.15%
603	131	NT	3268	3276	4132	4571	5107	5728	26.12%	10.62%	11.72%	12.15%	74.84%
603	186	CTSP	3268	3277	3810	4205	4839	5369	16.26%	10.36%	15.07%	10.95%	63.83%
603	186	RT	3268	3279	3847	4276	4944	5532	17.32%	11.15%	15.62%	11.89%	68.70%
603	186	NT	3268	3280	3975	4483	5205	5848	21.18%	12.77%	16.10%	12.35%	78.29%
603	201	CTSP	3268	3277	3865	4224	4719	5342	17.94%	9.28%	11.71%	13.20%	63.01%
603	201	RT	3268	3280	3901	4273	4821	5489	18.93%	9.53%	12.82%	13.85%	67.34%
603	201	NT	3268	3280	3977	4420	4970	5625	21.25%	11.13%	12.44%	13.17%	71.49%
603	503	CTSP	3268	3280	3340	3516	3924	4213	1.82%	5.26%	11.60%	7.36%	28.44%
603	508	CTFP	3268	3280	3334	3559	3823	4209	1.64%	6.74%	7.41%	10.09%	28.32%
603	508	RT	3268	3279	3338	3486	3825	4049	1.79%	4.43%	9.72%	5.85%	23.48%
611	131	CTFP	3091	3014	3778	4093	4514	5054	25.34%	8.33%	10.28%	11.96%	67.68%
611	131	NT	3091	3014	3915	4376	4873	5541	29.89%	11.77%	11.35%	13.70%	83.84%
611	186	CTFP	3091	3014	3559	3955	4539	4893	18.08%	11.12%	14.76%	7.79%	62.34%
611	186	RT	3091	3014	3656	4136	4816	5280	21.30%	13.12%	16.44%	9.63%	75.18%
611	186	NT	3091	3014	3757	4316	5021	5585	24.65%	14.87%	16.33%	11.23%	85.30%
611	350	CTSP	3091	3014	3332	3522	4049	4280	10.55%	5.70%	14.96%	5.70%	42.00%
611	350	RT	3091	3014	3289	3502	3980	4202	9.12%	6.47%	13.64%	5.57%	39.41%
611	350	NT	3091	3014	3321	3577	4083	4348	10.18%	7.70%	14.14%	6.49%	44.26%
611	458	CTFP	3091	3014	3264	3457	3696	4019	8.29%	5.91%	6.91%	8.73%	33.34%
611	458	RT	3091	3014	3304	3561	3853	4200	9.62%	7.77%	8.19%	9.00%	39.34%
611	458	NT	3091	3014	3375	3688	4049	4411	11.97%	9.27%	9.78%	8.94%	46.35%
611	503	CTSP	3091	3014	3144	3350	3669	3993	4.31%	6.55%	9.52%	8.83%	32.48%
611	503	RT	3091	3014	3155	3375	3714	4061	4.67%	6.97%	10.04%	9.34%	34.73%
611	508	CTFP	3091	3014	3001	3216	3365	3677	-0.43%	7.16%	4.63%	9.27%	21.99%
611	508	RT	3091	3014	2990	3080	3337	3497	-0.79%	3.01%	8.34%	4.79%	16.02%
611	508	NT	3091	3014	2992	3087	3329	3476	-0.72%	3.17%	7.83%	4.41%	15.32%
612	131	CTFP	2033	2003	2525	2715	2986	3327	26.06%	7.52%	9.98%	11.41%	66.10%
612	131	NT	2033	2005	2732	3075	3451	3904	36.25%	12.55%	12.22%	13.12%	94.71%
612	186	CTFP	2033	2005	2325	2582	2995	3163	15.96%	11.05%	15.99%	5.60%	57.75%
612	186	RT	2033	2005	2403	2722	3211	3453	19.85%	13.27%	17.96%	7.53%	72.21%
612	186	NT	2033	2005	2536	2949	3516	3858	26.48%	16.28%	19.22%	9.72%	92.41%
612	350	CTSP	2033	2005	2265	2406	2869	3016	12.96%	6.22%	19.24%	5.12%	50.42%
612	350	RT	2033	2005	2234	2396	2819	2967	11.42%	7.25%	17.65%	5.25%	47.98%
612	350	NT	2033	2005	2267	2461	2917	3102	13.06%	8.55%	18.52%	6.34%	54.71%
612	458	CTFP	2033	2005	2157	2273	2480	2678	7.58%	5.37%	9.10%	7.98%	33.56%
612	458	RT	2033	2005	2200	2373	2626	2845	9.72%	7.86%	10.66%	8.33%	41.89%
612	458	NT	2033	2005	2283	2515	2855	3105	13.86%	10.16%	13.51%	8.75%	54.86%
612	503	CTSP	2033	2005	2115	2276	2540	2770	5.48%	7.61%	11.59%	9.05%	38.15%
612	503	RT	2033	2005	2123	2294	2570	2818	5.88%	8.05%	12.03%	9.64%	40.54%
612	508	CTFP	2033	2004	2009	2156	2272	2436	0.24%	7.31%	5.38%	7.21%	21.55%
612	508	RT	2033	2004	1986	2059	2224	2293	-0.89%	3.67%	8.01%	3.10%	14.42%
612	508	NT	2033	2005	1991	2062	2218	2287	-0.69%	3.56%	7.56%	3.11%	14.06%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
631	186	CTSP	2039	2006	2622	2934	3434	3765	30.70%	11.89%	17.04%	9.63%	87.68%
631	186	RT	2039	2009	2658	2990	3529	3915	32.30%	12.49%	18.02%	10.93%	94.87%
631	186	NT	2039	2013	2855	3267	3921	4330	41.82%	14.43%	20.01%	10.43%	115.10%
631	218	CTFP	2039	2006	2667	3058	3654	4100	32.95%	14.66%	19.48%	12.20%	104.38%
631	218	CTSP	2039	2006	2687	3106	3718	4195	33.94%	15.59%	19.70%	12.82%	109.12%
631	218	RT	2039	2009	2771	3199	3880	4404	37.92%	15.44%	21.28%	13.50%	119.21%
631	218	NT	2039	2013	2910	3336	4056	4545	44.56%	14.63%	21.58%	12.05%	125.78%
631	490	RT	2039	2004	2586	2905	3586	4181	29.04%	12.33%	23.44%	16.59%	108.63%
631	490	NT	2039	2004	2754	3136	3878	4540	37.42%	13.87%	23.66%	17.07%	126.54%
631	503	CTFP	2039	2014	2068	2258	2451	2716	2.68%	9.18%	8.54%	10.81%	34.85%
631	503	RT	2039	2014	2076	2280	2486	2768	3.07%	9.82%	9.03%	11.34%	37.43%
631	508	CTSP	2039	2021	2782	2828	3239	3751	37.65%	1.65%	14.53%	15.80%	85.60%
631	508	RT	2039	2021	2815	2882	3325	3957	39.28%	2.38%	15.37%	19.00%	95.79%
631	508	NT	2039	2022	2855	2968	3447	4128	41.19%	3.95%	16.13%	19.75%	104.15%
632	186	CTSP	3275	3204	4139	4581	5343	5898	29.18%	10.67%	16.63%	10.38%	84.08%
632	186	RT	3275	3205	4163	4644	5418	6040	29.89%	11.55%	16.66%	11.48%	88.45%
632	186	NT	3275	3206	4219	4789	5610	6213	31.59%	13.51%	17.14%	10.74%	93.79%
632	218	CTFP	3275	3204	4143	4709	5523	6203	29.30%	13.66%	17.28%	12.31%	93.60%
632	218	CTSP	3275	3204	4188	4804	5657	6380	30.71%	14.70%	17.75%	12.78%	99.12%
632	218	RT	3275	3205	4261	4870	5775	6513	32.94%	14.29%	18.58%	12.77%	103.21%
632	218	NT	3275	3206	4256	4816	5701	6520	32.75%	13.15%	18.37%	14.36%	103.36%
632	490	RT	3275	3146	3684	3876	4439	5017	17.10%	5.21%	14.52%	13.02%	59.47%
632	490	NT	3275	3146	3819	4062	4627	5188	21.39%	6.36%	13.90%	12.12%	64.90%
632	503	CTFP	3275	3206	3270	3606	3853	4238	1.99%	10.27%	6.84%	9.99%	32.18%
632	503	RT	3275	3205	3278	3630	3897	4313	2.27%	10.73%	7.35%	10.67%	34.57%
632	508	CTSP	3275	3208	4094	4274	4778	5831	27.61%	4.39%	11.79%	22.03%	81.76%
632	508	RT	3275	3208	4177	4378	4886	5952	30.20%	4.81%	11.60%	21.81%	85.53%
632	508	NT	3275	3208	4214	4450	4970	6038	31.35%	5.60%	11.68%	21.48%	88.21%
633	186	CTSP	3178	3128	3964	4360	5054	5554	26.72%	9.98%	15.91%	9.89%	77.55%
633	186	RT	3178	3130	4007	4445	5161	5717	28.01%	10.93%	16.10%	10.77%	82.65%
633	186	NT	3178	3132	4111	4609	5387	5946	31.25%	12.11%	16.88%	10.37%	89.84%
633	218	CTFP	3178	3128	3923	4369	5015	5608	25.41%	11.36%	14.78%	11.82%	79.28%
633	218	CTSP	3178	3128	3965	4455	5139	5770	26.75%	12.35%	15.35%	12.27%	84.46%
633	218	RT	3178	3130	4041	4541	5287	5948	29.10%	12.37%	16.42%	12.50%	90.03%
633	218	NT	3178	3132	4091	4565	5328	5995	30.61%	11.58%	16.71%	12.51%	91.41%
633	490	RT	3178	3076	3521	3649	4122	4557	14.46%	3.63%	12.96%	10.55%	48.14%
633	490	NT	3178	3076	3678	3874	4375	4813	19.57%	5.32%	12.93%	10.01%	56.46%
633	503	CTFP	3178	3132	3166	3509	3745	4091	1.08%	10.83%	6.72%	9.23%	30.61%
633	503	RT	3178	3131	3176	3535	3783	4154	1.43%	11.30%	7.01%	9.80%	32.67%
633	508	CTSP	3178	3134	3772	4008	4797	5299	20.35%	6.25%	19.68%	10.46%	69.08%
633	508	RT	3178	3134	3887	4110	4954	5444	24.02%	5.73%	20.53%	9.89%	73.70%
633	508	NT	3178	3134	3924	4175	5020	5524	25.20%	6.39%	20.23%	10.03%	76.26%
634	186	CTSP	2968	2896	3666	4007	4620	5041	26.58%	9.30%	15.29%	9.11%	74.06%
634	186	RT	2968	2897	3703	4067	4690	5133	27.82%	9.82%	15.31%	9.44%	77.18%
634	186	NT	2968	2898	3794	4226	4917	5366	30.91%	11.38%	16.35%	9.13%	85.16%
634	218	CTFP	2968	2896	3744	4181	4813	5338	29.28%	11.67%	15.11%	10.90%	84.32%
634	218	CTSP	2968	2896	3794	4279	4965	5521	31.00%	12.78%	16.03%	11.19%	90.64%
634	218	RT	2968	2897	3864	4358	5092	5687	33.37%	12.78%	16.84%	11.68%	96.30%
634	218	NT	2968	2898	3915	4376	5109	5661	35.09%	11.77%	16.75%	10.80%	95.34%
634	490	RT	2968	2846	3215	3275	3728	4112	12.96%	1.86%	13.83%	10.30%	44.48%
634	490	NT	2968	2846	3365	3478	3969	4348	18.23%	3.35%	14.11%	9.54%	52.77%
634	503	CTFP	2968	2897	2928	3217	3451	3772	1.07%	9.87%	7.27%	9.30%	30.20%
634	503	RT	2968	2897	2936	3220	3471	3815	1.34%	9.67%	7.79%	9.91%	31.68%
634	508	CTSP	2968	2898	3475	3639	4141	4605	19.91%	4.71%	13.79%	11.20%	58.90%
634	508	RT	2968	2898	3492	3668	4179	4645	20.49%	5.04%	13.93%	11.15%	60.28%
634	508	NT	2968	2899	3531	3710	4227	4696	21.80%	5.06%	13.93%	11.09%	61.98%

Table C.1 (contd.)

CD #	CR #	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
641	100	NT	2962	3197	4080	4595	5311	5843	27.61%	12.62%	15.58%	10.01%	82.76%
641	131	CTSP	2962	3167	3644	3902	4047	4341	15.06%	7.08%	3.71%	7.26%	37.06%
641	131	RT	2962	3175	3697	3980	4140	4472	16.44%	7.65%	4.02%	8.01%	40.85%
641	131	NT	2962	3198	3791	4161	4388	4704	18.54%	9.75%	5.45%	7.20%	47.09%
641	218	CTFP	2962	3171	3663	3995	4458	4942	15.51%	9.06%	11.58%	10.85%	55.84%
641	218	RT	2962	3178	3806	4217	4781	5343	19.76%	10.79%	13.37%	11.75%	68.12%
641	366	CTSP	2962	3202	3500	3777	4398	4676	9.30%	7.91%	16.44%	6.32%	46.03%
641	490	RT	2962	3115	3506	3718	4244	4716	12.55%	6.04%	14.14%	11.12%	51.39%
641	503	CTSP	2962	3207	3451	3748	4215	4497	7.60%	8.60%	12.45%	6.69%	40.22%
642	100	NT	2846	3097	4094	4599	5340	5915	32.19%	12.33%	16.11%	10.76%	90.99%
642	131	CTSP	2846	3071	3622	3868	4200	4706	17.94%	6.79%	8.58%	12.04%	53.23%
642	131	RT	2846	3079	3681	3951	4309	4896	19.55%	7.33%	9.06%	13.62%	59.01%
642	131	NT	2846	3097	3777	4136	4542	5097	21.95%	9.50%	9.81%	12.21%	64.57%
642	218	CTFP	2846	3070	3641	3989	4455	4911	18.59%	9.55%	11.68%	10.23%	59.96%
642	218	RT	2846	3078	3787	4222	4789	5339	23.03%	11.48%	13.42%	11.48%	73.45%
642	366	CTSP	2846	3097	3265	3382	3845	4033	5.42%	3.58%	13.69%	4.88%	30.22%
642	490	RT	2846	3015	3436	3650	4208	4699	13.96%	6.22%	15.28%	11.66%	55.85%
642	503	CTSP	2846	3096	3150	3319	3662	3890	1.74%	5.36%	10.33%	6.22%	25.64%
643	100	NT	1787	1953	2898	3387	4097	4533	48.38%	16.87%	20.96%	10.64%	132.10%
643	131	CTSP	1787	1928	2414	2630	2885	3275	25.20%	8.94%	9.69%	13.51%	69.86%
643	131	RT	1787	1934	2476	2712	2987	3446	28.02%	9.53%	10.14%	15.36%	78.17%
643	131	NT	1787	1953	2630	2979	3341	3811	34.66%	13.26%	12.15%	14.06%	95.13%
643	218	CTFP	1787	1929	2419	2692	3105	3480	25.40%	11.28%	15.34%	12.07%	80.40%
643	218	RT	1787	1935	2571	2935	3460	3919	32.86%	14.15%	17.88%	13.26%	102.53%
643	366	CTSP	1787	1968	2290	2420	2968	3261	16.36%	5.67%	22.64%	9.87%	65.70%
643	490	RT	1787	1894	2350	2582	3060	3448	24.07%	9.87%	18.51%	12.67%	82.04%
643	503	CTSP	1787	1953	2044	2173	2509	2771	4.65%	6.31%	15.46%	10.44%	41.88%

Table C.2 Maximum, Minimum, and Average Percent Change in Total Soil Carbon for 1990-2030 by CD for the Status Quo Scenario

CD #	Maximum	Minimum	Average
CD221	42.97%	2.90%	19.87%
CD222	44.97%	0.13%	19.08%
CD223	46.69%	-1.90%	18.74%
CD231	94.97%	23.89%	48.14%
CD232	142.20%	29.43%	62.27%
CD241	49.43%	12.73%	28.20%
CD242	65.27%	20.06%	34.66%
CD251	60.23%	20.43%	33.15%
CD252	67.27%	35.27%	49.36%
CD253	68.77%	23.57%	37.07%
CD261	80.46%	26.95%	43.60%
CD262	107.26%	33.74%	55.79%
CD271	87.85%	34.65%	50.23%
CD272	104.08%	44.88%	59.68%
CD281	50.69%	27.44%	40.96%
CD282	54.42%	26.64%	43.37%
CD311	128.40%	34.82%	69.11%
CD312	186.19%	30.42%	90.98%
CD313	169.98%	23.87%	79.60%
CD314	141.90%	42.79%	79.88%
CD321	70.61%	45.39%	58.79%
CD322	65.57%	44.40%	56.46%
CD323	76.37%	46.74%	61.27%
CD341	51.10%	23.55%	34.39%
CD342	48.50%	25.76%	36.39%
CD351	103.84%	44.27%	61.57%
CD352	101.88%	46.07%	59.59%
CD353	98.43%	40.13%	54.71%
CD391	44.03%	25.21%	34.14%
CD392	58.74%	30.03%	40.48%
CD393	76.59%	35.11%	47.16%
CD401	69.01%	13.97%	33.70%
CD402	68.10%	12.03%	37.18%
CD403	74.24%	14.41%	43.42%

Table C.2 (contd.)

CD #	Maximum	Minimum	Average
CD411	74.05%	33.31%	46.19%
CD412	79.32%	27.45%	43.95%
CD413	72.25%	16.59%	39.60%
CD414	78.74%	32.59%	47.67%
CD415	75.38%	33.79%	47.96%
CD416	83.53%	33.66%	50.05%
CD421	74.12%	34.39%	49.02%
CD422	74.62%	25.93%	51.05%
CD431	61.55%	37.95%	49.10%
CD432	60.42%	35.92%	50.43%
CD433	61.02%	21.90%	45.95%
CD441	30.42%	12.26%	20.03%
CD442	53.84%	8.23%	28.62%
CD443	53.75%	15.79%	33.45%
CD444	65.36%	13.22%	38.90%
CD471	132.95%	16.02%	79.16%
CD472	147.03%	17.30%	93.26%
CD473	129.08%	15.16%	85.72%
CD474	227.10%	15.19%	130.22%
CD475	143.49%	13.49%	91.28%
CD531	89.94%	13.08%	53.19%
CD532	89.91%	14.16%	57.70%
CD533	110.91%	11.07%	64.40%
CD561	102.00%	27.26%	61.48%
CD562	103.05%	29.40%	62.35%
CD571	72.72%	42.52%	53.22%
CD572	78.40%	39.83%	55.03%
CD573	82.16%	24.63%	48.63%
CD581	67.25%	5.60%	38.56%
CD582	131.60%	20.82%	62.81%
CD583	96.06%	8.78%	47.11%
CD584	130.14%	23.23%	57.99%
CD591	86.38%	7.75%	47.59%
CD592	77.51%	4.60%	46.58%
CD601	59.21%	32.27%	43.15%
CD602	77.24%	26.06%	59.32%
CD603	78.29%	28.32%	57.89%
CD611	85.30%	15.33%	45.06%
CD612	92.42%	14.06%	46.76%

Table C.2 (contd.)

CD #	Maximum	Minimum	Average
CD631	115.10%	34.86%	92.53%
CD632	99.13%	32.19%	79.06%
CD633	89.85%	30.62%	70.21%
CD634	90.64%	30.20%	68.12%
CD641	82.77%	37.07%	50.60%
CD642	90.99%	25.65%	53.56%
CD643	132.10%	41.88%	78.60%
Maximum	227.10%	46.74%	130.22%
Minimum	30.42%	-1.90%	18.74%
Average	87.38%	25.26%	53.08%
All CD's Absolute	227.10%	-1.90%	54.66%

Table C.3 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for Crop Rotations with Cover Crops for the Study Region

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
241	201	CRN,SOY,WWT	RT-C	5591	6075	6755	7040	7602	8423	11.19%	4.21%	7.98%	10.79%	38.65%
241	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	5591	6079	6546	6760	7498	7910	7.68%	3.26%	10.91%	5.49%	30.12%
242	201	CRN,SOY,WWT	RT-C	4083	4516	5181	5548	6048	6823	14.72%	7.08%	9.01%	12.81%	51.08%
242	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	4083	4516	4875	5126	5730	6127	7.94%	5.14%	11.78%	6.92%	35.67%
271	201	CRN,SOY,WWT	RT-C	4256	4528	5300	5695	6251	6824	17.04%	7.45%	9.76%	9.16%	50.70%
271	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4256	4535	5508	6109	7102	7708	21.45%	10.91%	16.25%	8.53%	69.96%
272	201	CRN,SOY,WWT	RT-C	4289	4571	5514	6076	6756	7519	20.63%	10.19%	11.19%	11.29%	64.49%
272	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4289	4581	5614	6337	7370	8118	22.54%	12.87%	16.30%	10.14%	77.21%
281	458	SOY,WWT,SOY	RT-C	4892	5007	5729	6079	6586	7115	14.41%	6.10%	8.34%	8.03%	42.10%
282	458	SOY,WWT,SOY	RT-C	4711	4909	5450	5708	6084	6507	11.02%	4.73%	6.58%	6.95%	32.55%
311	250	CSL,CSL,SOY	RT-C	4385	4503	6809	8258	9577	11008	51.21%	21.28%	15.97%	14.94%	144.45%
311	250	CSL,CSL,SOY	NT-C	4385	4503	6721	8298	9753	11284	49.25%	23.46%	17.53%	15.69%	150.58%
312	250	CSL,CSL,SOY	RT-C	3543	3625	6919	8862	10694	12929	90.86%	28.08%	20.67%	20.89%	256.66%
312	250	CSL,CSL,SOY	NT-C	3543	3634	6712	8680	10626	12963	84.70%	29.32%	22.41%	21.99%	256.71%
313	250	CSL,CSL,SOY	RT-C	3105	3147	6065	7803	9525	11514	92.72%	28.65%	22.06%	20.88%	265.87%
313	250	CSL,CSL,SOY	NT-C	3105	3158	5894	7664	9496	11622	86.63%	30.03%	23.90%	22.38%	268.01%
314	250	CSL,CSL,SOY	RT-C	3780	3926	6309	7838	9325	10952	60.69%	24.23%	18.97%	17.44%	178.96%
314	250	CSL,CSL,SOY	NT-C	3780	3926	6237	7819	9449	11195	58.86%	25.36%	20.84%	18.47%	185.15%
341	186	CRN,SOY	NT-C	3294	3495	4005	4433	5088	5600	14.59%	10.68%	14.77%	10.06%	60.22%
342	186	CRN,SOY	NT-C	3502	3699	4381	4894	5471	5978	18.43%	11.70%	11.78%	9.26%	61.61%
351	201	CRN,SOY,WWT	RT-C	4049	4306	5148	5690	6516	7396	19.55%	10.52%	14.51%	13.50%	71.76%
352	201	CRN,SOY,WWT	RT-C	4845	5133	6219	6919	7818	8924	21.15%	11.25%	12.99%	14.14%	73.85%
353	201	CRN,SOY,WWT	RT-C	4072	4300	5241	5764	6538	7326	21.88%	9.97%	13.42%	12.05%	70.37%
411	137	CRN,CRN,SOY,WWT	CTSP-C	4972	5244	5979	6311	7135	7818	14.01%	5.55%	13.05%	9.57%	49.08%
411	137	CRN,CRN,SOY,WWT	RT-C	4972	5252	6068	6431	7334	8030	15.53%	5.98%	14.04%	9.49%	52.89%
411	186	CRN,SOY	CTFP-C	4972	5244	5734	6004	6602	7282	9.34%	4.70%	9.96%	10.29%	38.86%
411	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4972	5249	6720	7900	8770	9662	28.02%	17.55%	11.01%	10.17%	84.07%
411	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4972	5291	6569	7696	8428	9774	24.15%	17.15%	9.51%	15.97%	84.72%

Table C.3 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
412	137	CRN,CRN,SOY,WWT	CTSP-C	4566	4804	5499	5764	6517	7166	14.46%	4.81%	13.06%	9.95%	49.16%
412	137	CRN,CRN,SOY,WWT	RT-C	4566	4815	5580	5869	6698	7376	15.88%	5.17%	14.12%	10.12%	53.18%
412	186	CRN,SOY	CTFP-C	4566	4804	5151	5339	5867	6417	7.22%	3.64%	9.88%	9.37%	33.57%
412	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4566	4822	6039	6636	7795	8825	25.23%	9.88%	17.46%	13.21%	83.01%
412	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4566	4834	6005	6875	7488	8559	24.22%	14.48%	8.91%	14.30%	77.05%
413	137	CRN,CRN,SOY,WWT	CTSP-C	4677	4967	5602	5843	6541	7006	12.78%	4.30%	11.94%	7.10%	41.05%
413	137	CRN,CRN,SOY,WWT	RT-C	4677	4979	5690	5967	6734	7215	14.27%	4.86%	12.85%	7.14%	44.90%
413	186	CRN,SOY	CTFP-C	4677	4968	5340	5650	6154	6763	7.48%	5.80%	8.92%	9.89%	36.13%
413	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4677	4991	5893	6499	7584	8557	18.07%	10.28%	16.69%	12.82%	71.44%
413	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4677	5009	6250	7353	8197	9177	24.77%	17.64%	11.47%	11.95%	83.21%
414	137	CRN,CRN,SOY,WWT	CTSP-C	4856	5142	5868	6187	7024	7871	14.11%	5.43%	13.52%	12.05%	53.07%
414	137	CRN,CRN,SOY,WWT	RT-C	4856	5154	5949	6295	7191	8084	15.42%	5.81%	14.23%	12.41%	56.84%
414	186	CRN,SOY	CTFP-C	4856	5142	5483	5682	6331	7055	6.63%	3.62%	11.42%	11.43%	37.20%
414	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4856	5172	6408	7063	8258	9338	23.89%	10.22%	16.91%	13.07%	80.54%
414	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4856	5182	6432	7474	8296	9450	24.12%	16.20%	10.99%	13.91%	82.36%
415	137	CRN,CRN,SOY,WWT	CTSP-C	4649	4846	5415	5735	6480	7027	11.74%	5.90%	12.99%	8.44%	45.00%
415	137	CRN,CRN,SOY,WWT	RT-C	4649	4860	5487	5837	6656	7218	12.90%	6.37%	14.03%	8.44%	48.51%
415	186	CRN,SOY	CTFP-C	4649	4847	5206	5583	6115	6755	7.40%	7.24%	9.52%	10.46%	39.36%
415	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4649	4859	5776	6532	7758	8893	18.87%	13.08%	18.76%	14.63%	83.02%
415	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4649	4872	6109	7341	8105	9267	25.38%	20.16%	10.40%	14.33%	90.20%
416	137	CRN,CRN,SOY,WWT	CTSP-C	4946	5144	5911	6393	7192	7939	14.91%	8.15%	12.49%	10.38%	54.33%
416	137	CRN,CRN,SOY,WWT	RT-C	4946	5159	5982	6499	7370	8132	15.95%	8.64%	13.40%	10.33%	57.62%
416	186	CRN,SOY	CTFP-C	4946	5145	5589	6025	6589	7229	8.62%	7.80%	9.36%	9.71%	40.50%
416	243	CSL,CSL,OTS,HLH,HLH	CTSP-C	4946	5162	6159	6868	7975	9007	19.31%	11.51%	16.11%	12.94%	74.48%
416	277	CSL,SOY,HLH,HLH,HLH,HLH	CTSP-C	4946	5173	6687	7981	8767	10058	29.26%	19.35%	9.84%	14.72%	94.43%
421	201	CRN,SOY,WWT	RT-C	4631	4918	5726	6239	7092	8111	16.42%	8.95%	13.67%	14.36%	64.92%
421	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	4631	4913	6902	8879	10461	11662	40.48%	28.64%	17.81%	11.48%	137.37%
421	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	4631	4913	7192	9061	10996	12285	46.38%	25.98%	21.35%	11.72%	150.05%
422	201	CRN,SOY,WWT	RT-C	4419	4700	5391	5762	6635	7542	14.70%	6.88%	15.15%	13.66%	60.46%
422	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	4419	4700	6080	7162	8037	9639	29.36%	17.79%	12.21%	19.93%	105.08%
422	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	4419	4700	5457	5970	7691	8472	16.10%	9.40%	28.82%	10.15%	80.25%
431	201	CRN,SOY,WWT	CTSP-C	4522	4779	5474	5946	6656	7451	14.54%	8.62%	11.94%	11.94%	55.91%
431	201	CRN,SOY,WWT	RT-C	4522	4793	5522	5982	6731	7557	15.20%	8.33%	12.52%	12.27%	57.66%
431	218	CRN,WWT	CTSP-C	4522	4778	6177	7422	8688	9964	29.28%	20.15%	17.05%	14.68%	108.53%
431	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	4522	4792	5739	6507	7942	8476	19.76%	13.38%	22.05%	6.72%	76.87%

Table C.3 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
432	201	CRN,SOY,WWT	CTSP-C	3984	4218	5451	6216	7182	7935	29.23%	14.03%	15.54%	10.48%	88.12%
432	201	CRN,SOY,WWT	RT-C	3984	4232	5505	6262	7306	8101	30.08%	13.75%	16.67%	10.88%	91.42%
432	218	CRN,WWT	CTSP-C	3984	4215	5685	6828	8010	9121	34.87%	20.10%	17.31%	13.87%	116.39%
432	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	3984	4232	5055	5585	6750	7165	19.44%	10.48%	20.85%	6.14%	69.30%
433	201	CRN,SOY,WWT	CTSP-C	3359	3643	4219	4582	5095	5675	15.81%	8.60%	11.19%	11.38%	55.77%
433	201	CRN,SOY,WWT	RT-C	3359	3653	4255	4615	5167	5783	16.47%	8.46%	11.96%	11.92%	58.30%
433	218	CRN,WWT	CTSP-C	3359	3642	4775	5579	6511	7412	31.10%	16.83%	16.70%	13.83%	103.51%
433	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	3359	3661	4226	4662	5569	6010	15.43%	10.31%	19.45%	7.91%	64.16%
441	218	CRN,WWT	CTFP-C	3702	3897	4911	5739	6585	7406	26.02%	16.86%	14.74%	12.46%	90.04%
441	416	SRG,SOY,SOY	CTFP-C	3702	3897	4444	4804	5276	5772	14.03%	8.10%	9.82%	9.40%	48.11%
441	458	SOY,WWT,SOY	CTFP-C	3702	3867	4557	5366	5786	6287	17.84%	17.75%	7.82%	8.65%	62.58%
441	459	SOY,WWT,WWT,WWT	RT-C	3702	3872	5332	6191	6880	7701	37.70%	16.11%	11.12%	11.93%	98.88%
442	218	CRN,WWT	CTFP-C	2761	2985	4277	5260	6238	7153	43.28%	22.98%	18.59%	14.66%	139.63%
442	416	SRG,SOY,SOY	CTFP-C	2761	2985	4640	5393	6131	7077	55.44%	16.22%	13.68%	15.42%	137.08%
442	458	SOY,WWT,SOY	CTFP-C	2761	2934	3989	4818	5499	5952	35.95%	20.78%	14.13%	8.23%	102.86%
442	459	SOY,WWT,WWT,WWT	RT-C	2761	2939	3593	3993	4420	5042	22.25%	11.13%	10.69%	14.07%	71.55%
443	218	CRN,WWT	CTFP-C	2477	2682	4041	4944	5826	6561	50.67%	22.34%	17.83%	12.61%	144.63%
443	416	SRG,SOY,SOY	CTFP-C	2477	2681	4435	5176	5920	6734	65.42%	16.70%	14.37%	13.74%	151.17%
443	458	SOY,WWT,SOY	CTFP-C	2477	2634	3871	4762	5524	5873	46.96%	23.01%	16.00%	6.31%	122.96%
443	459	SOY,WWT,WWT,WWT	RT-C	2477	2638	3495	3996	4519	5189	32.48%	14.33%	13.08%	14.82%	96.70%
444	218	CRN,WWT	CTFP-C	2454	2632	4313	5532	6621	7569	63.86%	28.26%	19.68%	14.31%	187.57%
444	416	SRG,SOY,SOY	CTFP-C	2454	2632	4966	5936	6734	7802	88.67%	19.53%	13.44%	15.85%	196.42%
444	458	SOY,WWT,SOY	CTFP-C	2454	2594	4140	5105	5914	6382	59.59%	23.30%	15.84%	7.91%	146.02%
444	459	SOY,WWT,WWT,WWT	RT-C	2454	2597	3508	4049	4641	5406	35.07%	15.42%	14.62%	16.48%	108.16%
561	186	CRN,SOY	CTSP-C	3808	4158	5350	6417	7390	8376	28.66%	19.94%	15.16%	13.34%	101.44%
561	201	CRN,SOY,WWT	RT-C	3438	3772	4599	4937	5669	6607	21.92%	7.34%	14.82%	16.54%	75.15%
561	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	3438	3781	4725	5557	5893	7015	24.96%	17.60%	6.04%	19.03%	85.53%
561	246	CSL,CSL,OTS,HLH,NLH	RT-C	3438	3792	4745	5374	6623	7828	25.13%	13.25%	23.24%	18.19%	106.43%
561	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	3438	3711	5613	7486	8636	9595	51.25%	33.36%	15.36%	11.10%	158.55%
562	186	CRN,SOY	CTSP-C	3931	4289	4988	5577	6301	7437	16.29%	11.80%	12.98%	18.02%	73.39%
562	201	CRN,SOY,WWT	RT-C	3931	4304	5081	5447	6177	7413	18.05%	7.20%	13.40%	20.00%	72.23%
562	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	3931	4312	5342	6284	6900	8237	23.88%	17.63%	9.80%	19.37%	91.02%
562	246	CSL,CSL,OTS,NLH,NLH	RT-C	3931	4323	5331	6028	7581	8988	23.31%	13.07%	25.76%	18.55%	107.91%
562	262	CSL,OTS,HLH,HLH,HLH	CTSP-C	3931	4288	5501	6419	7410	8203	28.28%	16.68%	15.43%	10.70%	91.30%

Table C.3 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
571	125	CRN,CRN,OTS,NLH,NLH	RT-C	4204	4508	5383	5890	6842	7816	19.40%	9.41%	16.16%	14.23%	73.38%
571	186	CRN,SOY	CTFP-C	4204	4495	5169	5574	6142	6922	14.99%	7.83%	10.19%	12.69%	53.99%
571	218	CRN,WWT	RT-C	4204	4508	5504	6078	6934	8032	22.09%	10.42%	14.08%	15.83%	78.17%
572	125	CRN,CRN,OTS,NLH,NLH	RT-C	3822	4147	4807	5480	6531	7531	15.91%	14.00%	19.17%	15.31%	81.60%
572	186	CRN,SOY	CTFP-C	3822	4135	4824	5448	6075	7014	16.66%	12.93%	11.50%	15.45%	69.62%
572	218	CRN,WWT	RT-C	3822	4147	5256	6224	7354	9014	26.74%	18.41%	18.15%	22.57%	117.36%
573	125	CRN,CRN,OTS,NLH,NLH	RT-C	3085	3415	3865	4284	4996	5643	13.17%	10.84%	16.61%	12.95%	65.24%
573	186	CRN,SOY	CTFP-C	3085	3406	3707	4008	4482	5143	8.83%	8.11%	11.82%	14.74%	50.99%
573	218	CRN,WWT	RT-C	3085	3415	4378	5092	5999	7224	28.19%	16.30%	17.81%	20.42%	111.53%
591	218	CRN,WWT	CTFP-C	4635	5129	5946	6589	7635	8785	15.92%	10.81%	15.87%	15.06%	71.28%
591	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	4635	5170	6334	7475	8191	9774	22.51%	18.01%	9.57%	19.32%	89.05%
592	218	CRN,WWT	CTFP-C	3891	4264	4940	5645	6531	7396	15.85%	14.27%	15.69%	13.24%	73.45%
592	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP-C	3891	4291	5129	6132	6446	7531	19.52%	19.55%	5.12%	16.83%	75.50%
601	131	CRN,CRN,SOY	NT-C	4176	4283	5376	5996	6634	7317	25.51%	11.53%	10.64%	10.29%	70.83%
601	186	CRN,SOY	CTSP-C	4176	4298	4750	5229	5777	6414	10.51%	10.08%	10.48%	11.02%	49.23%
601	201	CRN,SOY,WWT	CTSP-C	4176	4298	4802	5220	5595	6429	11.72%	8.70%	7.18%	14.90%	49.58%
601	201	CRN,SOY,WWT	RT-C	4176	4310	4828	5250	5654	6527	12.01%	8.74%	7.69%	15.44%	51.43%
602	131	CRN,CRN,SOY	NT-C	3614	3606	5228	6121	7001	7791	44.98%	17.08%	14.37%	11.28%	116.05%
602	186	CRN,SOY	CTSP-C	3614	3604	4588	5383	6244	7073	27.30%	17.32%	15.99%	13.27%	96.25%
602	201	CRN,SOY,WWT	CTSP-C	3614	3604	4725	5462	6351	7449	31.10%	15.59%	16.27%	17.28%	106.68%
602	201	CRN,SOY,WWT	RT-C	3614	3611	4719	5444	6361	7478	30.68%	15.36%	16.84%	17.56%	107.08%
603	131	CRN,CRN,SOY	NT-C	3268	3277	4953	5963	6828	7593	51.14%	20.39%	14.50%	11.20%	131.70%
603	186	CRN,SOY	CTSP-C	3268	3277	4381	5276	6172	6864	33.68%	20.42%	16.98%	11.21%	109.45%
603	201	CRN,SOY,WWT	CTSP-C	3268	3277	4496	5283	6169	7052	37.19%	17.50%	16.77%	14.31%	115.19%
603	201	CRN,SOY,WWT	RT-C	3268	3280	4490	5267	6191	7079	36.89%	17.30%	17.54%	14.34%	115.82%
611	186	CRN,SOY	CTFP-C	3091	3014	3630	4078	4713	5103	20.43%	12.34%	15.57%	8.27%	69.30%
611	186	CRN,SOY	NT-C	3091	3014	4012	4760	5564	6221	33.11%	18.64%	16.89%	11.80%	106.40%
611	246	CSL,CSL,OTS,HLH,HLH	NT-C	3091	3014	4195	5084	6243	6968	39.18%	21.19%	22.79%	11.61%	131.18%
611	458	SOY,WWT,SOY	CTFP-C	3091	3014	3684	4235	4650	5036	22.22%	14.95%	9.79%	8.30%	67.08%
612	186	CRN,SOY	CTFP-C	2033	2005	2579	2950	3501	3765	28.62%	14.38%	18.67%	7.54%	87.78%
612	186	CRN,SOY	NT-C	2033	2005	3516	4511	5510	6280	75.36%	28.29%	22.14%	13.97%	213.21%
612	246	CSL,CSL,OTS,HLH,HLH	NT-C	2033	2005	2869	3425	4262	4656	43.09%	19.37%	24.43%	9.24%	132.21%
612	458	SOY,WWT,SOY	CTFP-C	2033	2004	3277	4286	5102	5622	63.52%	30.79%	19.03%	10.19%	180.53%

Table C.3 (contd.)

CD #	CR #	ROTATION SEQUENCE	TILL	Total Soil Carbon (gC/m2) 1980	1990	2000	2010	2020	2030	Percent Change in Total Soil Carbon for Selected Time Periods 1990/2000	2000/2010	2010/2020	2020/2030	1900/2030
641	218	CRN,WWT	RT-C	2962	3178	4307	5053	5860	6457	35.52%	17.32%	15.97%	10.18%	103.17%
641	458	SOY,WWT,SOY	CTFP-C	2962	3147	3859	4519	5497	6070	22.62%	17.10%	21.64%	10.42%	92.88%
642	218	CRN,WWT	RT-C	2846	3078	4320	5098	5918	6564	40.35%	18.00%	16.08%	10.91%	113.25%
642	458	SOY,WWT,SOY	CTFP-C	2846	3047	3924	4712	5630	6020	28.78%	20.08%	19.48%	6.92%	97.57%
643	218	CRN,WWT	RT-C	1787	1935	3151	3850	4594	5125	62.84%	22.18%	19.32%	11.55%	164.85%
643	458	SOY,WWT,SOY	CTFP-C	1787	1918	3256	4099	5137	5516	69.76%	25.89%	25.32%	7.37%	187.59%

Note: "-C" in the Till Column represents Crop Rotations with Cover Crops

Table C.4 Maximum, Minimum, and Average Percent Change in Total Soil Carbon for 1990-2030 by CD for Crop Rotations with Cover Crops

CD #	Maximum	Minimum	Average
CD241	49.43%	12.73%	29.60%
CD242	65.27%	20.06%	36.87%
CD271	87.85%	34.65%	50.50%
CD272	104.08%	44.88%	60.84%
CD281	50.69%	27.44%	41.68%
CD282	54.42%	32.55%	44.22%
CD311	150.59%	34.82%	82.48%
CD312	256.71%	30.42%	121.47%
CD313	268.02%	23.87%	115.47%
CD314	185.15%	42.79%	98.79%
CD341	60.23%	23.55%	37.22%
CD342	61.61%	26.21%	40.34%
CD351	103.84%	44.27%	62.84%
CD352	101.88%	46.07%	61.37%
CD353	98.43%	40.13%	56.67%
CD411	84.73%	33.31%	50.63%
CD412	83.02%	27.45%	47.10%
CD413	83.21%	16.59%	43.14%
CD414	82.36%	32.59%	50.97%
CD415	90.21%	33.79%	51.60%
CD416	94.43%	33.66%	53.23%
CD421	150.05%	34.39%	64.76%
CD422	105.09%	25.93%	57.12%
CD431	108.54%	37.95%	56.55%
CD432	116.39%	35.92%	62.72%
CD433	103.51%	21.90%	53.06%
CD441	98.89%	12.26%	41.33%
CD442	139.63%	8.23%	62.03%
CD443	151.17%	20.72%	71.72%
CD444	196.43%	13.22%	85.87%
CD561	180.92%	31.33%	89.55%
CD562	167.76%	30.99%	80.64%
CD571	78.17%	42.52%	54.37%
CD572	117.36%	39.83%	60.37%
CD573	111.54%	24.63%	50.78%
CD591	89.05%	7.75%	51.11%
CD592	75.87%	4.60%	49.63%

Table C.4 (contd.)

CD #	Maximum	Minimum	Average
CD601	70.84%	32.27%	47.05%
CD602	116.06%	26.06%	76.59%
CD603	131.71%	28.32%	81.13%
CD611	131.19%	22.00%	63.50%
CD612	213.22%	21.56%	91.51%
CD641	103.18%	37.07%	61.80%
CD642	113.26%	25.65%	65.72%
CD643	187.59%	41.88%	102.78%
Maximum	268.02%	46.07%	121.47%
Minimum	49.43%	4.60%	29.60%
Average	117.19%	28.64%	62.64%
All CD's Absolute	268.02%	4.60%	59.87%

Table C.5 Total Soil Carbon (gC/m2) and Percent Change in Total Soil Carbon for CRP and Dominant Crop Rotations for the Study Region

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
221	239	CSL,CSL,CSL,SWT	7344	7404	7985	8376	9032	9544	7.84%	4.89%	7.83%	5.66%	28.90%
221	239	CRP1	7344	7853	8419	8757	9096	9584	7.20%	4.02%	3.87%	5.37%	22.03%
221	999	CRP2	7344	7855	8423	8614	8722	8915	7.23%	2.26%	1.25%	2.21%	13.49%
222	239	CSL,CSL,CSL,SWT	6654	6692	7049	7334	8009	8662	5.33%	4.04%	9.20%	8.15%	29.43%
222	239	CRP1	6654	7180	7624	7940	8352	8799	6.17%	4.15%	5.19%	5.34%	22.54%
222	999	CRP2	6654	7182	7627	7832	7957	8167	6.19%	2.68%	1.59%	2.63%	13.71%
223	239	CSL,CSL,CSL,SWT	6022	6044	6400	6673	7362	7865	5.89%	4.26%	10.32%	6.83%	30.12%
223	239	CRP1	6022	6550	6944	7250	7584	7980	6.02%	4.41%	4.61%	5.22%	21.84%
223	999	CRP2	6022	6552	6952	7132	7246	7413	6.10%	2.58%	1.59%	2.30%	13.14%
231	145	CRN,CRN,WWT,HLH,HLH,HLH	5109	5361	5715	6144	6501	7132	6.60%	7.50%	5.81%	9.70%	33.03%
231	145	CRP1	5109	5745	6091	6470	6619	7040	6.03%	6.22%	2.30%	6.36%	22.54%
231	999	CRP2	5109	5747	6096	6285	6466	6711	6.07%	3.10%	2.87%	3.78%	16.77%
232	145	CRN,CRN,WWT,HLH,HLH,HLH	5232	5569	6189	6662	6984	7794	11.13%	7.64%	4.83%	11.59%	39.95%
232	145	CRP1	5232	5950	6392	6783	6912	7436	7.42%	6.11%	1.90%	7.59%	24.97%
232	999	CRP2	5232	5956	6400	6543	6667	6900	7.45%	2.23%	1.89%	3.49%	15.84%
241	100	CRN	5591	5942	6494	6800	7738	8293	9.28%	4.71%	13.79%	7.17%	39.56%
241	100	CRP1	5591	5997	6267	6472	7071	7520	4.50%	3.27%	9.25%	6.35%	25.39%
241	999	CRP2	5591	6008	6279	6364	6497	6720	4.51%	1.35%	2.08%	3.43%	11.85%
242	100	CRN	4083	4397	4928	5160	5866	6311	12.07%	4.70%	13.68%	7.58%	43.52%
242	100	CRP1	4083	4496	4687	4908	5411	5806	4.25%	4.72%	10.24%	7.30%	29.15%
242	999	CRP2	4083	4504	4698	4860	5024	5260	4.30%	3.44%	3.37%	4.69%	16.78%
251	186	CRN,SOY	4085	4244	4309	4450	4828	5111	1.53%	3.27%	8.49%	5.86%	20.42%
251	186	CRP1	4085	4352	4594	4850	5066	5306	5.55%	5.57%	4.45%	4.75%	21.92%
251	999	CRP2	4085	4354	4600	4807	4976	5186	5.64%	4.50%	3.51%	4.22%	19.10%
252	186	CRN,SOY	3927	4142	4418	4627	5171	5603	6.66%	4.73%	11.75%	8.35%	35.27%
252	186	CRP1	3927	4312	4551	4791	5183	5544	5.55%	5.27%	8.17%	6.97%	28.57%
252	999	CRP2	3927	4321	4562	4757	4989	5208	5.57%	4.27%	4.87%	4.38%	20.52%
253	186	CRN,SOY	3276	3407	3476	3577	3908	4210	2.02%	2.90%	9.25%	7.72%	23.56%
253	186	CRP1	3276	3555	3756	3959	4152	4416	5.65%	5.40%	4.88%	6.34%	24.19%
253	999	CRP2	3276	3561	3763	3964	4132	4354	5.67%	5.34%	4.23%	5.37%	22.26%
261	145	CRN,CRN,WWT,HLH,HLH,HLH	3461	3732	3987	4268	4464	4805	6.83%	7.04%	4.59%	7.63%	28.75%
261	145	CRP1	3461	4046	4260	4495	4581	4803	5.29%	5.52%	1.92%	4.85%	18.73%
261	999	CRP2	3461	4050	4268	4368	4539	4655	5.38%	2.34%	3.91%	2.55%	14.93%
262	145	CRN,CRN,WWT,HLH,HLH,HLH	3193	3466	3805	4114	4336	4819	9.78%	8.12%	5.39%	11.13%	39.03%
262	145	CRP1	3193	3815	4020	4274	4397	4723	5.37%	6.33%	2.87%	7.43%	23.82%
262	999	CRP2	3193	3823	4028	4148	4338	4505	5.36%	2.97%	4.58%	3.84%	17.83%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
271	186	CRN,SOY	4256	4518	4877	5112	5716	6115	7.94%	4.81%	11.81%	6.98%	35.34%
271	186	CRP1	4256	4609	4911	5054	5468	5759	6.56%	2.91%	8.20%	5.32%	24.97%
271	999	CRP2	4256	4617	4924	5017	5232	5375	6.64%	1.88%	4.28%	2.73%	16.41%
272	186	CRN,SOY	4289	4559	5029	5395	6076	6613	10.30%	7.27%	12.62%	8.83%	45.05%
272	186	CRP1	4289	4758	5027	5322	5788	6205	5.65%	5.87%	8.74%	7.22%	30.41%
272	999	CRP2	4289	4770	5040	5273	5502	5732	5.66%	4.62%	4.34%	4.18%	20.16%
281	144	CRN,CRN,WWT,HLH,HLH	5224	5496	5864	6132	6373	6825	6.69%	4.57%	3.93%	7.09%	24.18%
281	513	CRP1	5224	5824	6164	6659	7019	7386	5.83%	8.04%	5.39%	5.23%	26.81%
281	999	CRP2	5224	5837	6181	6455	6719	6972	5.89%	4.43%	4.08%	3.76%	19.44%
282	144	CRN,CRN,WWT,HLH,HLH	4981	5317	5770	6153	6356	6820	8.51%	6.63%	3.29%	7.30%	28.26%
282	513	CRP1	4981	5649	5988	6511	6898	7362	5.99%	8.73%	5.96%	6.72%	30.31%
282	999	CRP2	4981	5673	6006	6304	6545	6793	5.86%	4.96%	3.82%	3.78%	19.74%
311	145	CRN,CRN,WWT,HLH,HLH,HLH	4759	4750	5291	5861	5925	6433	11.38%	10.77%	1.09%	8.57%	35.43%
311	538	CRP1	4759	5200	5547	6136	6225	6734	6.69%	10.61%	1.46%	8.16%	29.50%
311	999	CRP2	4759	5213	5563	5918	6083	6360	6.71%	6.38%	2.78%	4.55%	22.00%
312	145	CRN,CRN,WWT,HLH,HLH,HLH	4032	4027	4448	4974	5011	5553	10.45%	11.82%	0.74%	10.81%	37.89%
312	538	CRP1	4032	4404	4750	5307	5384	5957	7.86%	11.72%	1.45%	10.66%	35.28%
312	999	CRP2	4032	4416	4764	5104	5304	5706	7.88%	7.13%	3.91%	7.57%	29.21%
313	145	CRN,CRN,WWT,HLH,HLH,HLH	3568	3494	3816	4205	4206	4630	9.21%	10.19%	0.01%	10.10%	32.51%
313	538	CRP1	3568	3852	4206	4651	4688	5115	9.17%	10.60%	0.79%	9.11%	32.78%
313	999	CRP2	3568	3862	4219	4519	4771	5137	9.24%	7.11%	5.57%	7.67%	33.01%
314	145	CRN,CRN,WWT,HLH,HLH,HLH	4169	4215	4676	5243	5401	5902	10.93%	12.12%	3.01%	9.27%	40.02%
314	538	CRP1	4169	4608	4925	5520	5687	6258	6.88%	12.08%	3.02%	10.05%	35.80%
314	999	CRP2	4169	4621	4942	5272	5490	5857	6.94%	6.67%	4.13%	6.68%	26.74%
321	203	CRN,SOY,WWT,HLH,HLH,HLH	4171	4466	4910	5430	5900	6493	9.94%	10.59%	8.65%	10.05%	45.38%
321	203	CRP1	4171	4901	5210	5615	5917	6367	6.29%	7.78%	5.37%	7.61%	29.89%
321	999	CRP2	4171	4916	5225	5497	5747	6066	6.28%	5.20%	4.54%	5.55%	23.39%
322	203	CRN,SOY,WWT,HLH,HLH,HLH	4345	4599	5080	5648	5990	6641	10.45%	11.18%	6.05%	10.86%	44.40%
322	203	CRP1	4345	5084	5380	5849	6029	6505	5.83%	8.72%	3.07%	7.89%	27.95%
322	999	CRP2	4345	5101	5397	5702	5886	6204	5.80%	5.65%	3.22%	5.40%	21.62%
323	203	CRN,SOY,WWT,HLH,HLH,HLH	3925	4202	4619	5165	5576	6166	9.92%	11.82%	7.95%	10.58%	46.73%
323	203	CRP1	3925	4626	4928	5412	5644	6091	6.53%	9.82%	4.28%	7.93%	31.67%
323	999	CRP2	3925	4643	4945	5277	5497	5845	6.50%	6.71%	4.16%	6.33%	25.88%
341	144	CRN,CRN,WWT,HLH,HLH	3294	3478	3620	3842	4316	4611	4.08%	6.13%	12.33%	6.83%	32.57%
341	144	CRP1	3294	3688	3998	4455	4742	5129	8.41%	11.45%	6.43%	8.17%	39.09%
341	999	CRP2	3294	3706	4014	4317	4549	4895	8.31%	7.54%	5.37%	7.60%	32.08%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
342	144	CRN,CRN,WWT,HLH,HLH	3502	3679	3940	4205	4727	5048	7.09%	6.72%	12.41%	6.79%	37.21%
342	144	CRP1	3502	3928	4307	4806	5149	5548	9.63%	11.59%	7.14%	7.76%	41.23%
342	999	CRP2	3502	3957	4329	4651	4880	5220	9.40%	7.43%	4.92%	6.96%	31.91%
351	186	CRN,SOY	4049	4294	4677	4962	5620	6195	8.91%	6.09%	13.26%	10.23%	44.27%
351	186	CRP1	4049	4502	4780	5084	5494	5924	6.16%	6.38%	8.05%	7.83%	31.57%
351	999	CRP2	4049	4513	4792	5062	5286	5533	6.18%	5.63%	4.42%	4.67%	22.60%
352	186	CRN,SOY	4845	5118	5654	6053	6769	7476	10.47%	7.05%	11.82%	10.44%	46.07%
352	186	CRP1	4845	5345	5713	6074	6527	7095	6.89%	6.32%	7.46%	8.70%	32.73%
352	999	CRP2	4845	5366	5733	6002	6212	6596	6.83%	4.69%	3.49%	6.18%	22.92%
353	186	CRN,SOY	4072	4285	4651	4951	5548	6050	8.54%	6.45%	12.05%	9.04%	41.19%
353	186	CRP1	4072	4512	4867	5222	5578	5983	7.87%	7.29%	6.83%	7.25%	32.60%
353	999	CRP2	4072	4530	4883	5180	5425	5774	7.79%	6.08%	4.72%	6.43%	27.46%
391	186	CRN,SOY	5201	5244	5566	5758	6200	6726	6.14%	3.44%	7.67%	8.48%	28.26%
391	186	CRP1	5201	5439	5842	6064	6261	6605	7.40%	3.80%	3.25%	5.49%	21.42%
391	999	CRP2	5201	5440	5843	6008	6102	6282	7.40%	2.82%	1.56%	2.94%	15.47%
392	186	CRN,SOY	4868	5045	5435	5669	6207	6903	7.73%	4.30%	9.49%	11.21%	36.82%
392	186	CRP1	4868	5205	5515	5747	6042	6533	5.95%	4.20%	5.14%	8.13%	25.52%
392	999	CRP2	4868	5207	5518	5681	5792	6025	5.97%	2.95%	1.95%	4.02%	15.70%
393	186	CRN,SOY	4779	5089	5614	5856	6586	7422	10.31%	4.31%	12.46%	12.69%	45.84%
393	186	CRP1	4779	5259	5571	5756	6229	6818	5.93%	3.33%	8.22%	9.44%	29.63%
393	999	CRP2	4779	5262	5575	5683	5875	6103	5.94%	1.93%	3.37%	3.88%	15.98%
401	100	CRN	6396	6695	7225	7540	8406	8935	7.91%	4.35%	11.48%	6.29%	33.45%
401	100	CRP1	6396	6745	7006	7376	8001	8468	3.87%	5.27%	8.47%	5.84%	25.54%
401	999	CRP2	6396	6747	7009	7178	7322	7510	3.88%	2.41%	2.00%	2.56%	11.30%
402	100	CRN	6241	6590	7351	7789	8708	9357	11.54%	5.95%	11.79%	7.45%	41.98%
402	100	CRP1	6241	6642	6907	7256	8011	8610	3.99%	5.06%	10.41%	7.48%	29.63%
402	999	CRP2	6241	6645	6911	7058	7192	7399	4.00%	2.12%	1.89%	2.87%	11.34%
403	100	CRN	5565	5953	6677	7037	8045	8705	12.16%	5.39%	14.32%	8.20%	46.22%
403	100	CRP1	5565	5993	6231	6509	7331	7954	3.97%	4.47%	12.64%	8.50%	32.73%
403	999	CRP2	5565	5999	6239	6361	6503	6690	4.00%	1.95%	2.23%	2.87%	11.51%
411	186	CRN,SOY	4972	5244	5615	5835	6387	6991	7.07%	3.91%	9.46%	9.45%	33.31%
411	186	CRP1	4972	5427	5741	5948	6330	6806	5.78%	3.62%	6.41%	7.53%	25.41%
411	999	CRP2	4972	5431	5745	5880	6071	6297	5.78%	2.34%	3.24%	3.72%	15.94%
412	186	CRN,SOY	4566	4804	5091	5245	5753	6267	5.97%	3.02%	9.68%	8.93%	30.45%
412	186	CRP1	4566	4978	5283	5462	5805	6196	6.12%	3.38%	6.28%	6.74%	24.46%
412	999	CRP2	4566	4984	5291	5426	5624	5830	6.15%	2.55%	3.64%	3.66%	16.97%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
413	186	CRN,SOY	4677	4966	5123	5286	5493	5790	3.16%	3.18%	3.91%	5.40%	16.59%
413	186	CRP1	4677	5155	5428	5655	5993	6452	5.31%	4.18%	5.97%	7.66%	25.17%
413	999	CRP2	4677	5159	5435	5586	5745	5970	5.34%	2.77%	2.84%	3.91%	15.72%
414	186	CRN,SOY	4856	5142	5399	5537	6150	6818	4.99%	2.55%	11.07%	10.86%	32.59%
414	186	CRP1	4856	5360	5686	5901	6306	6807	6.08%	3.78%	6.86%	7.96%	27.00%
414	999	CRP2	4856	5368	5697	5870	6108	6360	6.12%	3.03%	4.05%	4.12%	18.47%
415	186	CRN,SOY	4649	4847	5128	5419	5919	6485	5.79%	5.67%	9.22%	9.56%	33.79%
415	186	CRP1	4649	5079	5349	5640	5960	6443	5.32%	5.42%	5.69%	8.09%	26.85%
415	999	CRP2	4649	5088	5359	5597	5732	6031	5.32%	4.44%	2.41%	5.21%	18.53%
416	186	CRN,SOY	4946	5145	5498	5818	6328	6877	6.86%	5.82%	8.76%	8.67%	33.66%
416	186	CRP1	4946	5367	5724	6027	6364	6850	6.66%	5.28%	5.59%	7.64%	27.63%
416	999	CRP2	4946	5379	5740	5975	6106	6432	6.71%	4.09%	2.19%	5.33%	19.57%
421	186	CRN,SOY	4631	4904	5317	5607	6248	6914	8.42%	5.45%	11.43%	10.65%	40.98%
421	186	CRP1	4631	5116	5454	5738	6130	6621	6.60%	5.22%	6.83%	8.01%	29.42%
421	999	CRP2	4631	5126	5467	5709	5915	6186	6.65%	4.42%	3.60%	4.58%	20.67%
422	186	CRN,SOY	4419	4685	5141	5452	6237	6921	9.73%	6.04%	14.39%	10.96%	47.72%
422	186	CRP1	4419	4842	5213	5479	6012	6532	7.66%	5.11%	9.73%	8.65%	34.90%
422	999	CRP2	4419	4857	5229	5419	5701	6017	7.65%	3.63%	5.20%	5.54%	23.88%
431	201	CRN,SOY,WWT	4522	4779	5382	5686	6235	7009	12.61%	5.64%	9.65%	12.41%	46.66%
431	201	CRP1	4522	4952	5291	5675	6063	6640	6.83%	7.25%	6.84%	9.52%	34.07%
431	999	CRP2	4522	4967	5306	5567	5829	6161	6.82%	4.91%	4.70%	5.69%	24.03%
432	201	CRN,SOY,WWT	3984	4216	4830	5111	5706	6453	14.56%	5.81%	11.64%	13.09%	53.05%
432	201	CRP1	3984	4397	4719	5080	5513	6073	7.34%	7.63%	8.53%	10.16%	38.12%
432	999	CRP2	3984	4409	4734	4995	5278	5608	7.37%	5.51%	5.66%	6.25%	27.19%
433	201	CRN,SOY,WWT	3359	3605	4123	4372	4856	5431	14.36%	6.03%	11.07%	11.84%	50.65%
433	201	CRP1	3359	3776	4091	4491	4828	5262	8.34%	9.78%	7.50%	8.99%	39.36%
433	999	CRP2	3359	3791	4107	4435	4697	4996	8.33%	7.98%	5.90%	6.36%	31.78%
441	186	CRN,SOY	3702	3874	3922	3937	4329	4580	1.23%	0.38%	9.95%	5.79%	18.22%
441	186	CRP1	3702	4147	4473	4773	4964	5218	7.87%	6.70%	4.01%	5.12%	25.84%
441	999	CRP2	3702	4163	4490	4866	5115	5490	7.85%	8.37%	5.11%	7.33%	31.87%
442	186	CRN,SOY	2761	2950	3175	3310	3734	3973	7.62%	4.25%	12.80%	6.40%	34.67%
442	186	CRP1	2761	3141	3488	3789	4065	4347	11.06%	8.63%	7.28%	6.94%	38.40%
442	999	CRP2	2761	3156	3504	3851	4111	4472	11.02%	9.90%	6.75%	8.78%	41.69%
443	186	CRN,SOY	2477	2652	2851	2963	3305	3528	7.50%	3.92%	11.54%	6.74%	33.03%
443	186	CRP1	2477	2880	3303	3578	3793	4050	14.69%	8.33%	6.00%	6.76%	40.60%
443	999	CRP2	2477	2897	3320	3673	3973	4328	14.60%	10.63%	8.16%	8.93%	49.39%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
444	186	CRN,SOY	2454	2610	2921	3101	3544	3791	11.91%	6.16%	14.28%	6.96%	45.24%
444	186	CRP1	2454	2836	3240	3576	3872	4178	14.27%	10.37%	8.28%	7.89%	47.33%
444	999	CRP2	2454	2852	3256	3638	3915	4315	14.16%	11.73%	7.61%	10.21%	51.29%
471	463	SMF,SWT	3746	3714	3907	3963	4186	4309	5.19%	1.43%	5.62%	2.93%	16.02%
471	463	CRP1	3746	3917	4213	4269	4327	4395	7.56%	1.33%	1.35%	1.58%	12.21%
471	999	CRP2	3746	3917	4213	4278	4370	4463	7.55%	1.54%	2.15%	2.12%	13.93%
472	463	SMF,SWT	4227	4295	4576	4560	4812	5038	6.54%	-0.34%	5.52%	4.69%	17.29%
472	463	CRP1	4227	4485	4841	4996	5075	5190	7.94%	3.21%	1.58%	2.27%	15.72%
472	999	CRP2	4227	4485	4841	4966	5107	5250	7.93%	2.58%	2.83%	2.80%	17.05%
473	463	SMF,SWT	3895	3917	4128	4133	4345	4511	5.38%	0.12%	5.12%	3.82%	15.16%
473	463	CRP1	3895	4064	4359	4531	4584	4663	7.26%	3.95%	1.17%	1.72%	14.73%
473	999	CRP2	3895	4064	4359	4498	4658	4810	7.25%	3.18%	3.55%	3.26%	18.35%
474	463	SMF,SWT	3166	3219	3388	3430	3620	3708	5.25%	1.23%	5.53%	2.43%	15.19%
474	463	CRP1	3166	3440	3704	3854	3907	3958	7.67%	4.06%	1.37%	1.31%	15.07%
474	999	CRP2	3166	3440	3704	3841	3948	4082	7.67%	3.69%	2.78%	3.39%	18.66%
475	463	SMF,SWT	3650	3691	3866	3904	4124	4189	4.74%	0.98%	5.63%	1.57%	13.49%
475	463	CRP1	3650	3882	4167	4350	4404	4430	7.34%	4.39%	1.23%	0.59%	14.11%
475	999	CRP2	3650	3882	4167	4335	4473	4620	7.34%	4.03%	3.18%	3.28%	19.01%
531	463	SMF,SWT	3424	3418	3536	3582	3758	3865	3.45%	1.30%	4.91%	2.84%	13.07%
531	463	CRP1	3424	3734	4008	4124	4146	4213	7.34%	2.90%	0.52%	1.62%	12.83%
531	999	CRP2	3424	3734	4008	4123	4209	4367	7.33%	2.86%	2.08%	3.75%	16.95%
532	463	SMF,SWT	2956	2994	3176	3231	3340	3418	6.07%	1.73%	3.37%	2.33%	14.16%
532	463	CRP1	2956	3327	3605	3697	3731	3764	8.36%	2.54%	0.93%	0.88%	13.14%
532	999	CRP2	2956	3327	3605	3695	3832	3969	8.35%	2.49%	3.70%	3.57%	19.29%
533	463	SMF,SWT	2943	2963	3083	3084	3160	3291	4.04%	0.03%	2.46%	4.14%	11.06%
533	463	CRP1	2943	3241	3514	3670	3665	3743	8.42%	4.45%	-0.15%	2.12%	15.48%
533	999	CRP2	2943	3241	3514	3680	3829	4031	8.42%	4.72%	4.04%	5.27%	24.37%
561	131	CRN,CRN,SOY	3438	3714	4338	4641	5034	5628	16.80%	6.98%	8.46%	11.79%	51.53%
561	131	CRP1	3438	3793	4040	4531	5067	5558	6.51%	12.16%	11.82%	9.68%	46.53%
561	999	CRP2	3438	3793	4040	4168	4291	4463	6.51%	3.16%	2.95%	4.00%	17.66%
562	131	CRN,CRN,SOY	3931	4251	5026	5424	5937	6660	18.23%	7.91%	9.45%	12.17%	56.66%
562	131	CRP1	3931	4332	4594	5134	5753	6277	6.05%	11.76%	12.05%	9.10%	44.89%
562	999	CRP2	3931	4332	4594	4725	4879	5076	6.04%	2.85%	3.25%	4.03%	17.17%
571	131	CRN,CRN,SOY	4204	4439	5066	5368	5764	6354	14.12%	5.96%	7.37%	10.23%	43.14%
571	131	CRP1	4204	4586	4845	5266	5645	6098	5.65%	8.68%	7.20%	8.02%	32.96%
571	999	CRP2	4204	4586	4845	4961	5090	5288	5.64%	2.39%	2.60%	3.88%	15.30%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
572	131	CRN,CRN,SOY	3822	4044	4664	4960	5350	5939	15.33%	6.34%	7.86%	11.00%	46.85%
572	131	CRP1	3822	4260	4427	4949	5314	5766	3.92%	11.80%	7.37%	8.50%	35.34%
572	999	CRP2	3822	4260	4427	4625	4777	5028	3.92%	4.47%	3.28%	5.25%	18.02%
573	131	CRN,CRN,SOY	3085	3330	3902	4170	4456	4936	17.17%	6.86%	6.85%	10.77%	48.22%
573	131	CRP1	3085	3467	3684	4179	4465	4854	6.26%	13.42%	6.86%	8.71%	40.01%
573	999	CRP2	3085	3467	3684	3912	4072	4335	6.25%	6.18%	4.08%	6.45%	25.03%
581	100	CRN	2448	2537	2852	3049	3452	3644	12.41%	6.90%	13.21%	5.56%	43.63%
581	518	CRP1	2448	2570	2709	2839	3151	3322	5.43%	4.80%	10.97%	5.43%	29.27%
581	999	CRP2	2448	2572	2711	2840	2914	2977	5.40%	4.75%	2.60%	2.16%	15.74%
582	100	CRN	5375	5982	6520	6897	7314	7631	8.99%	5.78%	6.04%	4.33%	27.56%
582	518	CRP1	5375	5790	5963	6282	7730	8505	2.98%	5.35%	23.06%	10.03%	46.89%
582	999	CRP2	5375	5801	5969	6027	6165	6196	2.89%	0.97%	2.28%	0.50%	6.80%
583	100	CRN	5031	5466	5959	6310	6728	7007	9.01%	5.89%	6.62%	4.14%	28.19%
583	518	CRP1	5031	5380	5580	5896	6953	7524	3.72%	5.66%	17.93%	8.21%	39.86%
583	999	CRP2	5031	5388	5587	5711	5850	6005	3.69%	2.21%	2.43%	2.64%	11.45%
584	100	CRN	4944	5418	6028	6420	6869	7118	11.25%	6.50%	6.99%	3.62%	31.37%
584	518	CRP1	4944	5339	5577	5992	7223	7842	4.47%	7.43%	20.55%	8.57%	46.89%
584	999	CRP2	4944	5349	5587	5761	5919	6127	4.44%	3.11%	2.74%	3.51%	14.54%
591	100	CRN	4635	5054	5886	6301	7267	7846	16.46%	7.05%	15.33%	7.96%	55.24%
591	100	CRP1	4635	5078	5277	5747	6641	7174	3.92%	8.90%	15.56%	8.03%	41.27%
591	999	CRP2	4635	5078	5277	5375	5532	5720	3.91%	1.85%	2.92%	3.39%	12.64%
592	100	CRN	3891	4179	4987	5360	6176	6739	19.33%	7.47%	15.22%	9.11%	61.25%
592	100	CRP1	3891	4278	4465	5027	5970	6481	4.37%	12.59%	18.76%	8.55%	51.50%
592	999	CRP2	3891	4278	4465	4638	4874	5136	4.37%	3.87%	5.08%	5.37%	20.05%
601	201	CRN,SOY,WWT	4184	4270	4473	4679	4851	5231	4.75%	4.60%	3.67%	7.83%	22.50%
601	548	CRP1	4184	4537	4803	5158	5289	5826	5.86%	7.38%	2.55%	10.16%	28.41%
601	999	CRP2	4184	4547	4813	5052	5190	5501	5.85%	4.96%	2.73%	5.99%	20.98%
602	201	CRN,SOY,WWT	3938	4111	4398	4602	4968	5338	6.98%	4.63%	7.95%	7.44%	29.84%
602	548	CRP1	3938	4262	4561	4886	5250	5812	7.03%	7.11%	7.45%	10.71%	36.38%
602	999	CRP2	3938	4271	4571	4816	5025	5365	7.02%	5.35%	4.33%	6.76%	25.61%
603	201	CRN,SOY,WWT	3550	3688	3960	4136	4442	4762	7.37%	4.44%	7.39%	7.20%	29.12%
603	548	CRP1	3550	3899	4185	4545	4858	5282	7.34%	8.60%	6.90%	8.73%	35.49%
603	999	CRP2	3550	3910	4195	4450	4757	5026	7.28%	6.07%	6.89%	5.65%	28.54%
611	186	CRN,SOY	3397	3577	3792	4000	4289	4479	6.01%	5.48%	7.22%	4.42%	25.21%
611	528	CRP1	3397	3845	4161	4483	4797	5092	8.20%	7.76%	6.99%	6.16%	32.43%
611	999	CRP2	3397	3858	4174	4481	4773	5124	8.19%	7.35%	6.51%	7.35%	32.81%

Table C.5 (contd.)

CD #	CR #	ROTATION SEQUENCE	Total Soil Carbon (gC/m2)						Percent Change in Total Soil Carbon for Selected Time Periods				
			1980	1990	2000	2010	2020	2030	1990/2000	2000/2010	2010/2020	2020/2030	1990/2030
612	186	CRN,SOY	2148	2236	2436	2634	2887	2973	8.94%	8.12%	9.60%	2.97%	32.96%
612	528	CRP1	2148	2485	2826	3084	3327	3515	13.72%	9.15%	7.86%	5.65%	41.45%
612	999	CRP2	2148	2495	2837	3132	3463	3800	13.70%	10.39%	10.56%	9.73%	52.30%
631	218	CRN,WWT	2394	2593	3048	3312	3622	3899	17.54%	8.66%	9.35%	7.64%	50.36%
631	523	CRP1	2394	2625	2749	2869	3260	3541	4.74%	4.35%	13.63%	8.64%	34.92%
631	999	CRP2	2394	2626	2751	2822	2887	2907	4.76%	2.58%	2.30%	0.69%	10.70%
632	218	CRN,WWT	3727	4089	4606	4880	5192	5557	12.64%	5.94%	6.39%	7.03%	35.90%
632	523	CRP1	3727	4070	4260	4481	5037	5504	4.65%	5.19%	12.42%	9.26%	35.21%
632	999	CRP2	3727	4072	4264	4405	4522	4663	4.71%	3.30%	2.65%	3.11%	14.51%
633	218	CRN,WWT	3567	3844	4254	4500	4746	5062	10.66%	5.78%	5.46%	6.65%	31.68%
633	523	CRP1	3567	3890	4085	4288	4738	5146	4.99%	4.98%	10.50%	8.62%	32.29%
633	999	CRP2	3567	3892	4089	4233	4420	4560	5.06%	3.52%	4.41%	3.16%	17.16%
634	218	CRN,WWT	3409	3676	4101	4300	4524	4799	11.56%	4.85%	5.20%	6.07%	30.54%
634	523	CRP1	3409	3796	3995	4210	4646	5012	5.25%	5.37%	10.35%	7.89%	32.04%
634	999	CRP2	3409	3805	4002	4192	4406	4563	5.17%	4.74%	5.10%	3.56%	19.92%
641	131	CRN,CRN,SOY	2962	3167	3644	3902	4047	4341	15.06%	7.08%	3.71%	7.26%	37.06%
641	131	CRP1	2962	3290	3555	3884	4077	4333	8.04%	9.27%	4.96%	6.27%	31.68%
641	999	CRP2	2962	3292	3556	3754	3997	4261	8.01%	5.56%	6.47%	6.60%	29.43%
642	131	CRN,CRN,SOY	2846	3071	3622	3868	4200	4706	17.94%	6.79%	8.58%	12.04%	53.23%
642	131	CRP1	2846	3200	3488	3952	4276	4622	9.00%	13.29%	8.21%	8.10%	44.46%
642	999	CRP2	2846	3202	3489	3755	4072	4353	8.96%	7.62%	8.44%	6.90%	35.94%
643	131	CRN,CRN,SOY	1787	1928	2414	2630	2885	3275	25.20%	8.94%	9.69%	13.51%	69.86%
643	131	CRP1	1787	2063	2410	2811	3055	3355	16.80%	16.65%	8.66%	9.84%	62.61%
643	999	CRP2	1787	2065	2411	2708	3026	3344	16.75%	12.31%	11.74%	10.50%	61.93%

Table C.6 Percent Change in Total Soil Carbon from 1990-2030 for CRP Scenarios and Dominant Crop Rotation

CD #	Dominant Rotation Percent Change	CRP1 Percent Change	CRP2 Percent Change
221	28.90%	22.05%	13.49%
222	29.44%	22.56%	13.71%
223	30.13%	21.87%	13.14%
231	33.03%	22.58%	16.77%
232	39.95%	25.07%	15.85%
241	39.57%	25.57%	11.85%
242	43.53%	29.34%	16.79%
251	20.43%	21.96%	19.11%
252	35.27%	28.78%	20.53%
253	23.57%	24.35%	22.27%
261	28.75%	18.84%	14.94%
262	39.04%	24.04%	17.84%
271	35.35%	25.14%	16.42%
272	45.05%	30.66%	20.17%
281	24.18%	27.04%	19.44%
282	28.27%	30.74%	19.74%
311	35.43%	29.77%	22.00%
312	37.89%	35.58%	29.21%
313	32.51%	33.03%	33.01%
314	40.02%	36.10%	26.75%
321	45.39%	30.20%	23.39%
322	44.40%	28.30%	21.62%
323	46.74%	32.05%	25.89%
341	32.58%	39.64%	32.08%
342	37.21%	42.04%	31.92%
351	44.27%	31.82%	22.60%
352	46.07%	33.14%	22.92%
353	41.19%	33.01%	27.46%
391	28.26%	21.43%	15.48%
392	36.83%	25.55%	15.71%
393	45.84%	29.69%	15.98%
401	33.46%	25.57%	11.31%
402	41.99%	29.68%	11.35%
403	46.23%	32.84%	11.52%

Table C.6 (contd.)

CD #	Dominant Rotation Percent Change	CRP1 Percent Change	CRP2 Percent Change
411	33.31%	25.48%	15.95%
412	30.45%	24.57%	16.97%
413	16.59%	25.26%	15.72%
414	32.59%	27.15%	18.48%
415	33.79%	27.02%	18.53%
416	33.66%	27.87%	19.58%
421	40.99%	29.62%	20.68%
422	47.73%	35.23%	23.88%
431	46.66%	34.38%	24.04%
432	53.06%	38.43%	27.19%
433	50.65%	39.80%	31.79%
441	18.22%	26.23%	31.88%
442	34.68%	38.93%	41.70%
443	33.03%	41.25%	49.40%
444	45.25%	47.99%	51.30%
471	16.02%	12.21%	13.94%
472	17.30%	15.72%	17.06%
473	15.16%	14.73%	18.36%
474	15.19%	15.07%	18.66%
475	13.49%	14.11%	19.01%
531	13.08%	12.83%	16.95%
532	14.16%	13.14%	19.30%
533	11.07%	15.48%	24.38%
561	51.53%	46.53%	17.66%
562	56.67%	44.89%	17.17%
571	43.14%	32.96%	15.31%
572	46.86%	35.34%	18.03%
573	48.23%	40.01%	25.04%
581	43.63%	29.36%	15.75%
582	27.57%	47.10%	6.81%
583	28.19%	40.03%	11.45%
584	31.38%	47.11%	14.54%
591	55.24%	41.27%	12.64%
592	61.26%	51.50%	20.06%
601	22.51%	28.62%	20.98%
602	29.85%	36.60%	25.61%
603	29.12%	35.80%	28.54%

Table C.6 (contd.)

CD #	Dominant Rotation Percent Change	CRP1 Percent Change	CRP2 Percent Change
611	25.22%	32.78%	32.81%
612	32.96%	41.90%	52.30%
631	50.29%	34.96%	10.70%
632	35.90%	35.26%	14.51%
633	31.69%	32.33%	17.16%
634	30.55%	32.28%	19.92%
641	37.07%	31.73%	29.43%
642	53.24%	44.54%	35.95%
643	69.87%	62.72%	61.94%
Average	35.61%	30.98%	21.89%
Maximum	69.87%	62.72%	61.94%
Minimum	11.07%	12.21%	6.81%

APPENDIX D

Maps and Displays of Simulation Results and Study Region Characteristics

D.1 Climate Station Locations In and Near the Study Region
D.2 Production Areas and State Boundaries
D.3 Production Areas and Climate Divisions in the RAMS Study Area
D.4 Cropland Distribution for the Study Region
D.5 Cover Crop Land Distribution Within the Study Region
D.6 CRP Distribution Within the Study Region
D.7 Simulated 1990 Soil Carbon (gC/m2) Distribution Within the Study Region
D.8 Simulated 1990 Soil Carbon (gC/m2) Distribution Within the Study Region Weighted by Cropland Distribution
D.9 Simulated 2030 Soil Carbon (gC/m2) Distribution Within the Study Region
D.10 Simulated 2030 Soil Carbon (gC/m2) Distribution Within the Study Region Weighted by Cropland Distribution
D.11 Increase in Soil Carbon (gC/m2) Within the Study Region From 1990 to 2030 under the Status Quo Scenario
D.12 Increase in Soil Carbon (gC/m2) Within the Study Region From 1990 to 2030 under the Status Quo Scenario Weighted by Cropland Distribution
D.13 Percent Change in Soil Carbon Within the Study Region From 1990 to 2030 under the Status Quo Scenario
D.14 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **High Conservation** Relative to the Status Quo Scenario
D.15 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **High Conservation** Relative to the Status Quo Scenario Weighted by Cropland Distribution
D.16 Percent Difference in Soil Carbon Within the Study Region For 2030 For **High Conservation** Relative to the Status Quo Scenario
D.17 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **Cover Crops** Relative to the Status Quo Scenario
D.18 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **Cover Crops** Relative to the Status Quo Scenario Weighted by Cover Crop Distribution
D.19 Percent Difference in Soil Carbon Within the Study Region For 2030 For **Cover Crops** Relative to the Status Quo Scenario
D.20 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **CRP1** Relative to the Dominant Rotation

D.21 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **CRP1** Relative to the Dominant Rotation Weighted by CRP Distribution
D.22 Percent Difference in Soil Carbon Within the Study Region For 2030 For **CRP1** Relative to the Dominant Rotation
D.23 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **CRP2** Relative to the Dominant Rotation
D.24 Increase in Soil Carbon (gC/m2) Within the Study Region For 2030 For **CRP2** Relative to the Dominant Rotation Weighted by CRP Distribution
D.25 Percent Difference in Soil Carbon Within the Study Region For 2030 For **CRP2** Relative to the Dominant Rotation

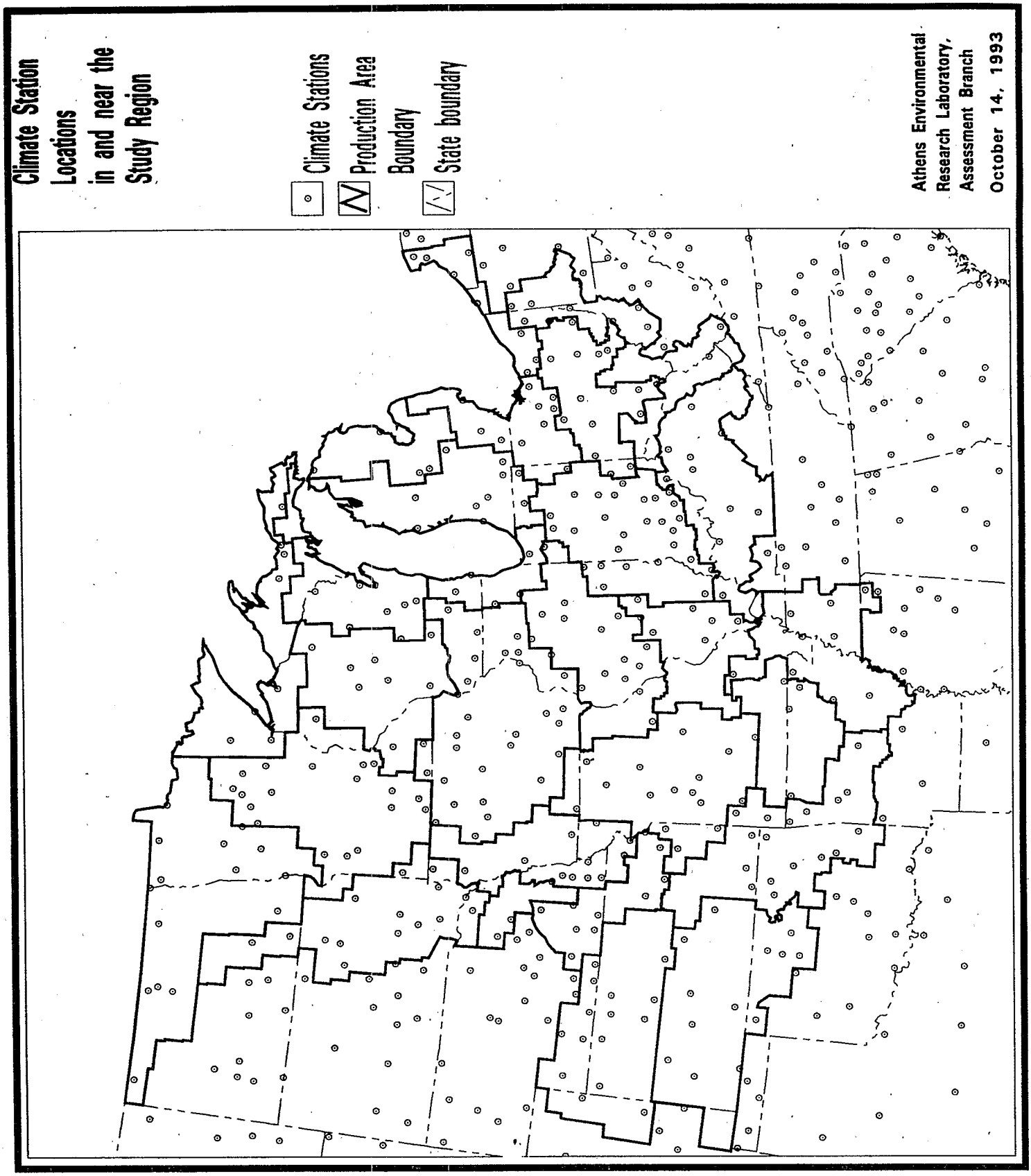

Figure D.1 Climate station locations in and near the study region

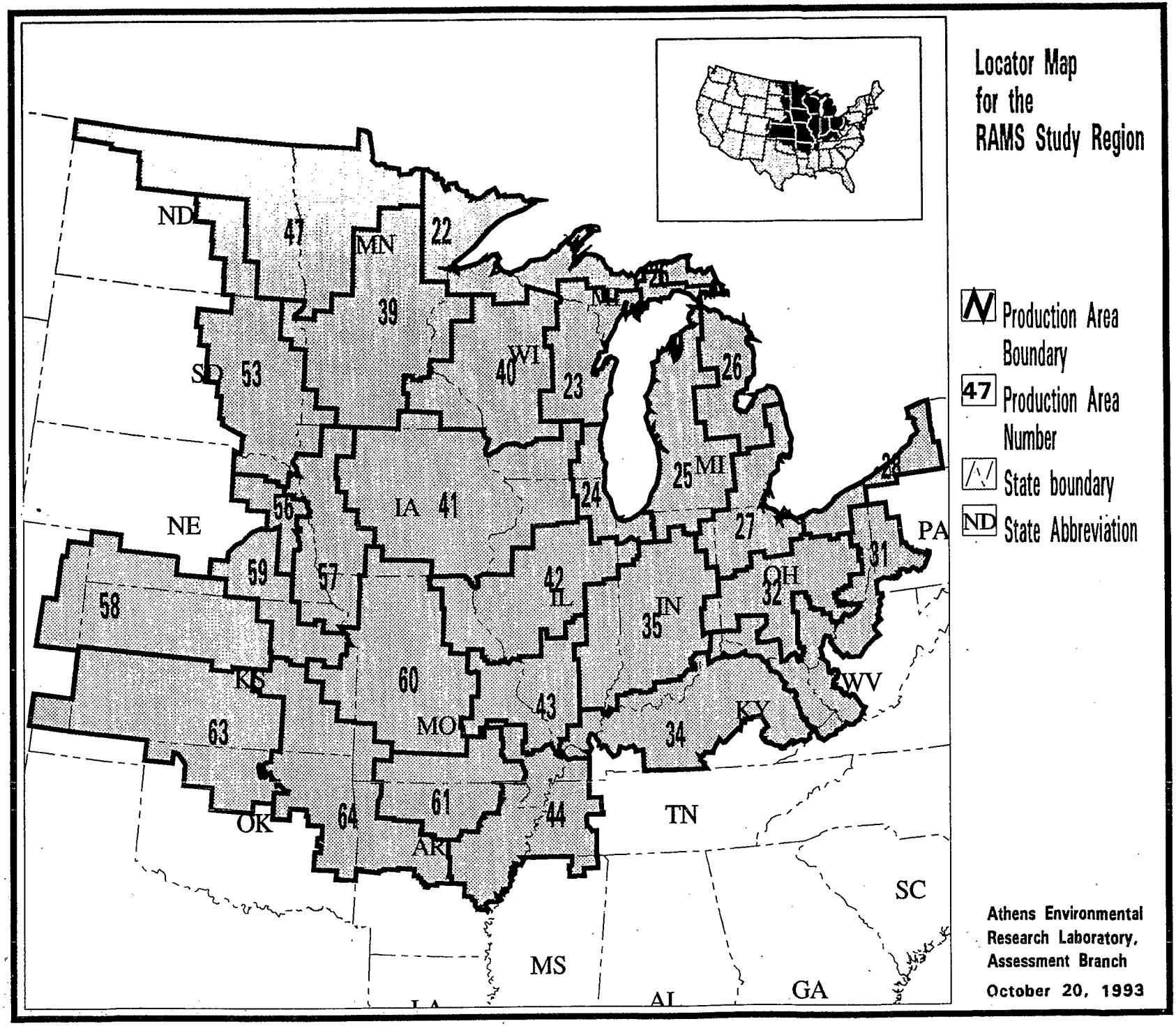

Figure D.2 Production areas and state boundaries

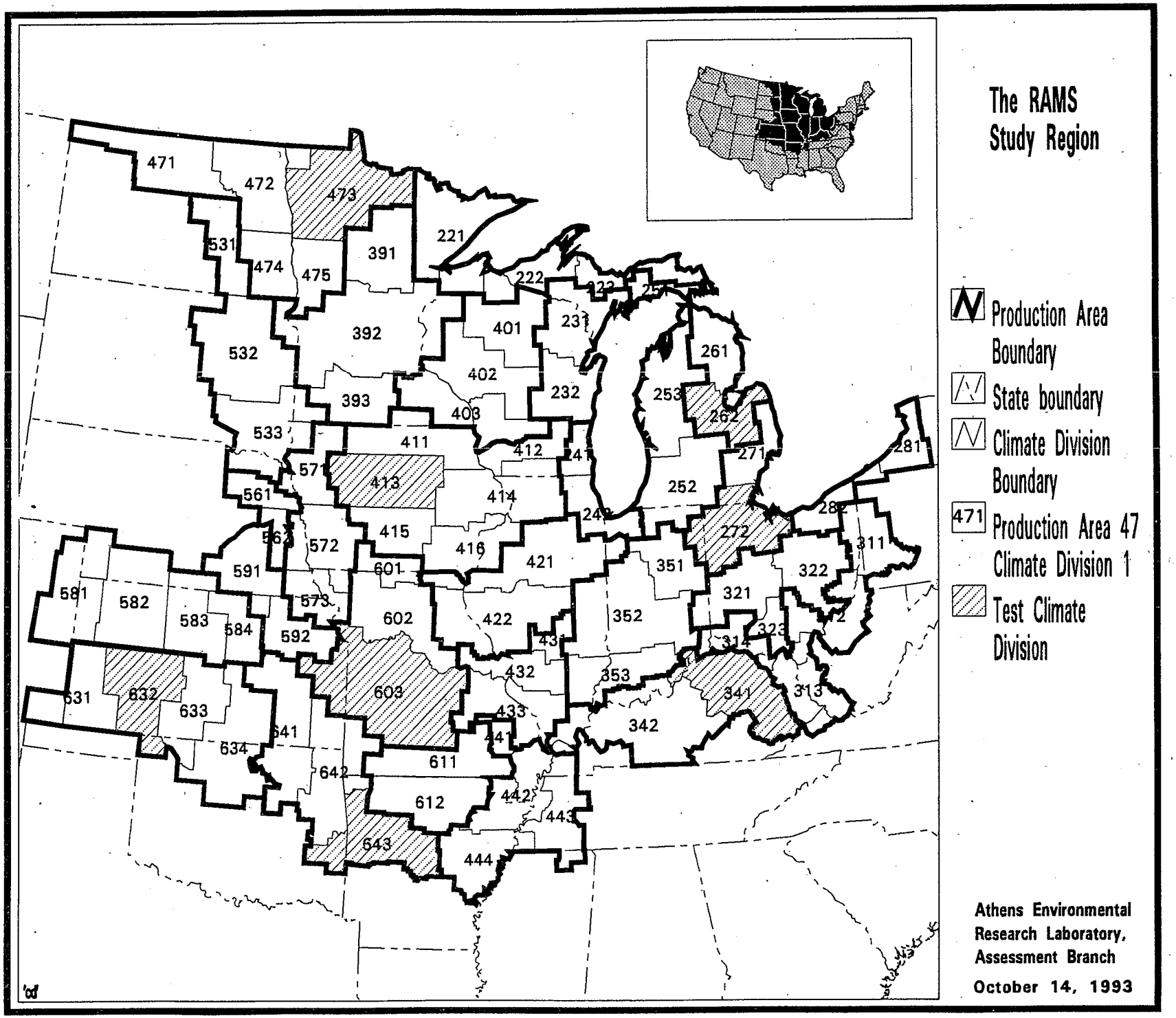

Figure D.3 Production areas and climate divisions in the RAMS study area

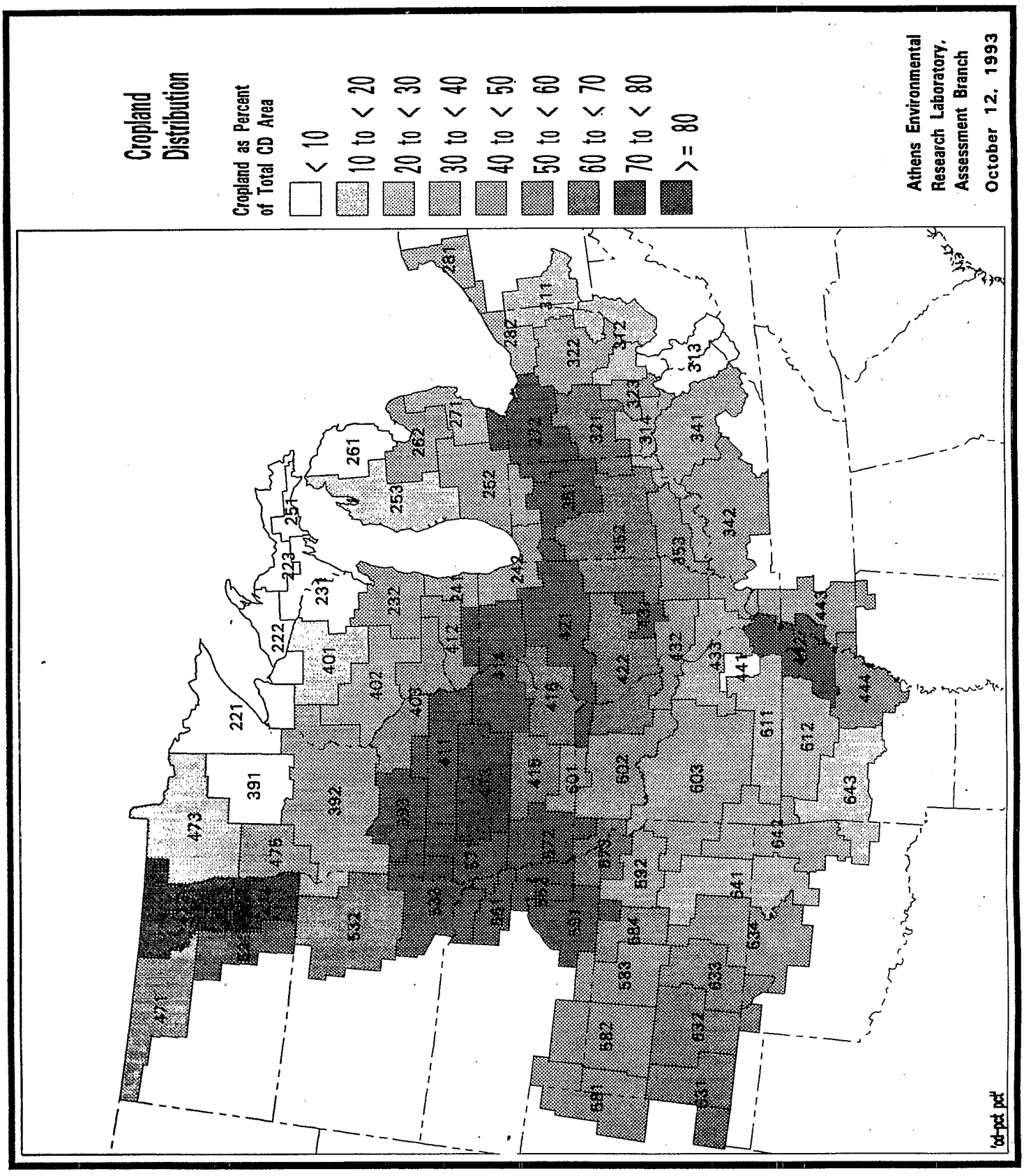

Figure D.4 Cropland distribution for the study region

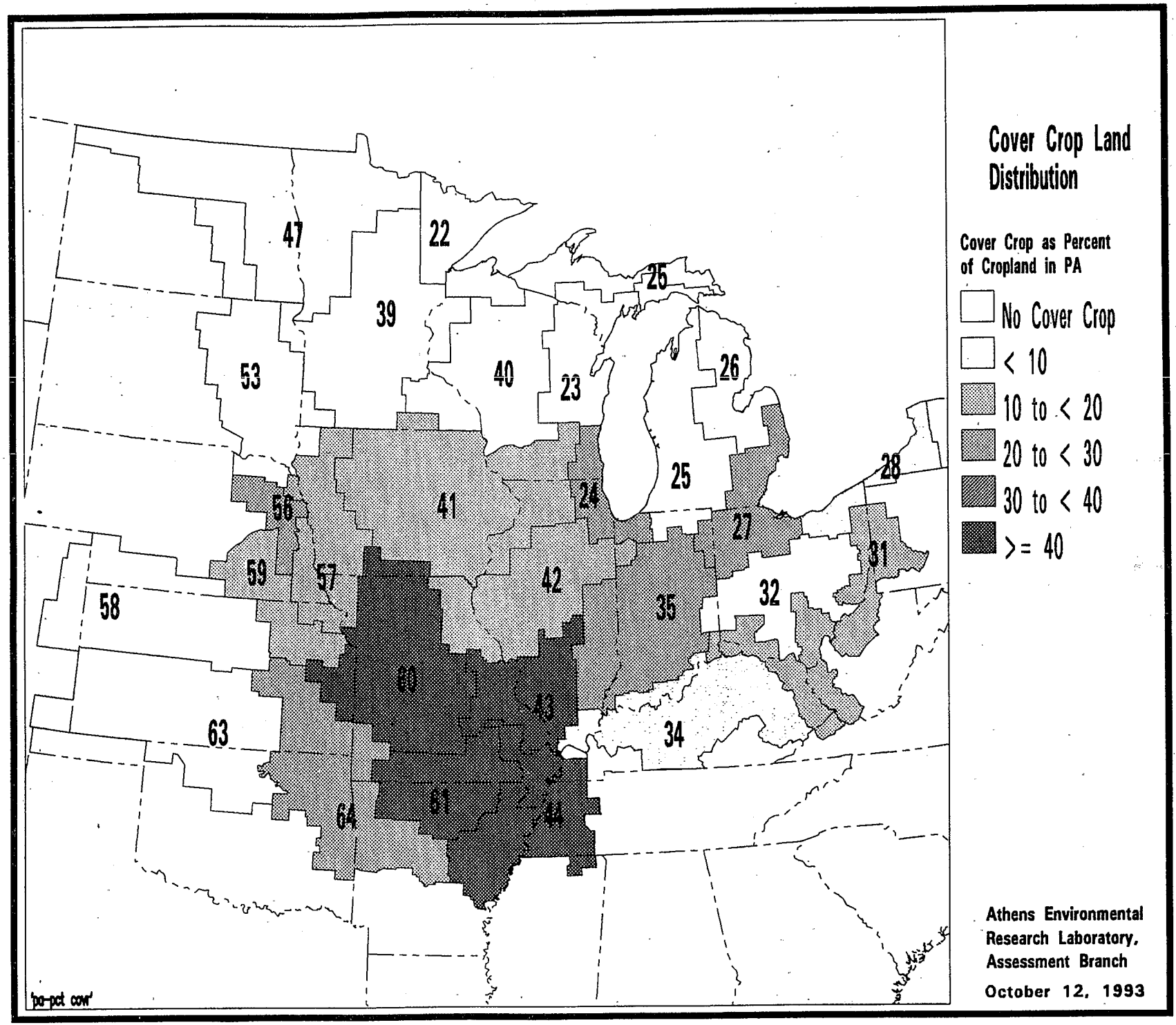

Figure D.5 Cover crop land distribution within the study region

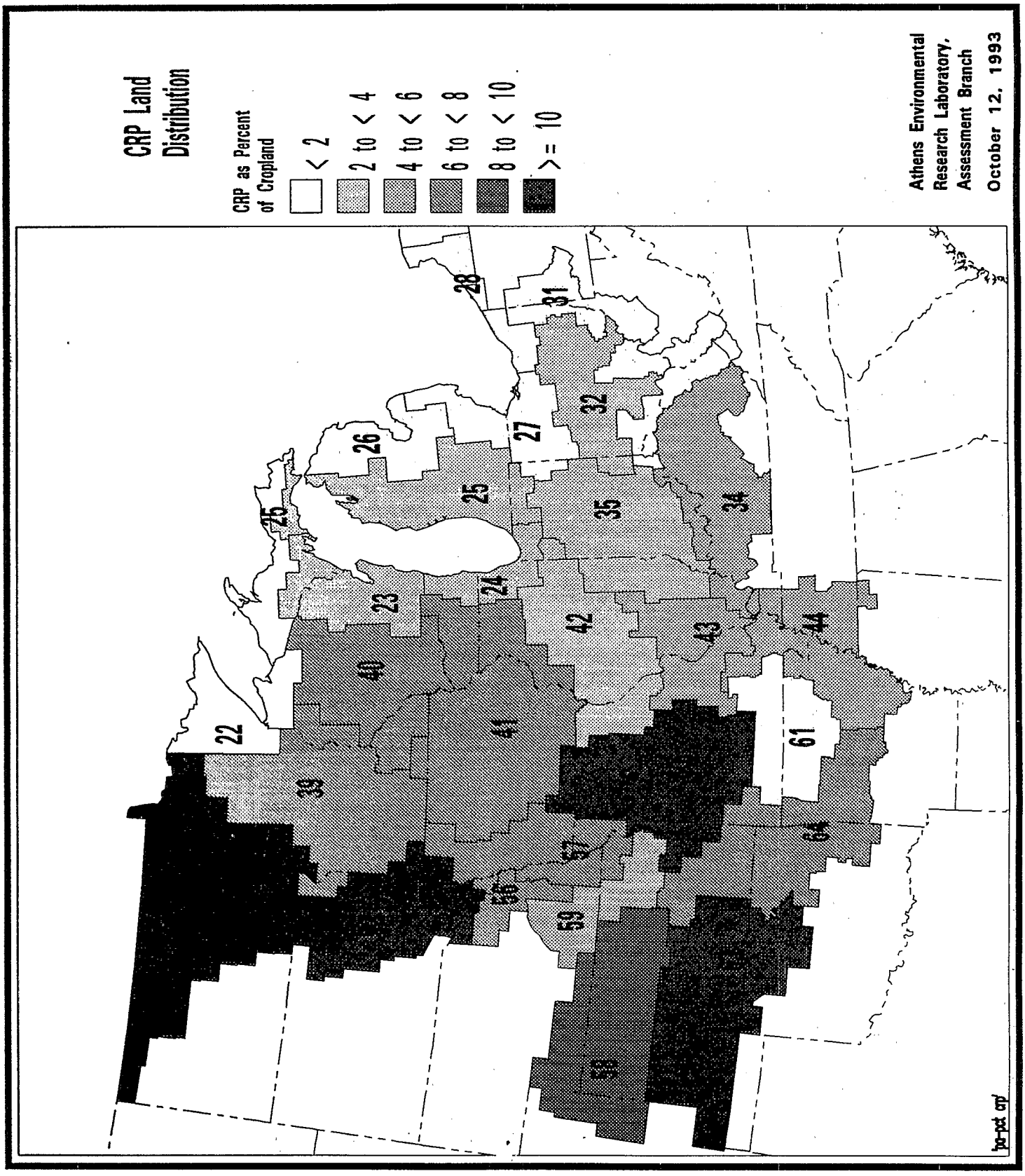

Figure D.6 CRP distribution within the study region

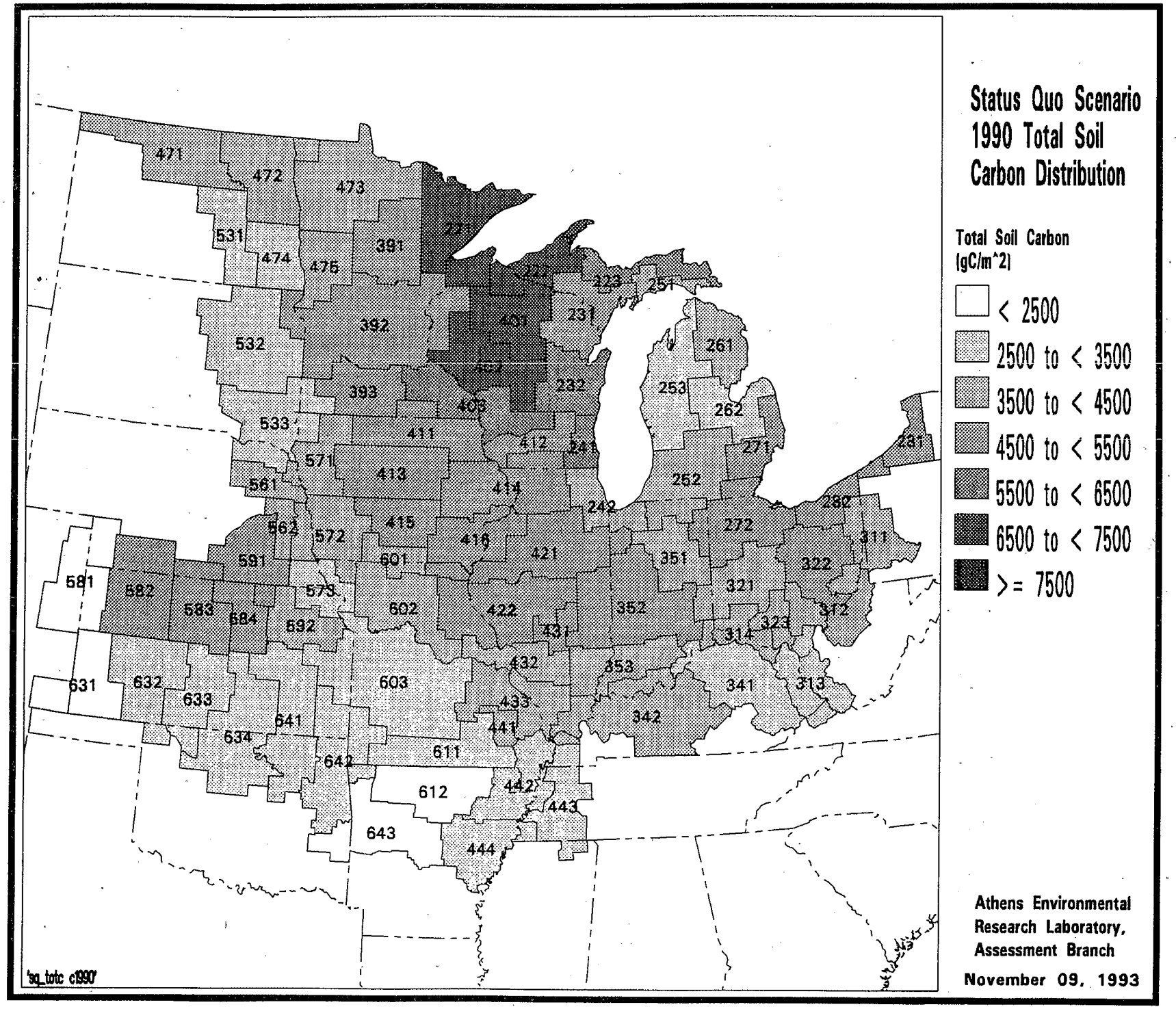

Figure D.7 Simulated 1990 Soil Carbon (gC/m2) distribution within the study region

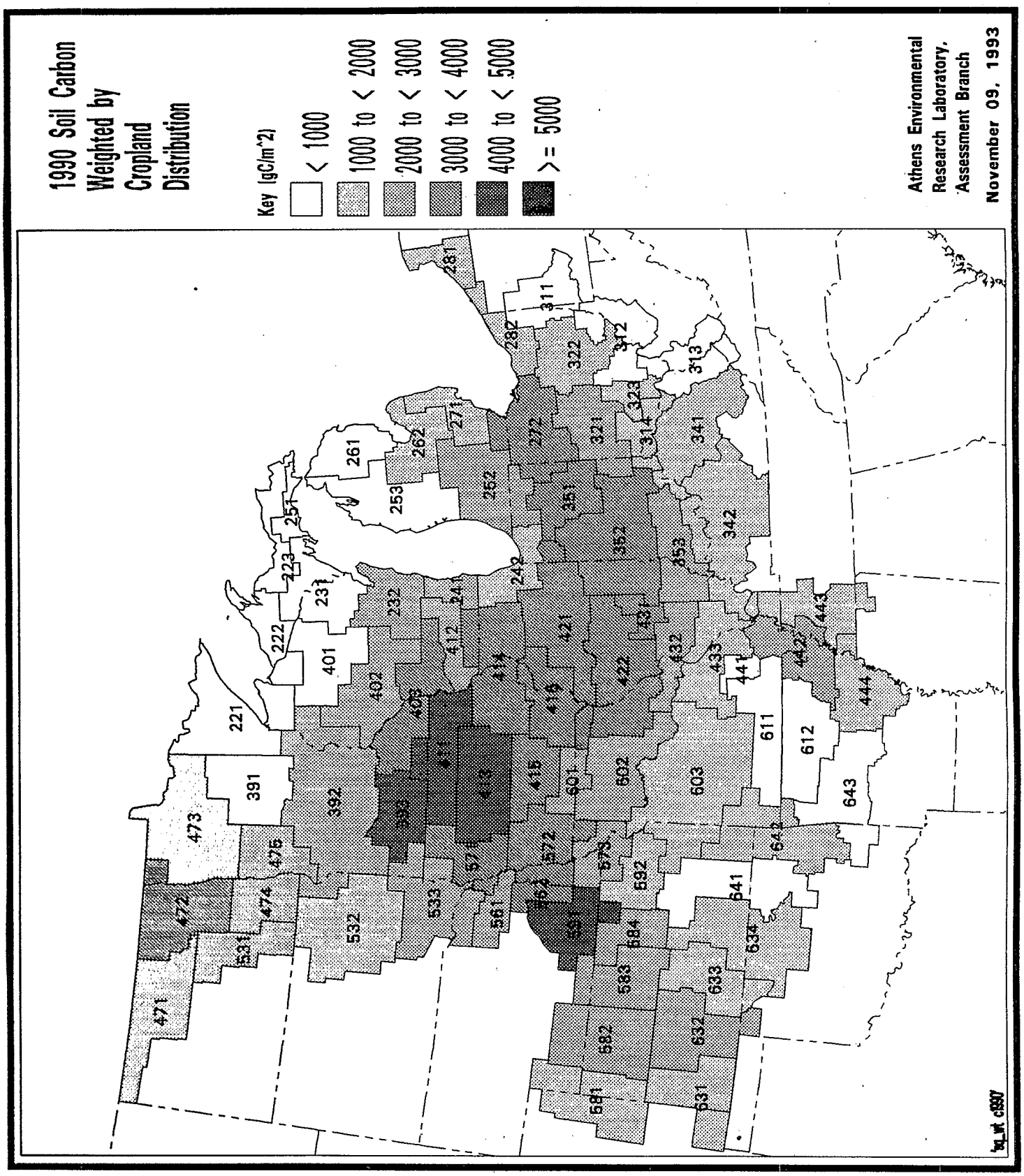

Figure D.8 Simulated 1990 Soil Carbon (gC/m2) distribution within the study region weighted by cropland distribution

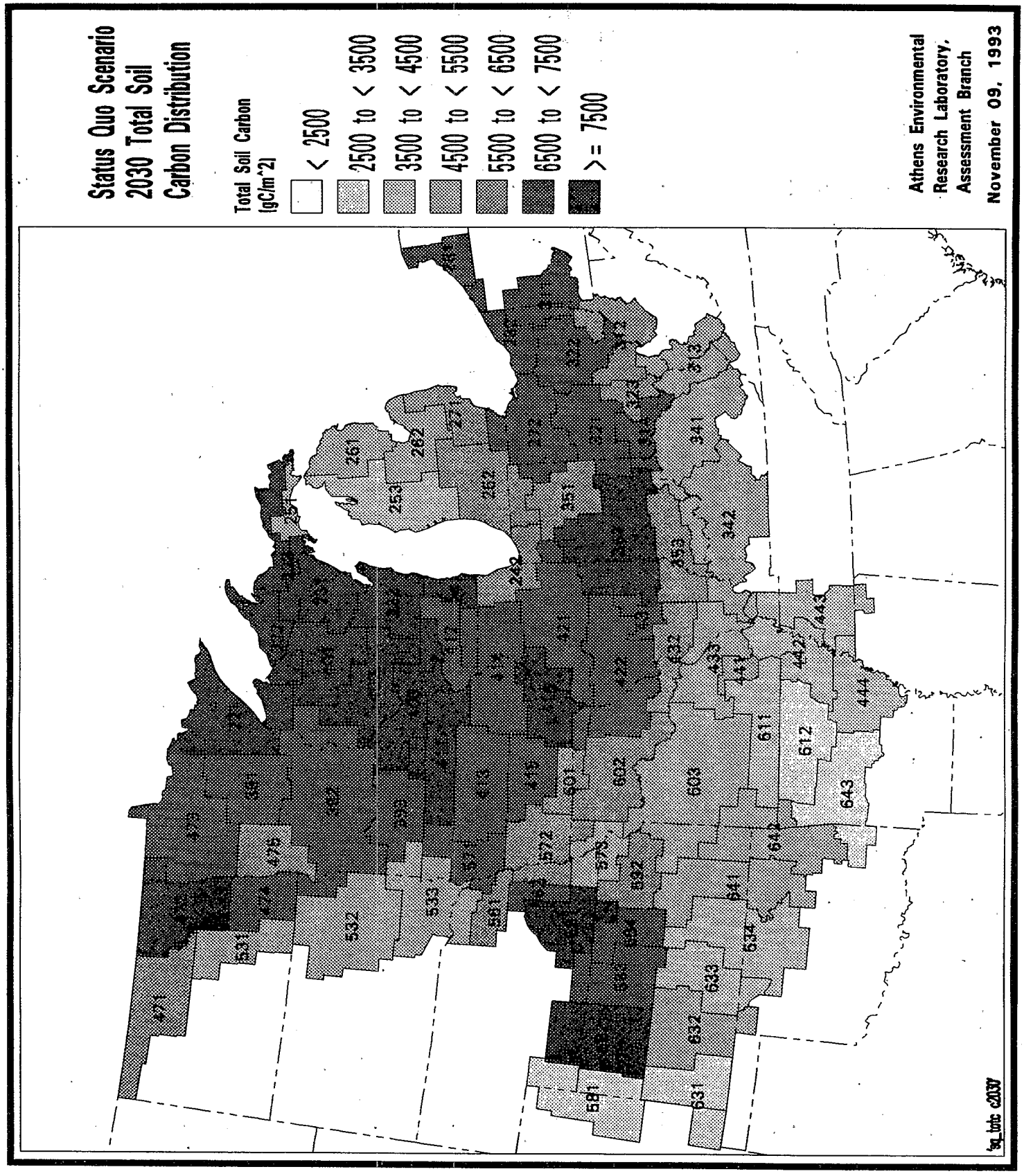

Figure D.9 Simulated 2030 Soil Carbon (gC/m2) distribution within the study region

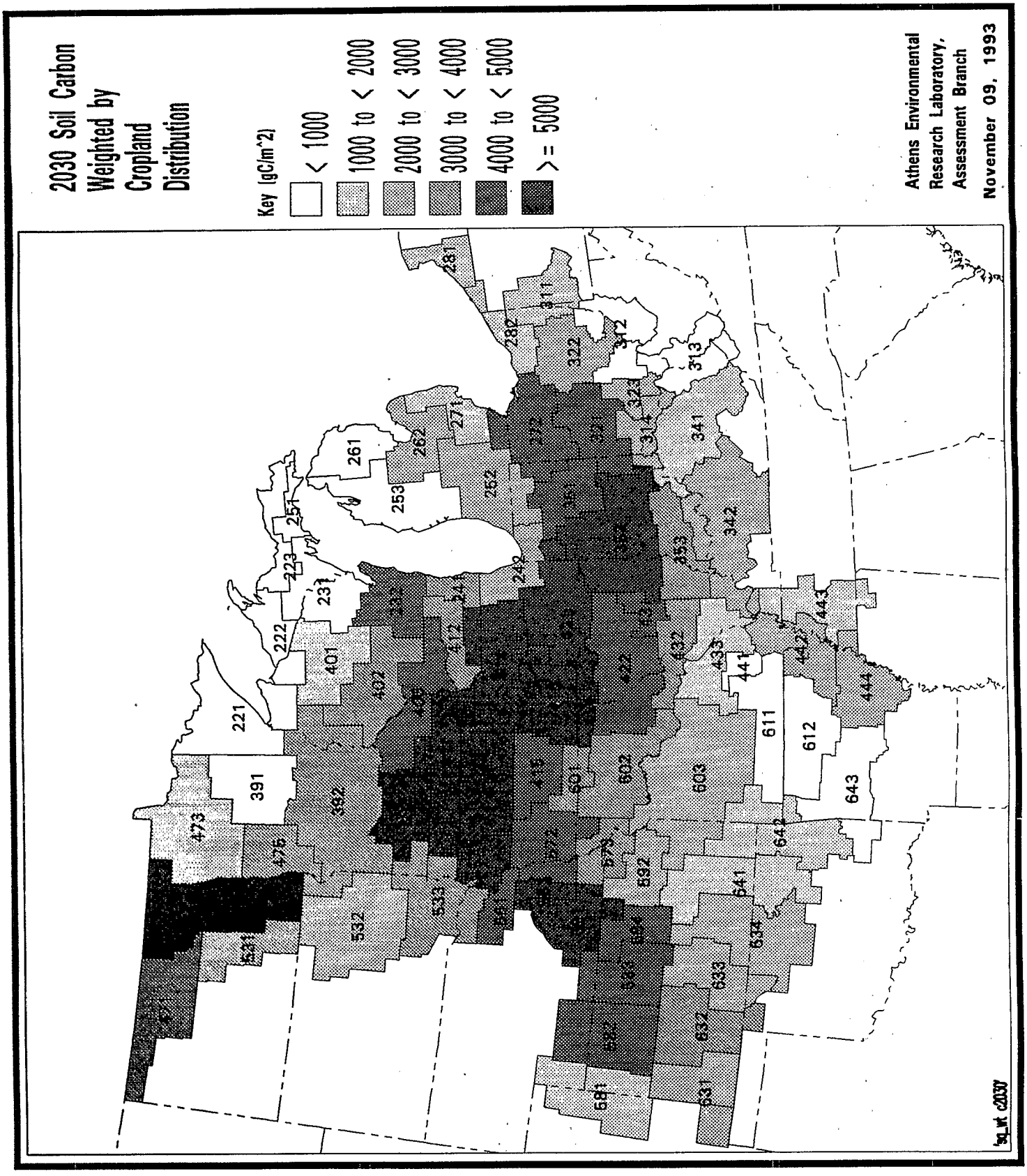

Figure D.10 Simulated 2030 Soil Carbon (gC/m2) distribution within the study region weighted by cropland distribution

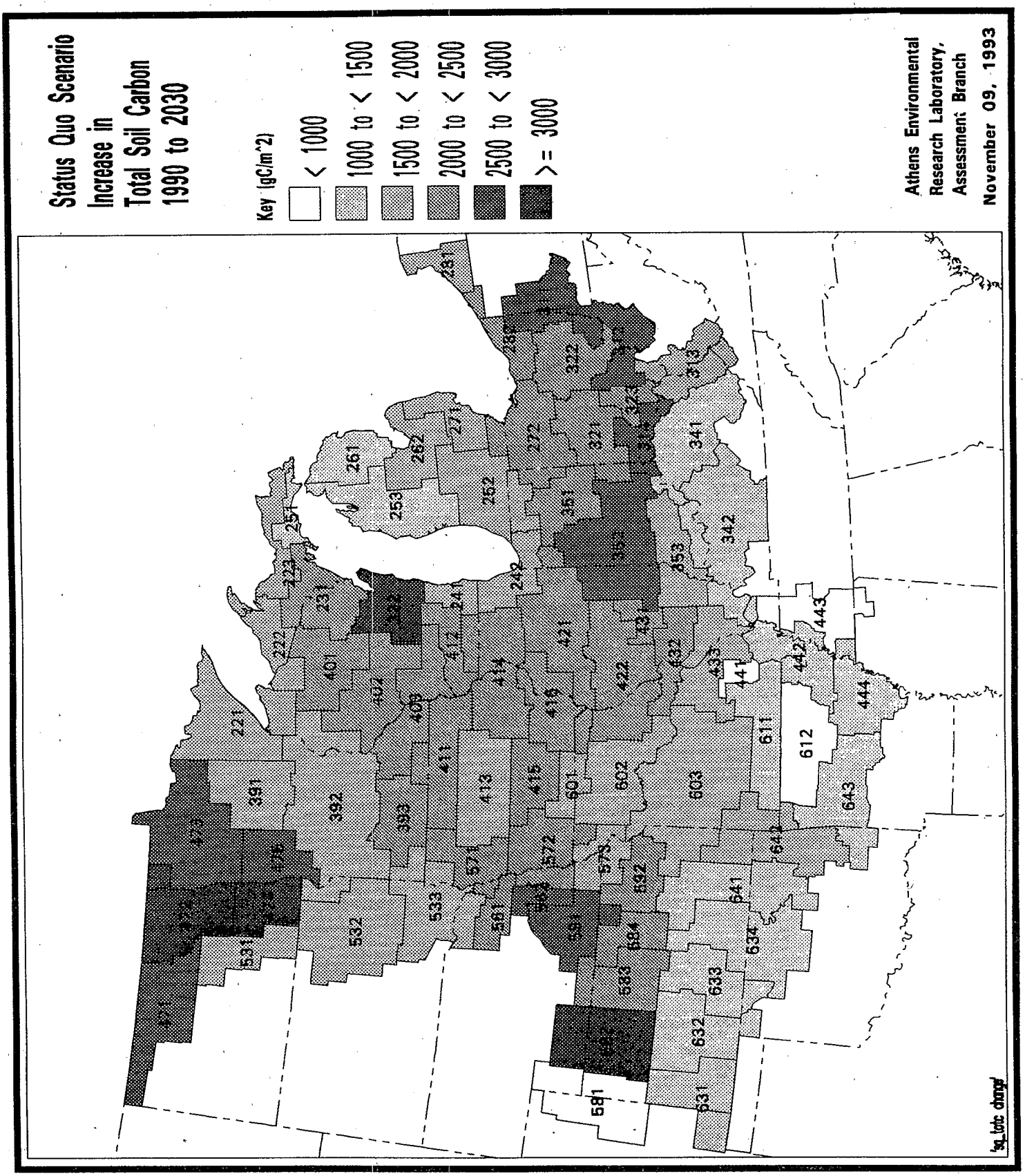

Figure D.11 Increase in Soil Carbon (gC/m2) within the study region from 1990 to 2030 under the Status Quo Scenario

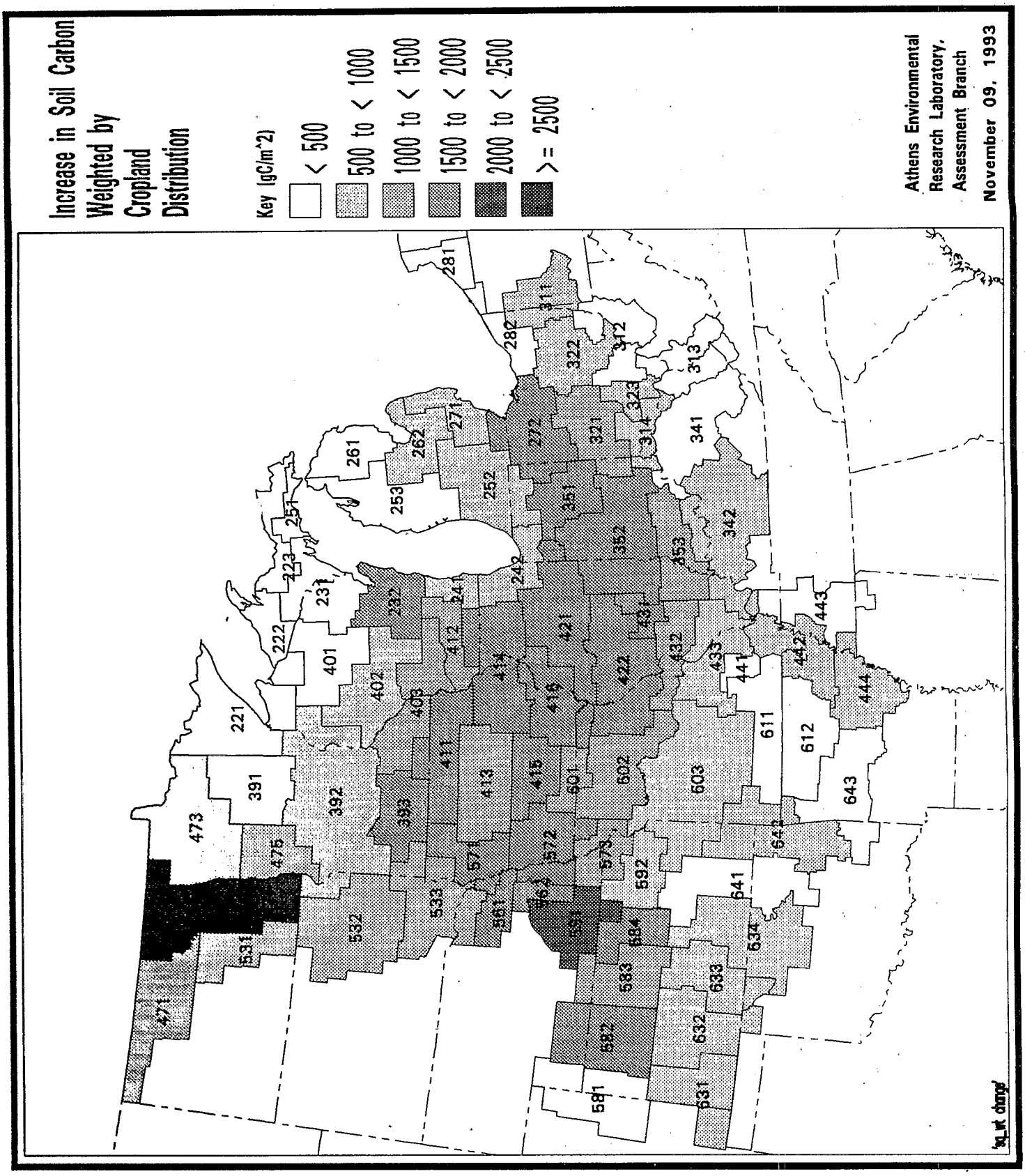

Figure D.12 Increase in Soil Carbon (gC/m2) within the study region from 1990 to 2030 under the Status Quo Scenario weighted by cropland distribution

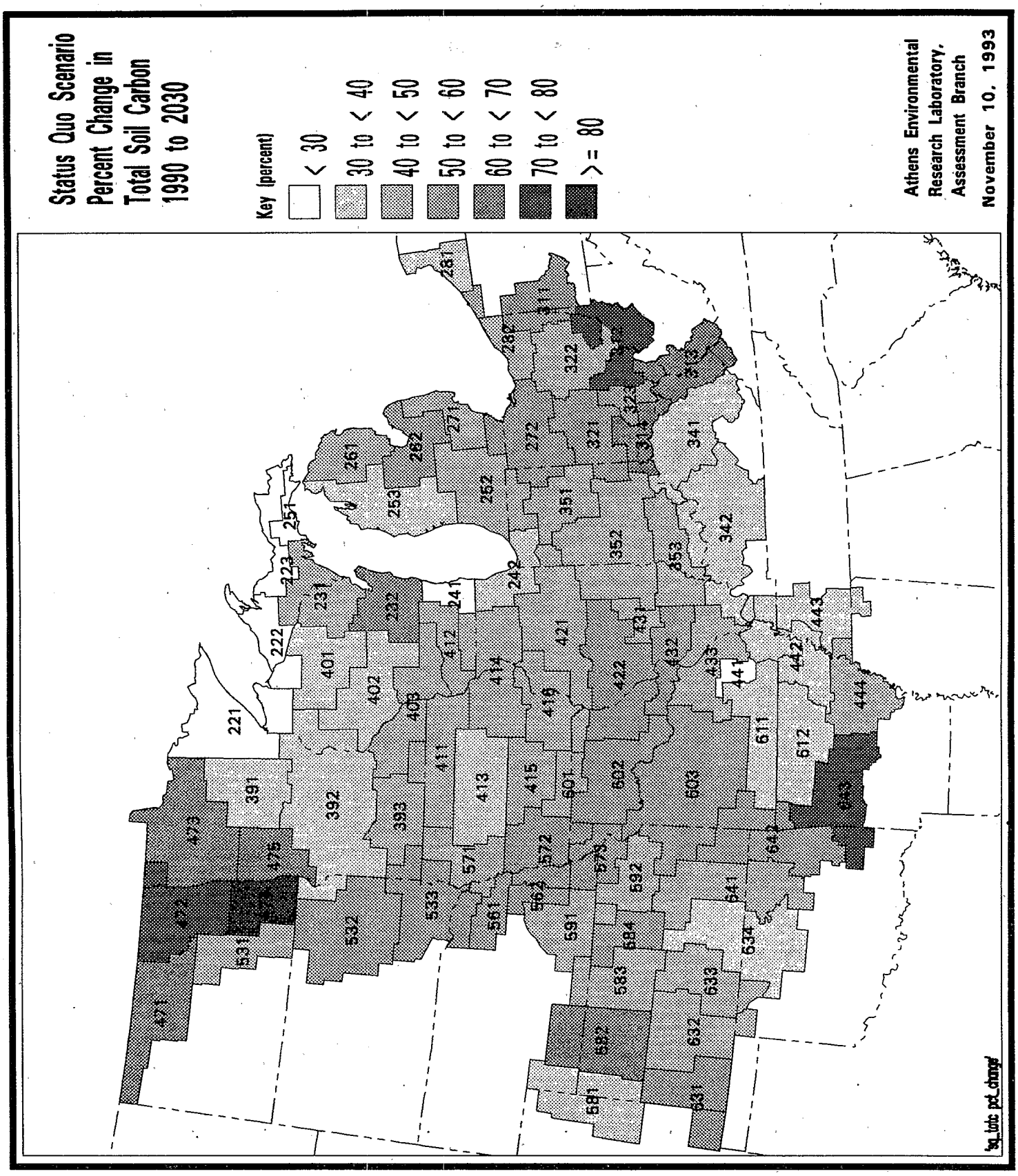

Figure D.13 Percent change in Soil Carbon within the study region from 1990 to 2030 under the Status Quo Scenario

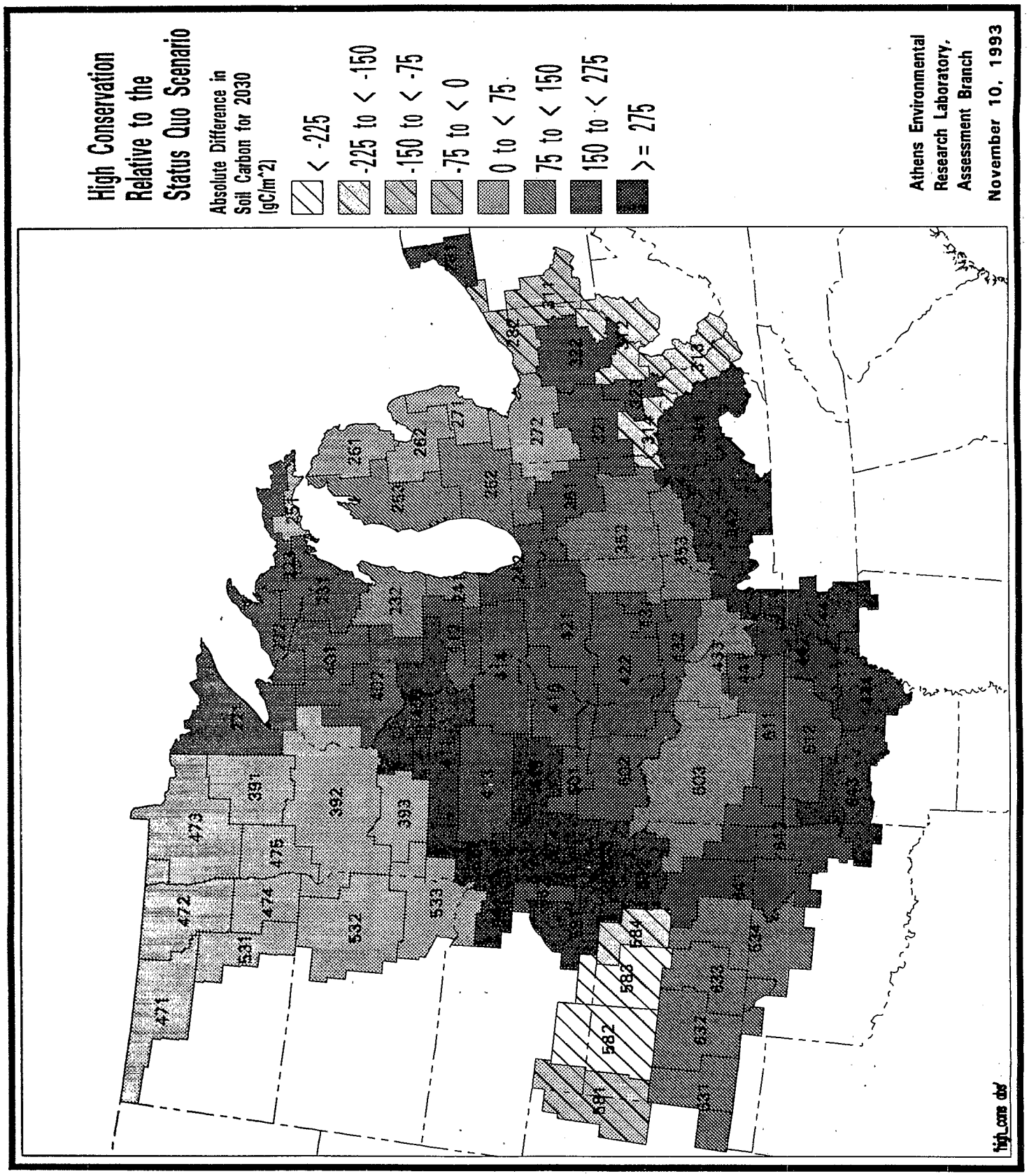

Figure D.14 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **High Conservation** relative to the Status Quo Scenario

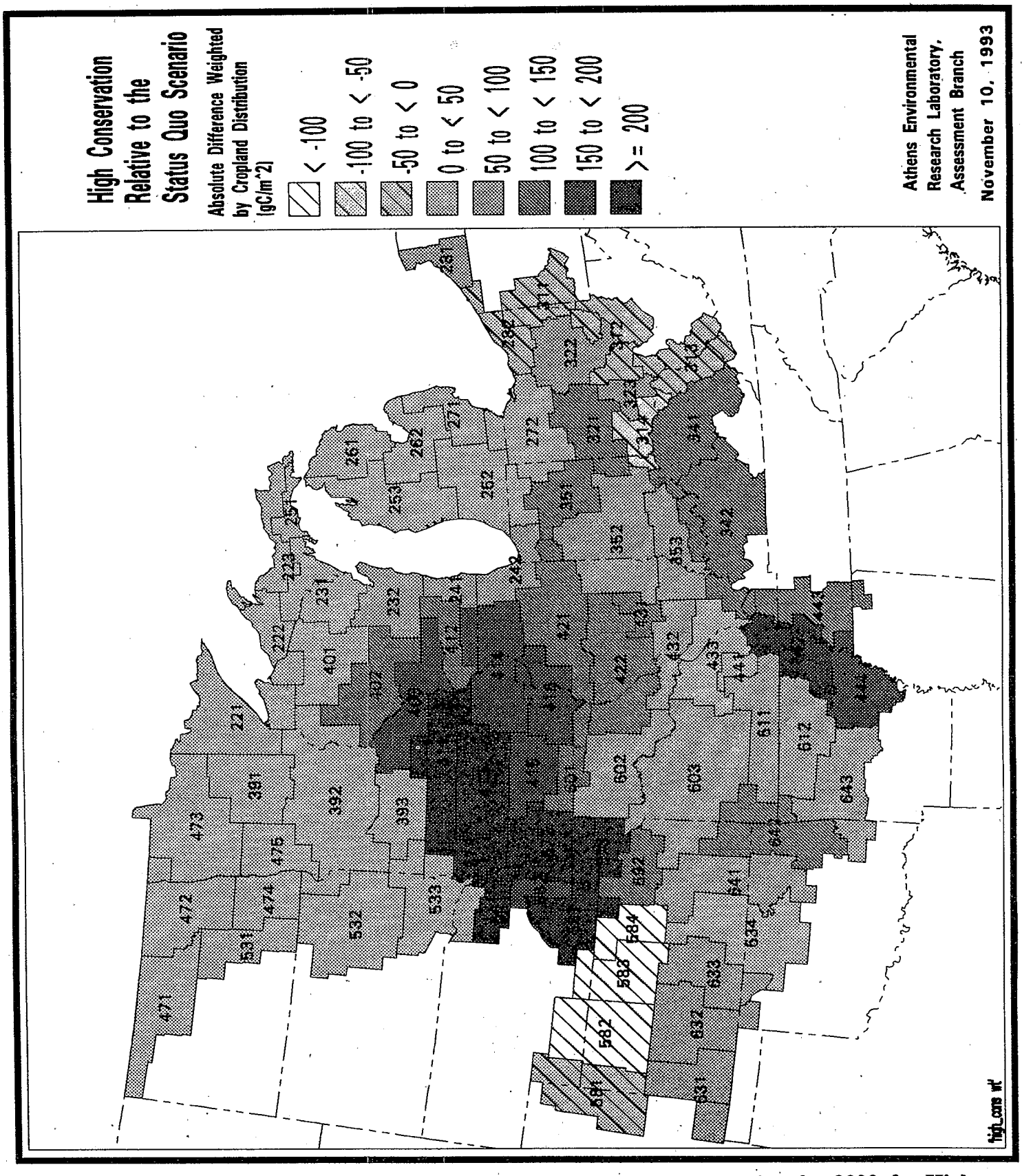

Figure D.15 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **High Conservation** relative to the Status Quo Scenario weighted by cropland distribution

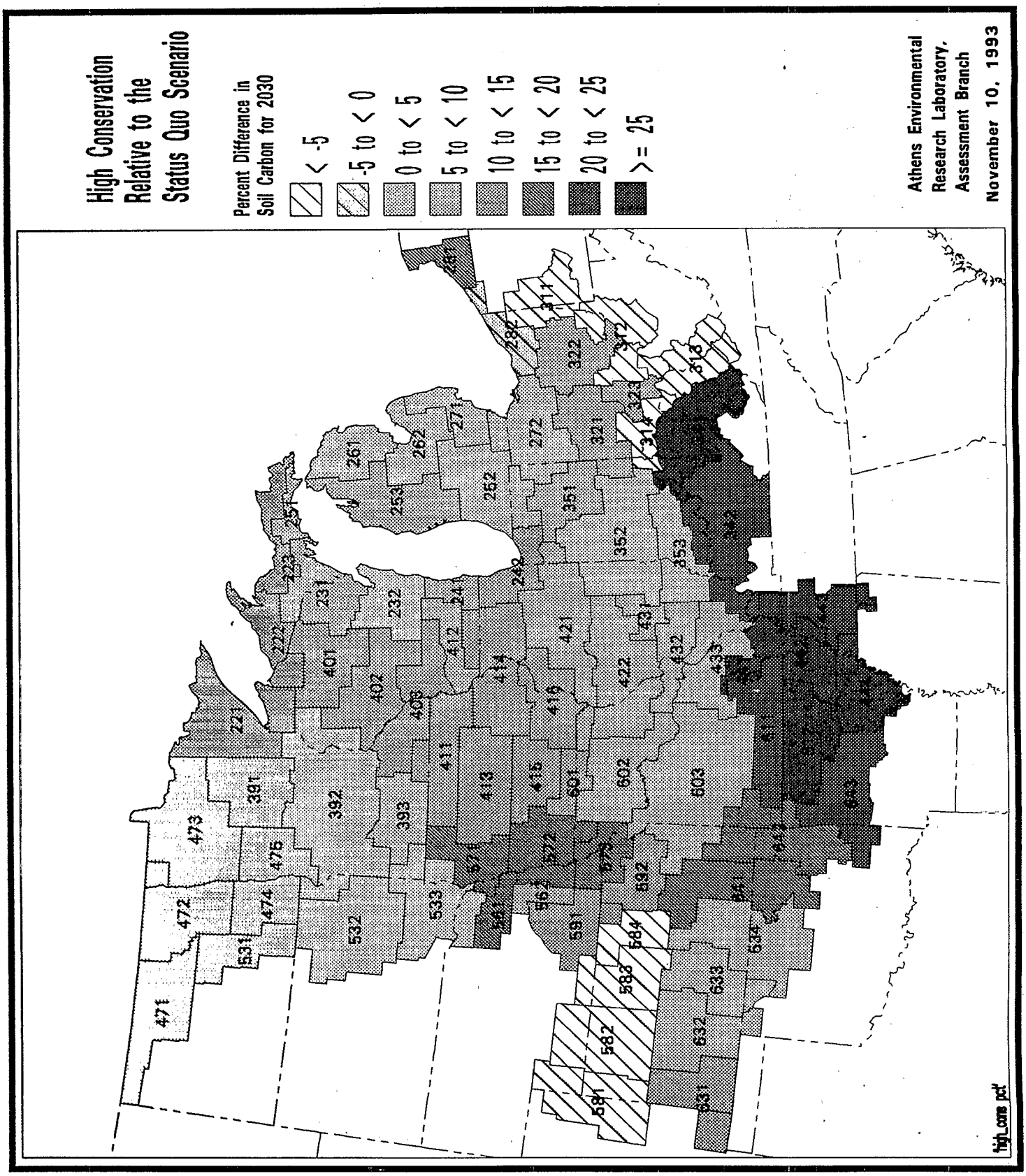

Figure D.16 Percent difference in Soil Carbon within the study region for 2030 for **High Conservation** relative to the Status Quo Scenario

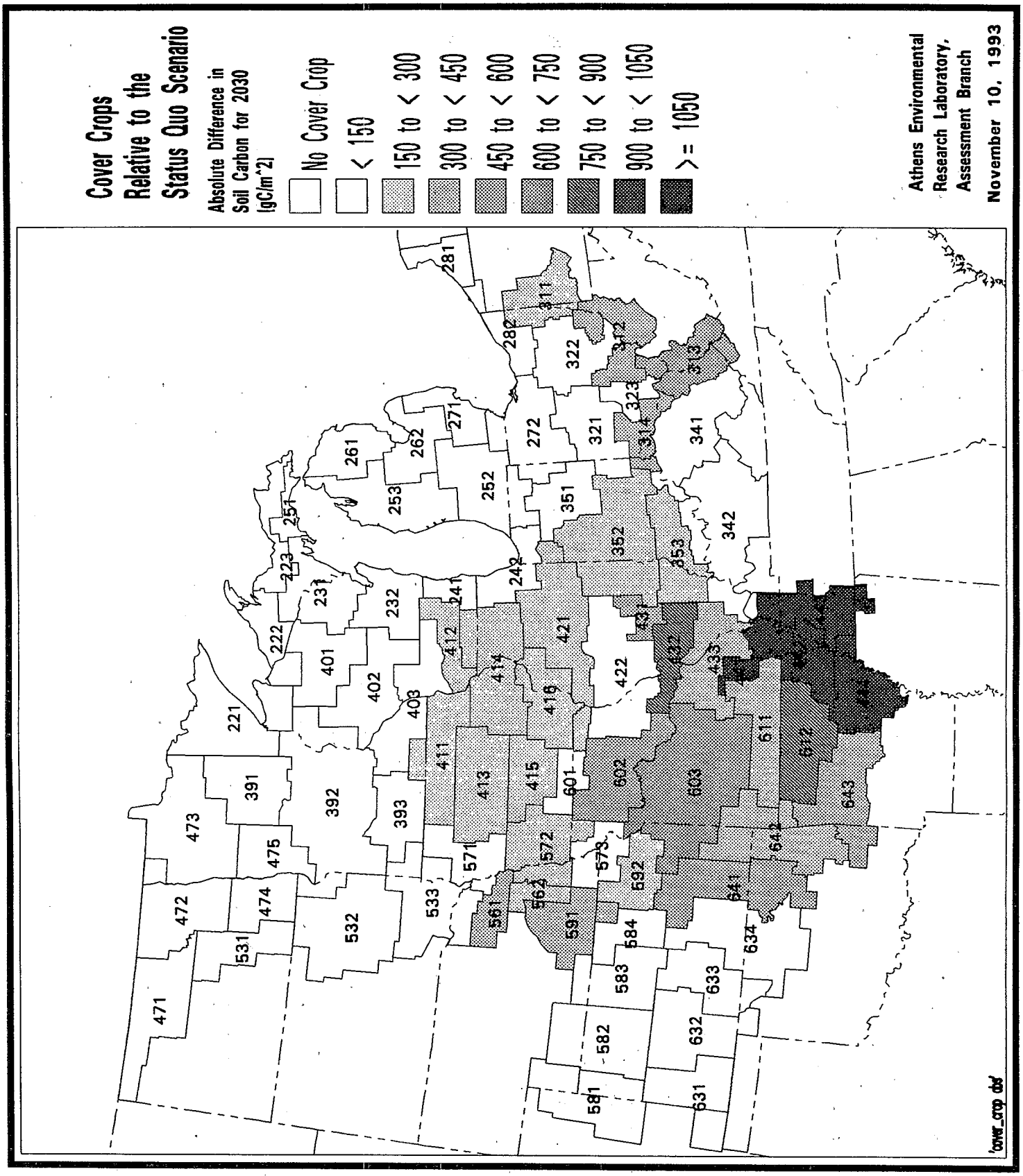

Figure D.17 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **Cover Crops** relative to the Status Quo Scenario

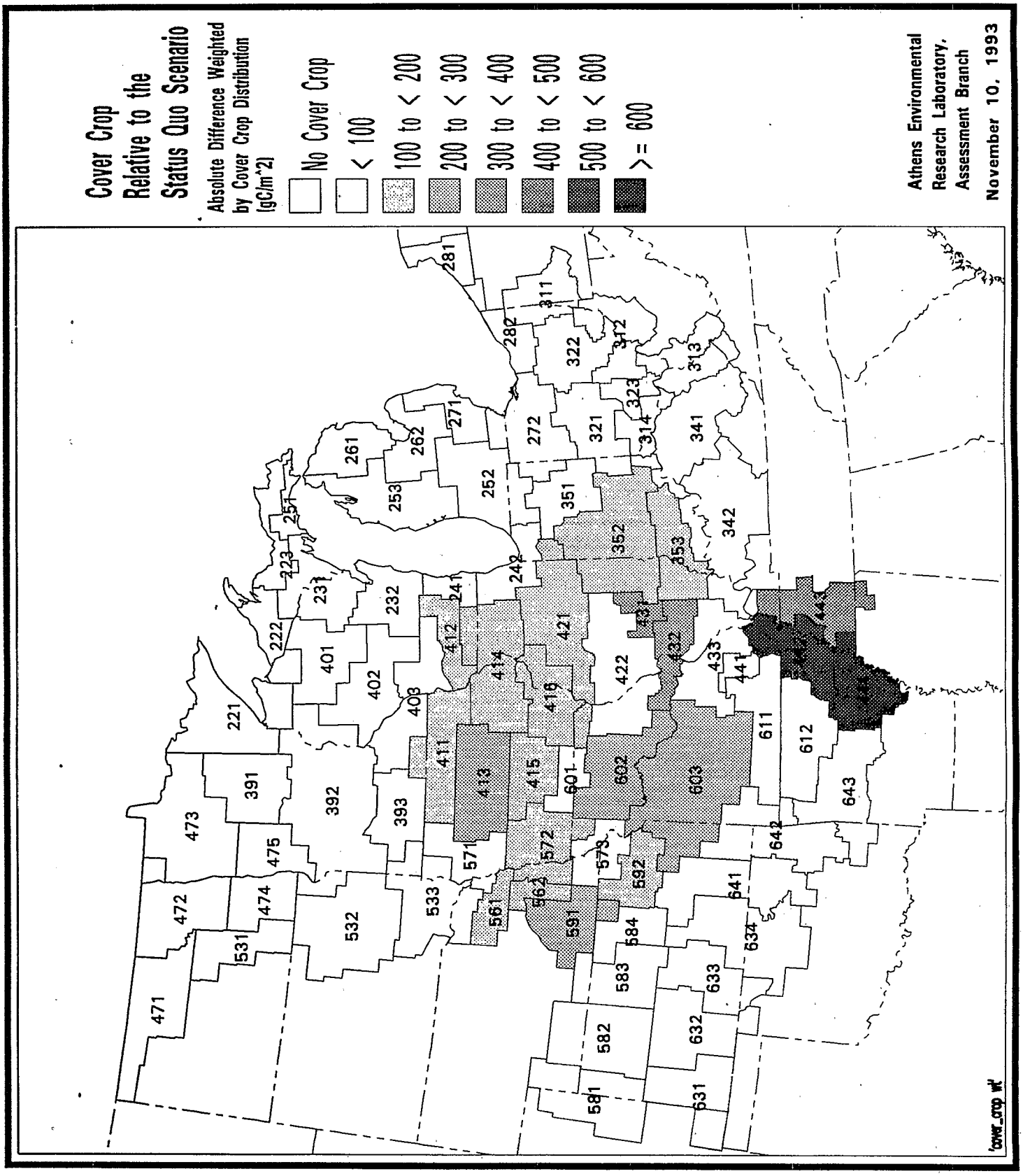

Figure D.18 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **Cover Crops** relative to the Status Quo Scenario weighted by cover crop distribution

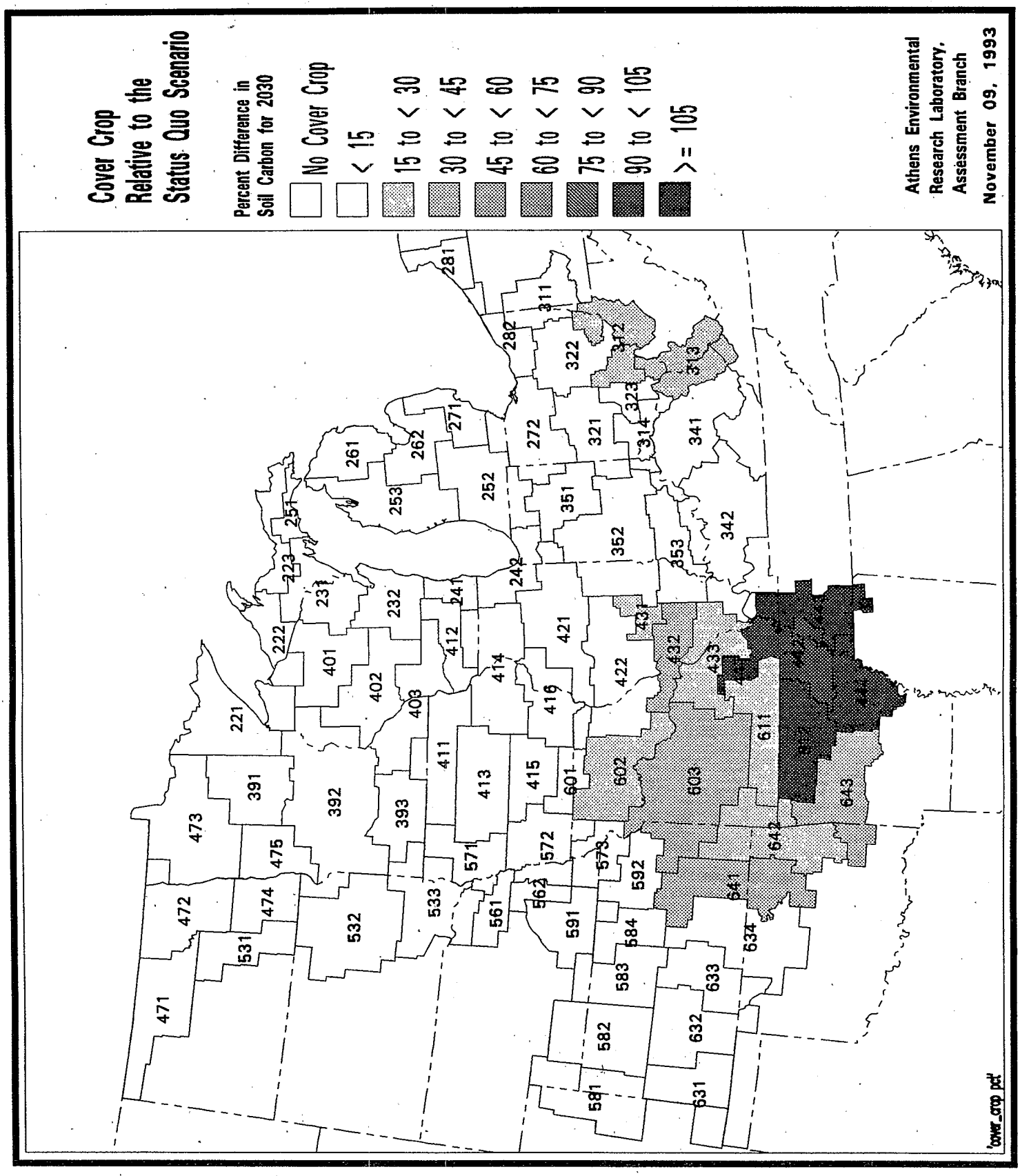

Figure D.19 Percent difference in Soil Carbon within the study region for 2030 for Cover Crops relative to the Status Quo Scenario

Figure D.20 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **CRP1** relative to the Dominant Rotation

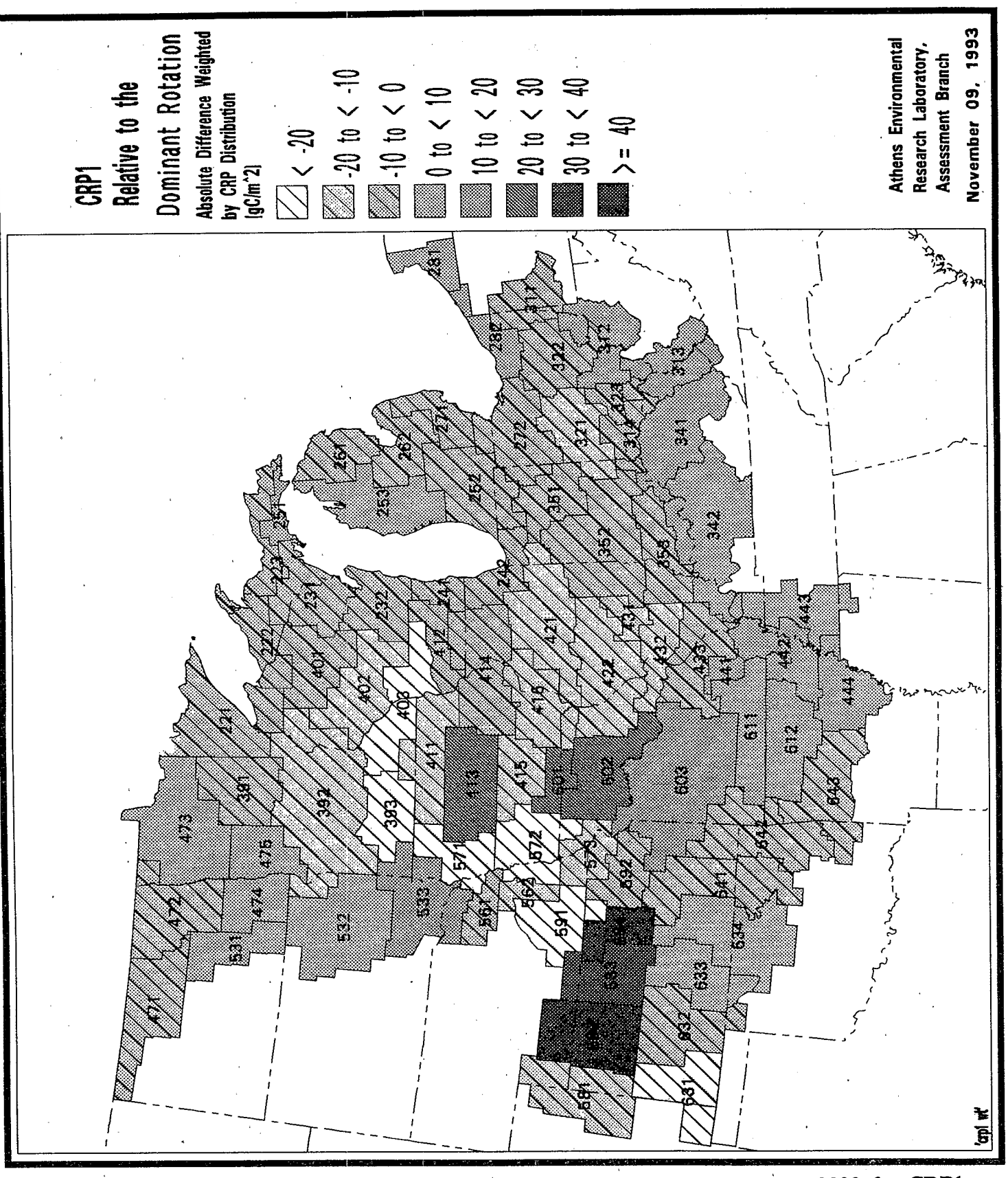

Figure D.21 Increase in Soil Carbon (gC/m2) within the study region for 2030 for CRP1 relative to the Dominant Rotation weighted by CRP distribution

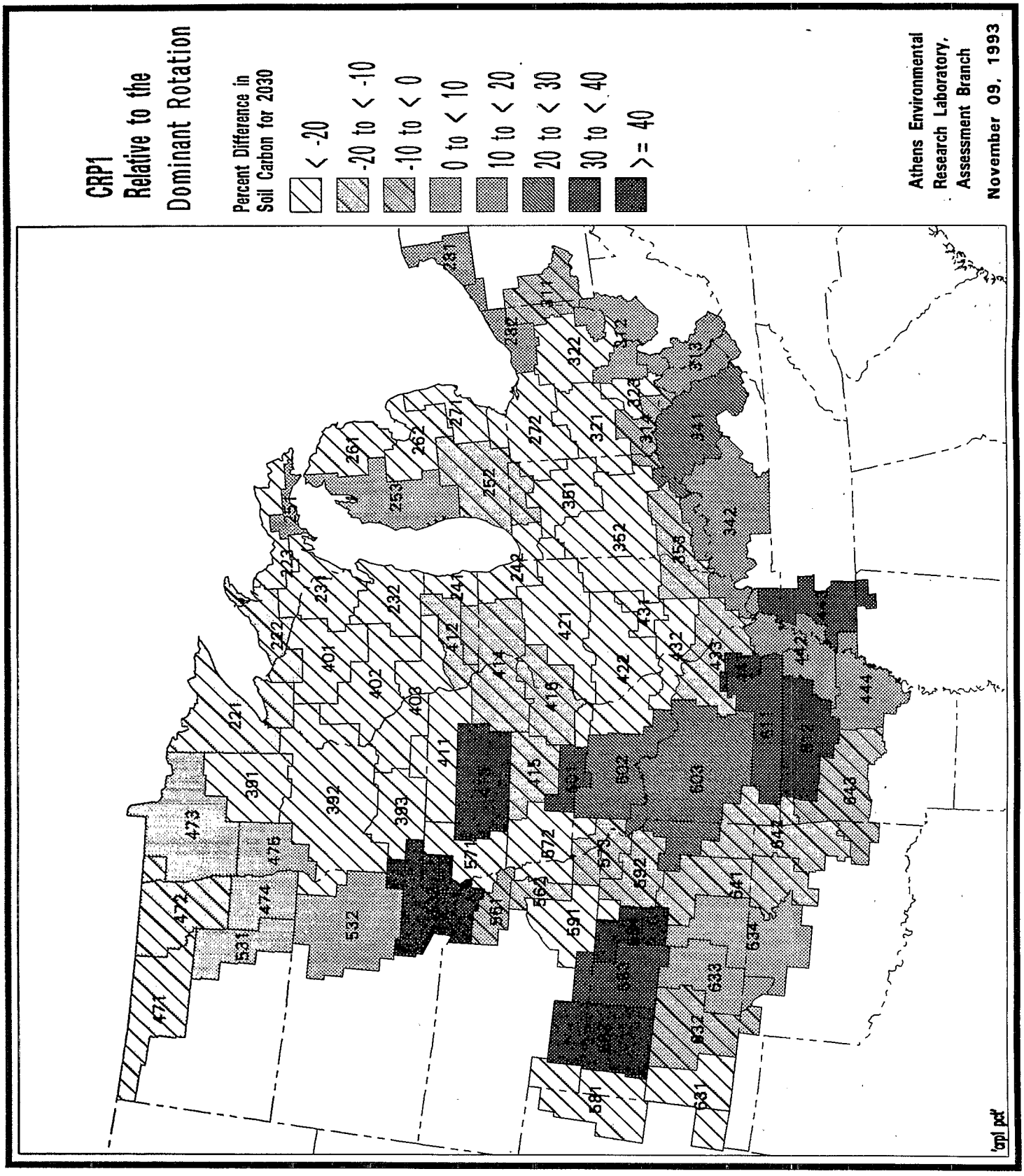

Figure D.22 Percent difference in Soil Carbon within the study region for 2030 for **CRP1** relative to the Dominant Rotation

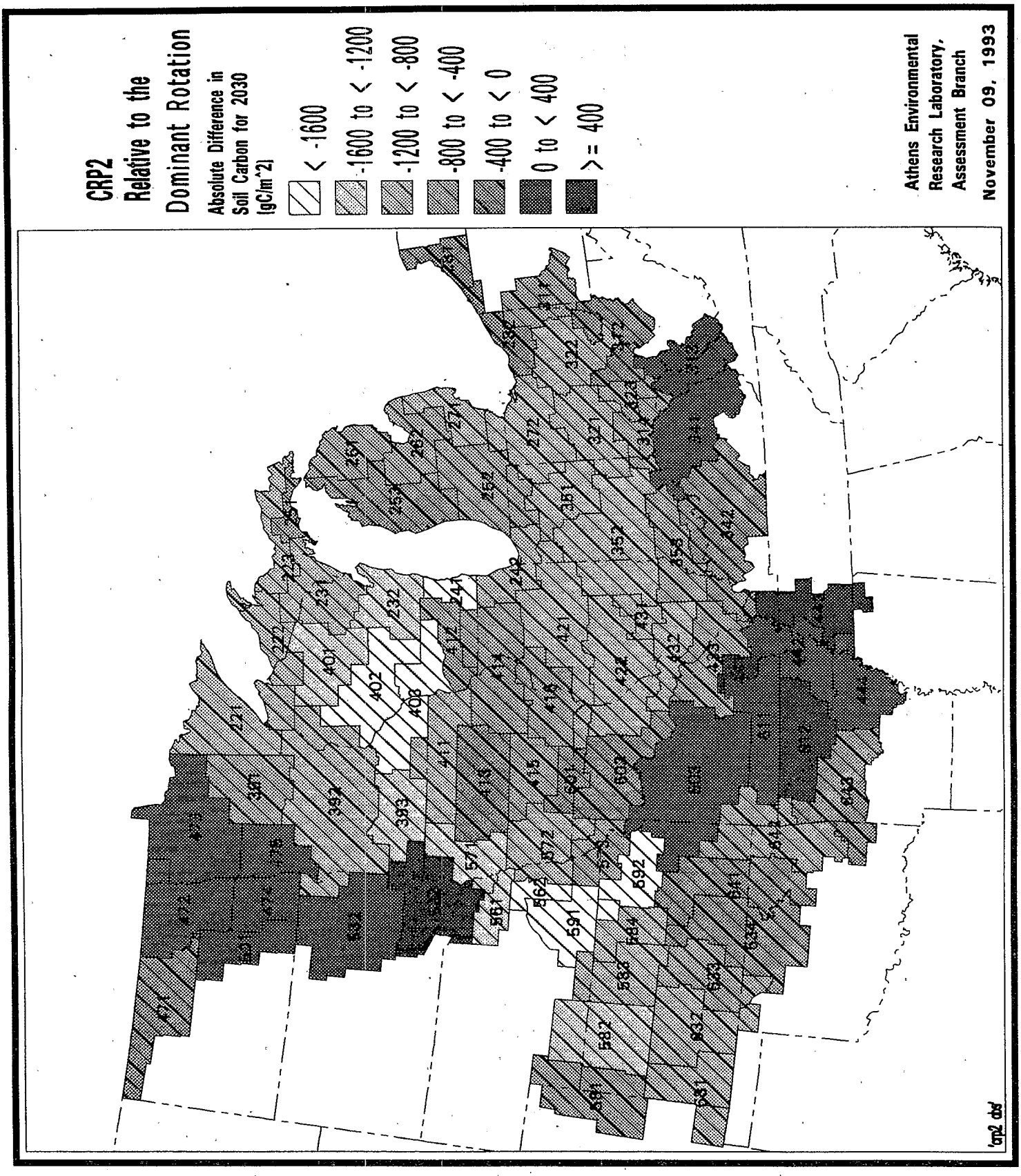

Figure D.23 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **CRP2** relative to the Dominant Rotation

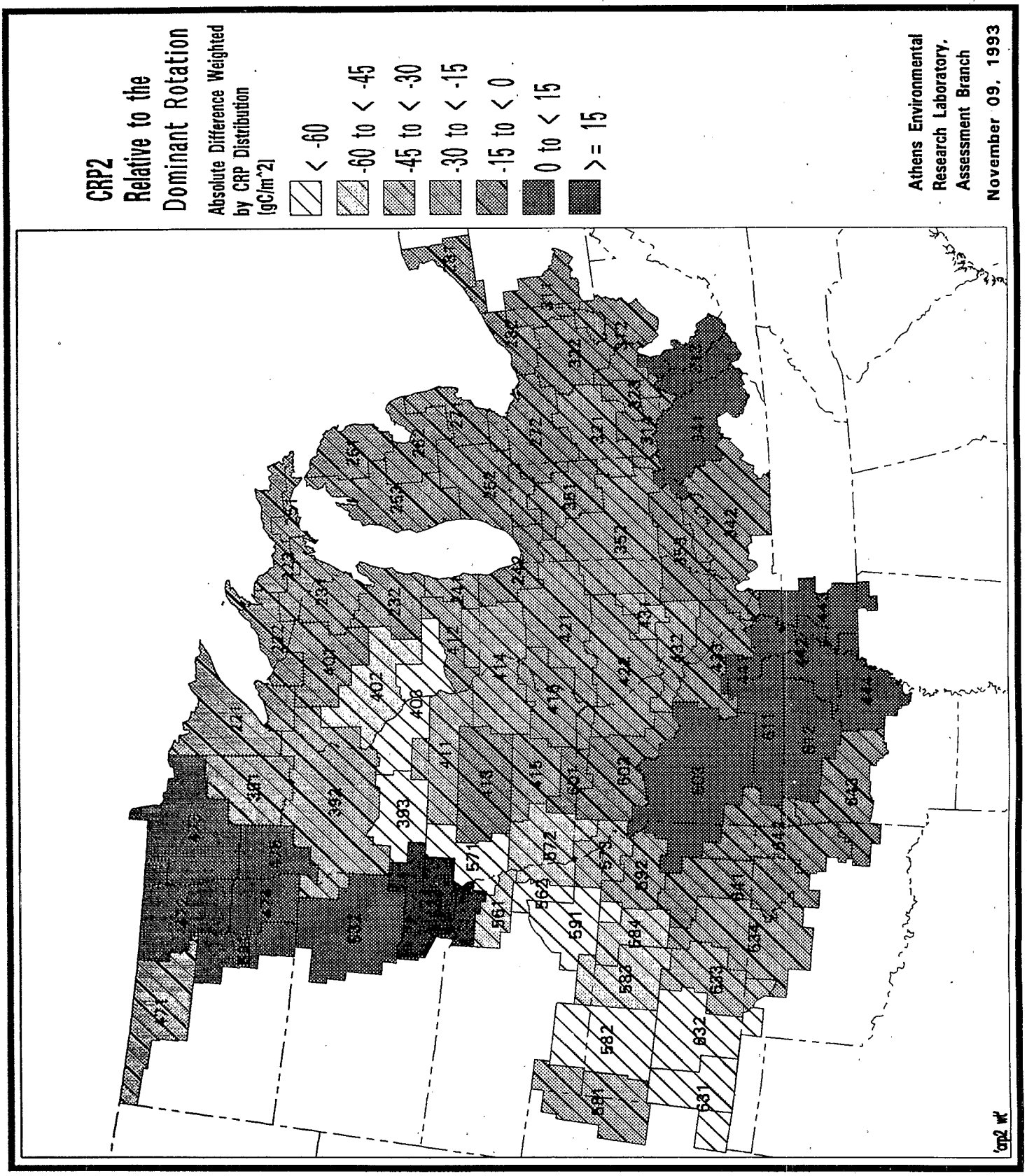

Figure D.24 Increase in Soil Carbon (gC/m2) within the study region for 2030 for **CRP2** relative to the Dominant Rotation weighted by CRP distribution

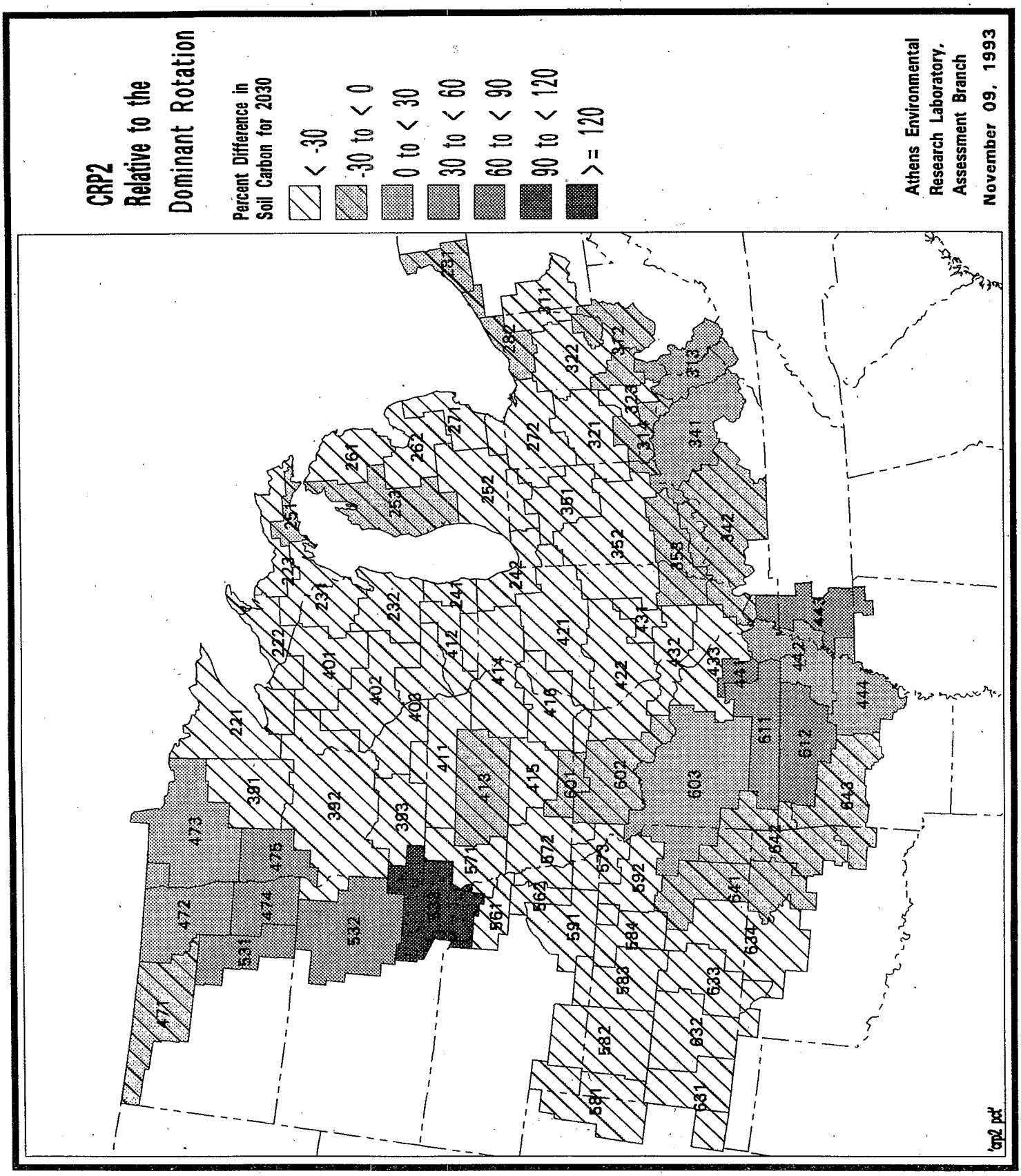

Figure D.25 Percent difference in Soil Carbon within the study region for 2030 for **CRP2** relative to the Dominant Rotation

APPENDIX E

Land Use and Soil Physical Properties for All Climate Divisions

E.1 Baseline and Conservation Tillage Policy Scenario Crop Rotations, and Acreages
E.2 Baseline and Cover Crop Rotations, Tillage, and Acreages
E.3 Soil Physical Properties, Percentage Weights, and Ranks for all Climate Divisions

Table E.1 Baseline and Conservation Tillage Policy Scenario Crop Rotations, and Acreages

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
22	239	CSL,CSL,CSL,SWT	CTFP	414,132	252,501	252,501	252,501
22	239	CSL,CSL,CSL,SWT	RT	0	160,817	160,817	160,817
22	239	CSL,CSL,CSL,SWT	NT	2,695	3,345	3,345	3,345
22	350	OTS,HLH,HLH,HLH	CTFP	40,887	38,052	38,052	38,052
22	350	OTS,HLH,HLH,HLH	CTSP	11,023	3,649	3,649	3,373
22	350	OTS,HLH,HLH,HLH	NT	0	10,370	10,370	10,646
		Total PA 22 Area =		468,736	468,734	468,734	468,734
23	100	CRN	RT	326,010	326,010	326,010	429,397
23	100	CRN	NT	83,411	83,411	83,411	358,626
23	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	1,158,930	1,158,930	1,158,930	0
23	145	CRN,CRN,WWT,HLH,HLH,HLH	RT	124,394	124,394	124,394	14,214
23	145	CRN,CRN,WWT,HLH,HLH,HLH	NT	0	0	0	124,302
23	235	CSL	RT	527,634	527,634	527,634	534,427
23	350	OTS,HLH,HLH,HLH	CTFP	501,821	501,821	501,821	1,264,970
23	366	OTS,NLH,NLH,NLH	CTFP	128,471	128,471	128,471	0
23	366	OTS,NLH,NLH,NLH	NT	0	0	0	124,740
		Total PA 23 Area =		2,850,672	2,850,671	2,850,671	2,850,676
24	100	CRN	CTSP	487,973	487,973	487,973	59,412
24	100	CRN	NT	63,320	63,320	63,320	491,881
24	131	CRN,CRN,SOY	RT	388,903	388,903	388,903	388,903
24	186	CRN,SOY	CTSP	529,266	529,266	529,266	529,266
24	201	CRN,SOY,WWT	RT	353,556	353,556	353,556	353,556
24	262	CSL,OTS,HLH,HLH,HLH	CTSP	244,873	244,873	244,873	244,873
24	503	HLH,HLH,HLH,HLH	CTSP	69,815	69,815	69,815	69,815
24	508	NLH,NLH,NLH,NLH	CTSP	26,332	26,332	26,332	26,332
		Total PA 24 Area =		2,164,038	2,164,038	2,164,038	2,164,037
25	100	CRN	NT	104,504	104,504	104,504	104,504
25	144	CRN,CRN,WWT,HLH,HLH	CTSP	1,747,290	1,747,290	1,747,290	1,728,790
25	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	455,881	455,881	455,881	456,927
25	186	CRN,SOY	CTSP	342,912	342,912	342,912	0
25	186	CRN,SOY	RT	1,473,020	1,473,020	1,473,020	1,373,110
25	186	CRN,SOY	NT	21,121	21,121	21,121	481,404
25	366	OTS,NLH,NLH,NLH	CTSP	148,664	148,664	148,664	48,752
25	366	OTS,NLH,NLH,NLH	RT	0	0	0	99,914
		Total PA 25 Area =		4,293,392	4,293,392	4,293,392	4,293,401
26	100	CRN	CTSP	21,487	21,487	21,487	21,487
26	100	CRN	RT	257,928	257,928	257,928	257,928
26	100	CRN	NT	72,426	72,426	72,426	72,426
26	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	1,157,930	1,157,930	1,157,930	1,157,930
26	215	CRN,SWT,SWT	RT	223,820	223,820	223,820	223,820
26	280	CSL,SWT	RT	367,488	367,488	367,488	367,488
26	366	OTS,NLH,NLH,NLH	CTSP	374,181	374,181	374,181	374,181
		Total PA 26 Area =		2,475,260	2,475,260	2,475,260	2,475,260
27	100	CRN	NT	10,267	10,267	10,267	10,267
27	138	CRN,CRN,SOY,WWT,HLH	CTSP	2,283,309	2,283,309	2,283,309	2,283,308
27	186	CRN,SOY	CTSP	1,124,760	1,124,760	1,124,760	1,124,760
27	186	CRN,SOY	RT	1,141,290	1,141,290	1,141,290	1,141,290
27	186	CRN,SOY	NT	175,720	175,720	175,720	175,720
27	201	CRN,SOY,WWT	RT	1,041,609	1,041,610	1,041,610	1,041,610
27	243	CSL,CSL,OTS,HLH,HLH	CTSP	442,480	442,480	442,480	442,480
27	366	OTS,NLH,NLH,NLH	CTSP	136,927	136,927	136,926	136,926
		Total PA 27 Area =		6,356,362	6,356,363	6,356,362	6,356,361

Table E.1 (contd.)

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
28	144	CRN,CRN,WWT,HLH,HLH	CTSP	98,744	98,744	0	0
28	144	CRN,CRN,WWT,HLH,HLH	RT	75,641	75,641	10,810	0
28	144	CRN,CRN,WWT,HLH,HLH	NT	69,980	69,980	233,988	244,787
28	186	CRN,SOY	RT	118,464	118,464	136,347	30,026
28	186	CRN,SOY	NT	0	0	0	7,255
28	201	CRN,SOY,WWT	RT	0	0	0	104,335
28	201	CRN,SOY,WWT	NT	0	0	0	95,840
28	458	SOY,WWT,SOY	RT	83,091	83,091	130,040	119,931
28	458	SOY,WWT,SOY	NT	0	0	0	279,914
28	503	HLH,HLH,HLH,HLH	CTSP	433,669	433,669	368,405	0
28	508	NLH,NLH,NLH,NLH	CTFP	358,112	358,112	358,112	0
28	508	NLH,NLH,NLH,NLH	CTSP	0	0	0	332,708
28	508	NLH,NLH,NLH,NLH	RT	0	0	0	22,905
		Total PA 28 Area =		1,237,701	1,237,701	1,237,702	1,237,701
31	131	CRN,CRN,SOY	RT	292,342	30,233	298,712	298,712
31	131	CRN,CRN,SOY	NT	0	312,683	323,204	0
31	138	CRN,CRN,SOY,WWT,HLH	NT	0	0	0	82,408
31	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	604,068	542,929	0	0
31	196	CRN,SOY,OTS,NLH,NLH	CTSP	588,494	0	0	0
31	196	CRN,SOY,OTS,NLH,NLH	RT	0	538,506	270,028	270,028
31	196	CRN,SOY,OTS,NLH,NLH	NT	0	0	315,072	1,351,230
31	250	CSL,CSL,SOY	RT	276,398	0	0	0
31	250	CSL,CSL,SOY	NT	170,859	474,779	433,623	215,004
31	503	HLH,HLH,HLH,HLH	CTSP	34,087	63,987	329,515	303,636
31	508	NLH,NLH,NLH,NLH	CTSP	735,089	738,218	731,185	180,319
		Total PA 31 Area =		2,701,336	2,701,336	2,701,339	2,701,337
32	125	CRN,CRN,OTS,NLH,NLH	CTSP	747,307	0	0	0
32	125	CRN,CRN,OTS,NLH,NLH	RT	152,283	887,650	887,650	0
32	125	CRN,CRN,OTS,NLH,NLH	NT	264,955	264,955	264,955	1,131,570
32	131	CRN,CRN,SOY	CTSP	10,753	10,753	10,753	0
32	131	CRN,CRN,SOY	NT	0	0	0	10,753
32	186	CRN,SOY	CTSP	1,533,360	476,310	476,310	0
32	186	CRN,SOY	RT	0	1,127,210	1,127,210	652,754
32	186	CRN,SOY	NT	0	0	0	1,006,510
32	203	CRN,SOY,WWT,HLH,HLH,HLH	CTSP	3,350,542	3,292,322	3,292,320	1,895,510
32	203	CRN,SOY,WWT,HLH,HLH,HLH	RT	97,415	97,415	97,413	1,459,520
		Total PA 32 Area =		6,156,615	6,156,615	6,156,611	6,156,617
34	144	CRN,CRN,WWT,HLH,HLH	CTSP	3,441,446	2,655,770	2,005,620	839,390
34	144	CRN,CRN,WWT,HLH,HLH	RT	526,685	1,088,400	1,088,400	1,088,400
34	144	CRN,CRN,WWT,HLH,HLH	NT	496,755	1,371,860	2,022,010	3,188,250
34	186	CRN,SOY	CTFP	4,775	0	0	0
34	186	CRN,SOY	NT	3,246	8,021	8,021	8,021
34	232	CRN,NLH,NLH,NLH	CTSP	273,007	0	0	0
34	232	CRN,NLH,NLH,NLH	RT	378,153	0	0	0
		Total PA 34 Area =		5,124,067	5,124,051	5,124,051	5,124,061
35	100	CRN	NT	52,432	52,432	52,432	0
35	115	CRN,CRN,CRN,HLH,HLH,HLH	CTSP	713,294	713,294	713,294	713,294
35	131	CRN,CRN,SOY	NT	0	0	0	52,432
35	186	CRN,SOY	CTSP	7,620,040	7,620,040	7,620,040	4,982,120
35	186	CRN,SOY	RT	1,926,500	1,926,500	1,926,500	1,926,500
35	186	CRN,SOY	NT	354,424	354,424	354,424	2,992,330
35	201	CRN,SOY,WWT	RT	2,844,111	2,844,111	2,844,111	2,844,120
35	366	OTS,NLH,NLH,NLH	CTSP	394,064	394,064	394,064	394,064
		Total PA 35 Area =		13,904,865	13,904,865	13,904,865	13,904,860

Table E.1 (contd.)

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
39	131	CRN,CRN,SOY	CTSP	395,228	395,228	395,228	395,228
39	131	CRN,CRN,SOY	RT	2,320,303	2,320,300	2,320,303	2,320,300
39	131	CRN,CRN,SOY	NT	302,075	302,075	302,075	302,075
39	186	CRN,SOY	CTSP	3,087,080	3,087,080	3,087,080	3,087,080
39	186	CRN,SOY	RT	1,799,120	1,799,120	1,799,120	1,799,120
39	186	CRN,SOY	NT	44,343	44,343	44,343	44,343
39	189	CRN,SOY,CRN,WWT,HLH,HLH	CTSP	1,325,780	1,325,780	1,325,780	1,325,780
39	201	CRN,SOY,WWT	CTFP	975,345	975,345	975,345	975,345
39	243	CSL,CSL,OTS,HLH,HLH	CTSP	1,188,890	1,188,890	1,188,890	1,188,890
39	350	OTS,HLH,HLH,HLH	CTSP	51,390	51,390	51,390	51,390
39	366	OTS,NLH,NLH,NLH	CTSP	716,869	716,869	716,869	716,869
		Total PA 39 Area =		12,206,423	12,206,420	12,206,423	12,206,420
40	100	CRN	CTSP	127,269	127,269	0	0
40	100	CRN	RT	2,083,560	2,083,560	2,223,610	2,246,930
40	186	CRN,SOY	CTFP	963,468	963,468	640,520	0
40	186	CRN,SOY	NT	177,694	177,694	487,882	1,086,800
40	246	CSL,CSL,OTS,NLH,NLH	CTSP	255,575	255,575	255,490	0
40	246	CSL,CSL,OTS,NLH,NLH	NT	0	0	0	232,988
40	280	CSL,SWT	CTSP	649,324	649,324	649,334	0
40	280	CSL,SWT	NT	0	0	0	687,899
40	366	OTS,NLH,NLH,NLH	CTFP	207,687	207,687	207,732	1,214
40	366	OTS,NLH,NLH,NLH	NT	0	0	0	208,737
40	503	HLH,HLH,HLH,HLH	CTFP	1,608,340	1,608,340	1,608,340	1,608,340
		Total PA 40 Area =		6,072,917	6,072,917	6,072,908	6,072,908
41	100	CRN	CTSP	4,156,220	4,156,220	4,156,220	1,916,370
41	100	CRN	RT	0	0	0	1,001,220
41	115	CRN,CRN,CRN,HLH,HLH,HLH	CTSP	0	0	0	3,780,750
41	138	CRN,CRN,SOY,WWT,HLH	CTSP	2,081,734	2,081,734	2,081,734	552,384
41	138	CRN,CRN,SOY,WWT,HLH	RT	1,017,390	1,017,390	1,017,390	0
41	186	CRN,SOY	CTFP	6,331,762	6,331,762	6,331,762	2,922
41	186	CRN,SOY	CTSP	69,249	69,249	69,249	69,249
41	186	CRN,SOY	RT	7,634,120	7,634,120	7,634,120	7,650,280
41	186	CRN,SOY	NT	737,830	737,830	737,830	7,721,150
41	243	CSL,CSL,OTS,HLH,HLH	CTSP	916,740	916,740	916,740	442,153
41	503	HLH,HLH,HLH,HLH	CTSP	1,966,396	1,966,395	1,966,395	1,774,960
41	508	NLH,NLH,NLH,NLH	CTFP	304,965	304,965	304,965	304,965
		Total PA 41 Area =		25,216,406	25,216,405	25,216,405	25,216,403
42	100	CRN	CTSP	2,948,080	2,948,080	2,948,080	2,988,410
42	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	240,286	240,286	465,109	240,286
42	186	CRN,SOY	CTSP	4,601,100	4,601,100	4,601,100	1,845,550
42	186	CRN,SOY	RT	2,352,500	2,352,500	2,352,500	2,352,500
42	186	CRN,SOY	NT	397,254	397,254	397,254	3,112,480
42	201	CRN,SOY,WWT	RT	2,301,078	2,301,078	2,301,080	2,301,070
42	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	191,004	191,004	0	191,004
42	262	CSL,OTS,HLH,HLH,HLH	CTSP	33,820	33,820	0	33,819
42	503	HLH,HLH,HLH,HLH	CTSP	325,569	325,569	325,569	325,569
42	508	NLH,NLH,NLH,NLH	CTSP	186,067	186,067	186,067	186,067
		Total PA 42 Area =		13,576,758	13,576,758	13,576,759	13,576,755

Table E.1 (contd.)

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
43	100	CRN	CTSP	12,901	12,901	12,901	14,878
43	131	CRN,CRN,SOY	CTSP	576,681	576,681	576,681	486,900
43	131	CRN,CRN,SOY	NT	0	0	0	19,255
43	186	CRN,SOY	RT	938,150	938,150	704,002	0
43	186	CRN,SOY	NT	142,733	142,733	379,248	1,160,470
43	201	CRN,SOY,WWT	CTSP	1,791,717	1,791,717	1,555,210	0
43	201	CRN,SOY,WWT	RT	735,471	735,471	969,618	1,673,620
43	201	CRN,SOY,WWT	NT	0	0	0	841,623
43	262	CSL,OTS,HLH,HLH,HLH	CTSP	115,942	115,942	115,942	117,719
43	503	HLH,HLH,HLH,HLH	CTSP	183,180	183,180	183,180	182,316
43	508	NLH,NLH,NLH,NLH	CTFP	381,302	381,302	381,302	381,302
		Total PA 43 Area =		4,878,077	4,878,077	4,878,084	4,878,083
44	186	CRN,SOY	CTFP	2,455,120	2,455,120	2,455,120	2,455,120
44	186	CRN,SOY	CTSP	1,267,650	1,267,650	679,658	0
44	186	CRN,SOY	NT	328,052	328,052	928,424	1,605,080
44	218	CRN,WWT	NT	0	0	0	68,888
44	366	OTS,NLH,NLH,NLH	CTFP	204,999	204,999	294,225	330,802
44	366	OTS,NLH,NLH,NLH	RT	0	0	0	51,004
44	416	SRG,SOY,SOY	CTFP	1,987,066	1,987,066	1,912,440	0
44	416	SRG,SOY,SOY	NT	0	0	0	1,895,600
44	458	SOY,WWT,SOY	CTFP	884,594	884,594	923,264	0
44	459	SOY,WWT,WWT,WWT	RT	1,677,812	1,677,812	1,677,810	1,626,810
44	459	SOY,WWT,WWT,WWT	NT	0	0	0	922,129
44	503	HLH,HLH,HLH,HLH	CTSP	27,385	27,385	27,385	27,385
44	508	NLH,NLH,NLH,NLH	CTFP	150,135	150,135	84,486	0
		Total PA 44 Area =		8,982,813	8,982,813	8,982,812	8,982,818
47	2	BAR,BAR,SOY	CTSP	1,051,320	1,051,320	1,051,320	1,051,320
47	2	BAR,BAR,SOY	RT	4,190,350	4,190,350	4,190,350	4,190,350
47	100	CRN	NT	176,275	176,275	176,275	176,275
47	125	CRN,CRN,OTS,NLH,NLH	CTSP	172,299	172,299	172,299	172,299
47	145	CRN,CRN,WWT,HLH,HLH,HLH	CTFP	405,282	405,282	405,282	405,282
47	215	CRN,SWT,SWT	CTSP	4,377,087	4,377,087	4,377,080	4,377,080
47	215	CRN,SWT,SWT	RT	245,827	245,827	245,827	245,827
47	215	CRN,SWT,SWT	NT	179,008	179,008	179,008	179,008
47	262	CSL,OTS,HLH,HLH,HLH	CTFP	1,054,480	1,054,480	1,054,480	1,054,480
47	463	SMF,SWT	CTSP	6,371,460	6,371,460	6,371,460	6,371,460
47	463	SMF,SWT	RT	919,378	919,378	919,378	919,378
47	508	NLH,NLH,NLH,NLH	CTFP	794,545	794,545	794,545	794,545
		Total PA 47 Area =		19,937,310	19,937,311	19,937,304	19,937,304
53	4	BAR,BAR,SMF	CTSP	2,674,590	2,674,590	2,674,590	2,751,340
53	4	BAR,BAR,SMF	RT	390,970	390,970	390,970	390,970
53	100	CRN	CTSP	116,479	116,479	116,479	116,479
53	100	CRN	RT	2,926,710	2,926,710	2,926,710	1,999,450
53	100	CRN	NT	217,153	217,153	217,153	1,148,800
53	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	1,398,143	1,398,144	1,398,144	1,122,970
53	463	SMF,SWT	CTSP	4,161,760	4,161,760	4,161,760	3,382,580
53	463	SMF,SWT	RT	291,494	291,494	291,494	1,218,760
53	503	HLH,HLH,HLH,HLH	CTFP	0	0	0	56,872
53	508	NLH,NLH,NLH,NLH	CTSP	2,232,310	2,232,310	2,232,310	2,221,390
		Total PA 53 Area =		14,409,609	14,409,610	14,409,610	14,409,611

Table E.1 (contd.)

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
56	100	CRN	NT	0	28,484	34,515	44,857
56	131	CRN,CRN,SOY	CTSP	1,602,820	1,190,540	909,217	368,382
56	131	CRN,CRN,SOY	RT	263,518	405,084	405,083	405,083
56	131	CRN,CRN,SOY	NT	34,678	251,909	527,205	1,057,690
56	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	177,729	29,559	29,936	31,656
56	145	CRN,CRN,WWT,HLH,HLH,HLH	RT	33,770	0	0	0
56	186	CRN,SOY	CTSP	42,860	187,905	187,905	187,905
56	201	CRN,SOY,WWT	RT	224,954	224,954	224,954	224,954
56	246	CSL,CSL,OTS,NLH,NLH	CTSP	0	19,318	19,318	19,318
56	246	CSL,CSL,OTS,NLH,NLH	RT	107,794	0	0	0
56	262	CSL,OTS,HLH,HLH,HLH	CTSP	134,538	245,735	245,359	243,638
56	366	OTS,NLH,NLH,NLH	CTSP	26,553	65,725	65,725	65,725
		Total PA 56 Area =		2,649,214	2,649,213	2,649,217	2,649,209
57	125	CRN,CRN,OTS,NLH,NLH	RT	216,102	0	0	0
57	131	CRN,CRN,SOY	CTSP	5,131,259	3,436,520	2,500,090	1,291,250
57	131	CRN,CRN,SOY	RT	1,786,693	2,553,900	2,423,750	1,659,420
57	131	CRN,CRN,SOY	NT	246,912	1,439,650	2,519,800	4,536,080
57	138	CRN,CRN,SOY,WWT,HLH	RT	0	414,352	341,021	474,756
57	186	CRN,SOY	CTFP	425,206	903,436	729,988	90,055
57	186	CRN,SOY	RT	0	0	0	730,904
57	218	CRN,WWT	CTFP	0	34,949	0	0
57	218	CRN,WWT	RT	848,572	192,448	395,925	295,624
57	339	HLH,HLH,HLH,HLH,SRG,SOY	CTSP	632,251	220,497	802,432	655,007
57	339	HLH,HLH,HLH,HLH,SRG,SOY	RT	309,341	0	0	0
57	350	OTS,HLH,HLH,HLH	CTSP	252,900	637,284	120,009	251,053
57	366	OTS,NLH,NLH,NLH	CTSP	110,116	0	0	0
57	508	NLH,NLH,NLH,NLH	CTFP	197,473	0	0	0
57	508	NLH,NLH,NLH,NLH	CTSP	0	323,787	323,787	172,686
		Total PA 57 Area =		10,156,825	10,156,823	10,156,802	10,156,835
58	100	CRN	RT	2,049,830	2,049,830	2,049,830	0
58	100	CRN	NT	164,984	164,984	164,984	2,343,716
58	186	CRN,SOY	CTSP	83,817	83,817	83,817	0
58	186	CRN,SOY	RT	337,128	337,128	337,128	0
58	186	CRN,SOY	NT	0	0	0	421,528
58	218	CRN,WWT	CTFP	1,275,058	1,275,058	1,275,060	0
58	218	CRN,WWT	RT	0	0	0	722,858
58	218	CRN,WWT	NT	0	0	0	625,026
58	262	CSL,OTS,HLH,HLH,HLH	CTSP	378,581	378,581	378,581	378,581
58	463	SMF,SWT	RT	0	0	0	2,122,180
58	490	WWT	RT	1,018,680	1,018,680	1,018,680	560,601
58	503	HLH,HLH,HLH,HLH	CTFP	169,989	169,989	169,989	169,989
58	508	NLH,NLH,NLH,NLH	CTFP	8,250,320	8,250,320	8,250,320	6,383,910
58	508	NLH,NLH,NLH,NLH	CTSP	31,758	31,758	31,758	31,758
		Total PA 58 Area =		13,760,145	13,760,145	13,760,147	13,760,147
59	100	CRN	CTSP	2,468,150	2,468,148	1,319,597	385,491
59	100	CRN	RT	370,376	370,376	822,931	58,808
59	100	CRN	NT	71,274	71,274	766,241	2,466,218
59	186	CRN,SOY	CTFP	853,576	853,576	1,307,170	541,296
59	186	CRN,SOY	RT	572,148	572,148	119,594	883,716
59	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	192,474	192,475	192,475	192,475
59	339	HLH,HLH,HLH,HLH,SRG,SOY	CTFP	202,938	202,938	202,938	202,938
59	490	WWT	RT	352,391	352,391	352,391	352,390
59	508	NLH,NLH,NLH,NLH	CTSP	361,605	361,605	361,605	361,605
		Total PA 59 Area =		5,444,932	5,444,931	5,444,942	5,444,937

Table E.1 (contd.)

PA #	CR #	CROP ROTATION	TILLAGE TYPE	Baseline ROTATION ACRES	Low-CST ROTATION ACRES	Medium-CST ROTATION ACRES	High-CST ROTATION ACRES
60	131	CRN,CRN,SOY	CTSP	91,638	431,327	115,558	0
60	131	CRN,CRN,SOY	NT	0	377,032	101,745	91,638
60	186	CRN,SOY	CTSP	788,444	44,218	0	0
60	186	CRN,SOY	RT	1,271,970	1,049,420	1,132,310	0
60	186	CRN,SOY	NT	238,916	492,444	1,316,790	2,637,580
60	201	CRN,SOY,WWT	CTSP	1,292,619	722,805	0	0
60	201	CRN,SOY,WWT	RT	1,656,246	1,878,790	1,795,900	1,369,300
60	201	CRN,SOY,WWT	NT	0	343,791	1,145,420	1,572,400
60	503	HLH,HLH,HLH,HLH	CTSP	490,083	490,083	490,083	490,083
60	508	NLH,NLH,NLH,NLH	CTFP	3,145,170	3,145,170	2,877,270	1,255,170
60	508	NLH,NLH,NLH,NLH	RT	0	0	0	1,558,910
		Total PA 60 Area =		8,975,086	8,975,080	8,975,076	8,975,081
61	131	CRN,CRN,SOY	CTFP	21,072	21,071	21,063	260
61	131	CRN,CRN,SOY	NT	0	0	0	21,973
61	186	CRN,SOY	CTFP	206,940	193,433	165,904	0
61	186	CRN,SOY	RT	0	8,443	4,852	0
61	186	CRN,SOY	NT	8,992	14,282	45,942	226,756
61	350	OTS,HLH,HLH,HLH	CTSP	3,301	0	0	0
61	350	OTS,HLH,HLH,HLH	RT	0	3,343	3,343	0
61	350	OTS,HLH,HLH,HLH	NT	0	0	0	3,318
61	458	SOY,WWT,SOY	CTFP	177,462	0	0	66,052
61	458	SOY,WWT,SOY	RT	0	206,040	209,630	0
61	458	SOY,WWT,SOY	NT	0	0	0	150,888
61	503	HLH,HLH,HLH,HLH	CTSP	50,128	50,099	50,099	0
61	503	HLH,HLH,HLH,HLH	RT	0	0	0	50,089
61	508	NLH,NLH,NLH,NLH	CTFP	387,714	358,960	354,829	108,510
61	508	NLH,NLH,NLH,NLH	RT	0	5,236	5,236	172,972
61	508	NLH,NLH,NLH,NLH	NT	8,400	3,110	3,110	63,190
		Total PA 61 Area =		864,009	864,017	864,008	864,007
63	186	CRN,SOY	CTSP	42,041	0	0	0
63	186	CRN,SOY	RT	918,236	961,323	961,323	0
63	186	CRN,SOY	NT	192,202	192,202	192,202	1,145,744
63	218	CRN,WWT	CTFP	1,338,510	1,039,770	1,039,770	0
63	218	CRN,WWT	CTSP	99,701	99,701	99,701	99,701
63	218	CRN,WWT	RT	0	338,246	338,246	338,246
63	218	CRN,WWT	NT	0	0	0	1,201,550
63	490	WWT	RT	1,204,860	1,187,790	1,187,790	0
63	490	WWT	NT	0	0	0	1,116,810
63	503	HLH,HLH,HLH,HLH	CTFP	13,162,800	12,431,700	12,431,700	9,450,470
63	503	HLH,HLH,HLH,HLH	RT	0	707,199	707,199	3,614,070
63	508	NLH,NLH,NLH,NLH	CTSP	514,543	0	0	0
63	508	NLH,NLH,NLH,NLH	RT	0	514,943	514,943	0
63	508	NLH,NLH,NLH,NLH	NT	0	0	0	506,310
		Total PA 63 Area =		17,472,893	17,472,874	17,472,874	17,472,901
64	100	CRN	NT	56,076	56,076	565,222	0
64	131	CRN,CRN,SOY	CTSP	2,226,539	2,226,540	1,540,050	178,121
64	131	CRN,CRN,SOY	RT	674,106	674,106	513,001	0
64	131	CRN,CRN,SOY	NT	0	0	330,004	2,743,270
64	218	CRN,WWT	CTFP	690,688	690,688	538,024	51,902
64	218	CRN,WWT	RT	0	0	167,580	701,198
64	366	OTS,NLH,NLH,NLH	CTSP	50,603	50,602	50,602	50,602
64	490	WWT	RT	272,811	272,811	266,336	245,718
64	503	HLH,HLH,HLH,HLH	CTSP	173,778	173,778	173,778	173,778
		Total PA 64 Area =		4,144,601	4,144,601	4,144,597	4,144,589

Table E.2 Baseline and Cover Crop Rotations, Tillage, and Acreages

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES
22	239	CSL,CSL,CSL,SWT	CTFP	414,132	CTFP		414,132
22	239	CSL,CSL,CSL,SWT	NT	2,695	NT		2,695
22	350	OTS,HLH,HLH,HLH	CTFP	40,887	CTFP		40,886
22	350	OTS,HLH,HLH,HLH	CTSP	11,023	CTSP		11,022
		Total PA 22 Area =		468,736			468,735
23	100	CRN	RT	326,010	RT		326,010
23	100	CRN	NT	83,411	NT		83,411
23	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	1,158,930	CTSP		1,158,930
23	145	CRN,CRN,WWT,HLH,HLH,HLH	RT	124,394	RT		124,394
23	235	CSL	RT	527,634	RT		527,634
23	350	OTS,HLH,HLH,HLH	CTFP	501,821	CTFP		501,821
23	366	OTS,NLH,NLH,NLH	CTFP	128,471	CTFP		128,471
		Total PA 23 Area =		2,850,672			2,850,671
24	100	CRN	CTSP	487,973	CTSP		484,857
24	100	CRN	NT	63,320	NT		63,320
24	131	CRN,CRN,SOY	RT	388,903	RT		388,903
24	186	CRN,SOY	CTSP	529,266	CTSP		529,266
24	201	CRN,SOY,WWT	RT	353,556	RT		8,081
24	201	CRN,SOY,WWT	Cover	0	RT	Cover	345,477
24	262	CSL,OTS,HLH,HLH,HLH	CTSP	244,873	CTSP		0
24	262	CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	252,447
24	503	HLH,HLH,HLH,HLH	CTSP	69,815	CTSP		65,357
24	508	NLH,NLH,NLH,NLH	CTSP	26,332	CTSP		26,332
		Total PA 24 Area =		2,164,038			2,164,040
25	100	CRN	NT	104,504	NT		104,504
25	144	CRN,CRN,WWT,HLH,HLH	CTSP	1,747,290	CTSP		1,747,290
25	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	455,881	CTSP		455,881
25	186	CRN,SOY	CTSP	342,912	CTSP		342,912
25	186	CRN,SOY	RT	1,473,020	RT		1,473,020
25	186	CRN,SOY	NT	21,121	NT		21,121
25	366	OTS,NLH,NLH,NLH	CTSP	148,664	CTSP		148,664
		Total PA 25 Area =		4,293,392			4,293,392
26	100	CRN	CTSP	21,487	CTSP		21,487
26	100	CRN	RT	257,928	RT		257,928
26	100	CRN	NT	72,426	NT		72,426
26	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	1,157,930	CTSP		1,157,930
26	215	CRN,SWT,SWT	RT	223,820	RT		223,820
26	280	CSL,SWT	RT	367,488	RT		367,488
26	366	OTS,NLH,NLH,NLH	CTSP	374,181	CTSP		374,181
		Total PA 26 Area =		2,475,260			2,475,260
27	100	CRN	NT	10,267	NT		10,267
27	138	CRN,CRN,SOY,WWT,HLH	CTSP	2,283,309	CTSP		2,269,431
27	186	CRN,SOY	CTSP	1,124,760	CTSP		1,131,800
27	186	CRN,SOY	RT	1,141,290	RT		1,129,290
27	186	CRN,SOY	NT	175,720	NT		175,720
27	201	CRN,SOY,WWT	RT	1,041,609	RT		30,619
27	201	CRN,SOY,WWT	Cover	0	RT	Cover	1,022,990
27	243	CSL,CSL,OTS,HLH,HLH	CTSP	442,480	CTSP	Cover	449,317
27	366	OTS,NLH,NLH,NLH	CTSP	136,927	CTSP		136,927
		Total PA 27 Area =		6,356,362			6,356,361

Table E.2 (contd.)

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES
28	144	CRN,CRN,WWT,HLH,HLH	CTSP	98,744	CTSP		98,744
28	144	CRN,CRN,WWT,HLH,HLH	RT	75,641	RT		75,641
28	144	CRN,CRN,WWT,HLH,HLH	NT	69,980	NT		69,980
28	186	CRN,SOY	RT	118,464	RT		118,464
28	458	SOY,WWT,SOY	RT	83,091	RT		0
28	458	SOY,WWT,SOY	Cover	0	RT	Cover	83,091
28	503	HLH,HLH,HLH,HLH	CTSP	433,669	CTSP		433,669
28	508	NLH,NLH,NLH,NLH	CTFP	358,112	CTFP		358,112
		Total PA 28 Area =		1,237,701			1,237,701
31	131	CRN,CRN,SOY	RT	292,342	RT		290,201
31	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	604,068	CTSP		604,068
31	196	CRN,SOY,OTS,NLH,NLH	CTSP	588,494	CTSP		595,315
31	250	CSL,CSL,SOY	RT	276,398	RT		0
31	250	CSL,CSL,SOY	NT	170,859	NT		6,614
31	250	CSL,CSL,SOY	Cover	0	RT	Cover	278,539
31	250	CSL,CSL,SOY	Cover	0	NT	Cover	164,246
31	503	HLH,HLH,HLH,HLH	CTSP	34,087	CTSP		34,087
31	508	NLH,NLH,NLH,NLH	CTSP	735,089	CTSP		728,267
		Total PA 31 Area =		2,701,336			2,701,337
32	125	CRN,CRN,OTS,NLH,NLH	CTSP	747,307	CTSP		747,307
32	125	CRN,CRN,OTS,NLH,NLH	RT	152,283	RT		152,283
32	125	CRN,CRN,OTS,NLH,NLH	NT	264,955	NT		264,955
32	131	CRN,CRN,SOY	CTSP	10,753	CTSP		10,753
32	186	CRN,SOY	CTSP	1,533,360	CTSP		1,533,360
32	203	CRN,SOY,WWT,HLH,HLH,HLH	CTSP	3,350,542	CTSP		3,350,542
32	203	CRN,SOY,WWT,HLH,HLH,HLH	RT	97,415	RT		97,415
		Total PA 32 Area =		6,156,615			6,156,615
34	144	CRN,CRN,WWT,HLH,HLH	CTSP	3,441,446	CTSP		3,446,220
34	144	CRN,CRN,WWT,HLH,HLH	RT	526,685	RT		526,685
34	144	CRN,CRN,WWT,HLH,HLH	NT	496,755	NT		491,980
34	186	CRN,SOY	CTFP	4,775	CTFP		0
34	186	CRN,SOY	NT	3,246	NT		0
34	186	CRN,SOY	Cover	0	NT	Cover	8,021
34	232	CRN,NLH,NLH,NLH	CTSP	273,007	CTSP		273,007
34	232	CRN,NLH,NLH,NLH	RT	378,153	RT		378,153
		Total PA 34 Area =		5,124,067			5,124,066
35	100	CRN	NT	52,432	NT		52,432
35	115	CRN,CRN,CRN,HLH,HLH,HLH	CTSP	713,294	CTSP		713,294
35	186	CRN,SOY	CTSP	7,620,040	CTSP		7,620,040
35	186	CRN,SOY	RT	1,926,500	RT		1,926,500
35	186	CRN,SOY	NT	354,424	NT		354,424
35	201	CRN,SOY,WWT	RT	2,844,111	RT		28,448
35	201	CRN,SOY,WWT	Cover	0	RT	Cover	2,815,670
35	366	OTS,NLH,NLH,NLH	CTSP	394,064	CTSP		394,064
		Total PA 35 Area =		13,904,865			13,904,872

Table E.2 (contd.)

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES	
39	131	CRN,CRN,SOY	CTSP	395,228	CTSP		395,228	
39	131	CRN,CRN,SOY	RT	2,320,303	RT		2,320,300	
39	131	CRN,CRN,SOY	NT	302,075	NT		302,075	
39	186	CRN,SOY	CTSP	3,087,080	CTSP		3,087,080	
39	186	CRN,SOY	RT	1,799,120	RT		1,799,120	
39	186	CRN,SOY	NT	44,343	NT		44,343	
39	189	CRN,SOY,CRN,WWT,HLH,HLH	CTSP	1,325,780	CTSP		1,325,780	
39	201	CRN,SOY,WWT	CTFP	975,345	CTFP		975,345	
39	243	CSL,CSL,OTS,HLH,HLH	CTSP	1,188,890	CTSP		1,188,890	
39	350	OTS,HLH,HLH,HLH	CTSP	51,390	CTSP		51,390	
39	366	OTS,NLH,NLH,NLH	CTSP	716,869	CTSP		716,869	
		Total PA 39 Area =		12,206,423			12,206,420	
40	100	CRN	CTSP	127,269	CTSP		127,269	
40	100	CRN	RT	2,083,560	RT		2,083,560	
40	186	CRN,SOY	CTFP	963,468	CTFP		963,468	
40	186	CRN,SOY	NT	177,694	NT		177,694	
40	246	CSL,CSL,OTS,NLH,NLH	CTSP	255,575	CTSP		255,575	
40	280	CSL,SWT	CTSP	649,324	CTSP		649,324	
40	366	OTS,NLH,NLH,NLH	CTFP	207,687	CTFP		207,687	
40	503	HLH,HLH,HLH,HLH	CTFP	1,608,340	CTFP		1,608,340	
		Total PA 40 Area =		6,072,917			6,072,917	
41	100	CRN	CTSP	4,156,220	CTSP		4,251,550	
41	138	CRN,CRN,SOY,WWT,HLH	CTSP	2,081,734	CTSP		3,431,450	
41	138	CRN,CRN,SOY,WWT,HLH	RT	1,017,390	RT		0	
41	137	CRN,CRN,SOY,WWT	Cover	0	CTSP	Cover	236,067	
41	137	CRN,CRN,SOY,WWT	Cover	0	RT	Cover	321,200	
41	186	CRN,SOY	CTFP	6,331,762	CTFP		4,650,540	
41	186	CRN,SOY	Cover	0	CTFP	Cover	2,967	
41	186	CRN,SOY	CTSP	69,249	CTSP		69,249	
41	186	CRN,SOY	RT	7,634,120	RT		8,330,300	
41	186	CRN,SOY	NT	737,830	NT		737,830	
41	243	CSL,CSL,OTS,HLH,HLH	CTSP	916,740	CTSP		0	
41	243	CSL,CSL,OTS,HLH,HLH	Cover	0	CTSP	Cover	217,705	
41	277	CSL,SOY,HLH	Cover	0	CTSP	Cover	2,543,600	New
41	503	HLH,HLH,HLH,HLH	CTSP	1,966,396	CTSP		118,994	
41	508	NLH,NLH,NLH,NLH	CTFP	304,965	CTFP		304,965	
		Total PA 41 Area =		25,216,406			25,216,417	
42	100	CRN	CTSP	2,948,080	CTSP		2,970,260	
42	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	240,286	CTSP		240,286	
42	186	CRN,SOY	CTSP	4,601,100	CTSP		4,576,720	
42	186	CRN,SOY	RT	2,352,500	RT		2,352,500	
42	186	CRN,SOY	NT	397,254	NT		397,254	
42	201	CRN,SOY,WWT	RT	2,301,078	RT		21,950	
42	201	CRN,SOY,WWT	Cover	0	RT	Cover	2,279,120	
42	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	191,004	CTSP		0	
42	244	CSL,CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	189,061	
42	262	CSL,OTS,HLH,HLH,HLH	CTSP	33,820	CTSP		0	
42	262	CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	40,099	
42	503	HLH,HLH,HLH,HLH	CTSP	325,569	CTSP		323,420	
42	508	NLH,NLH,NLH,NLH	CTSP	186,067	CTSP		186,067	
		Total PA 42 Area =		13,576,758			13,576,737	

Table E.2 (contd.)

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES
43	100	CRN	CTSP	12,901	CTSP		65,409
43	131	CRN,CRN,SOY	CTSP	576,681	CTSP		603,994
43	186	CRN,SOY	CTSP	0	CTSP		152,126
43	186	CRN,SOY	RT	938,150	RT		1,040,970
43	186	CRN,SOY	NT	142,733	NT		142,733
43	201	CRN,SOY,WWT	CTSP	1,791,717	CTSP		0
43	201	CRN,SOY,WWT	Cover	0	CTSP	Cover	888,156
43	201	CRN,SOY,WWT	RT	735,471	RT		26,316
43	201	CRN,SOY,WWT	Cover	0	RT	Cover	606,333
43	218	CRN,WWT	Cover	0	CTSP	Cover	671,618
43	262	CSL,OTS,HLH,HLH,HLH	CTSP	115,942	CTSP		0
43	262	CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	115,942
43	503	HLH,HLH,HLH,HLH	CTSP	183,180	CTSP		183,180
43	508	NLH,NLH,NLH,NLH	CTFP	381,302	CTFP		381,302
		Total PA 43 Area =		4,878,077			4,878,079
44	186	CRN,SOY	CTFP	2,455,120	CTFP		2,455,120
44	186	CRN,SOY	CTSP	1,267,650	CTSP		1,279,160
44	186	CRN,SOY	NT	328,052	NT		328,052
44	218	CRN,WWT	Cover	0	CTFP	Cover	1,279,800
44	366	OTS,NLH,NLH,NLH	CTFP	204,999	CTFP		172,419
44	416	SRG,SOY,SOY	CTFP	1,987,066	CTFP		0
44	416	SRG,SOY,SOY	Cover	0	CTFP	Cover	164,861
44	458	SOY,WWT,SOY	CTFP	884,594	CTFP		0
44	458	SOY,WWT,SOY	Cover	0	CTFP	Cover	1,618,710
44	459	SOY,WWT,WWT,WWT	RT	1,677,812	RT		0
44	459	SOY,WWT,WWT,WWT	Cover	0	RT	Cover	1,483,200
44	503	HLH,HLH,HLH,HLH	CTSP	27,385	CTSP		27,385
44	508	NLH,NLH,NLH,NLH	CTFP	150,135	CTFP		174,106
		Total PA 44 Area =		8,982,813			8,982,813
47	2	BAR,BAR,SOY	CTSP	1,051,320	CTSP		1,051,320
47	2	BAR,BAR,SOY	RT	4,190,350	RT		4,190,350
47	100	CRN	NT	176,275	NT		176,275
47	125	CRN,CRN,OTS,NLH,NLH	CTSP	172,299	CTFP		405,282
47	145	CRN,CRN,WWT,HLH,HLH,HLH	CTFP	405,282	CTSP		172,299
47	215	CRN,SWT,SWT	CTSP	4,377,087	CTSP		4,377,080
47	215	CRN,SWT,SWT	RT	245,827	RT		245,827
47	215	CRN,SWT,SWT	NT	179,008	NT		179,008
47	262	CSL,OTS,HLH,HLH,HLH	CTFP	1,054,480	CTFP		1,054,480
47	463	SMF,SWT	CTSP	6,371,460	CTSP		6,371,460
47	463	SMF,SWT	RT	919,378	RT		919,378
47	508	NLH,NLH,NLH,NLH	CTFP	794,545	CTFP		794,545
		Total PA 47 Area =		19,937,310			19,937,304
53	4	BAR,BAR,SMF	CTSP	2,674,590	CTSP		2,674,590
53	4	BAR,BAR,SMF	RT	390,970	RT		390,970
53	100	CRN	CTSP	116,479	CTSP		116,479
53	100	CRN	RT	2,926,710	RT		2,926,710
53	100	CRN	NT	217,153	NT		217,153
53	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	1,398,143	CTSP		1,398,144
53	463	SMF,SWT	CTSP	4,161,760	CTSP		4,161,760
53	463	SMF,SWT	RT	291,494	RT		291,494
53	508	NLH,NLH,NLH,NLH	CTSP	2,232,310	CTSP		2,232,310
		Total PA 53 Area =		14,409,609			14,409,610

Table E.2 (contd.)

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES
56	100	CRN	NT	0	NT		24,808
56	131	CRN,CRN,SOY	CTSP	1,602,820	CTSP		1,481,960
56	131	CRN,CRN,SOY	RT	263,518	RT		373,512
56	131	CRN,CRN,SOY	NT	34,678	NT		9,870
56	145	CRN,CRN,WWT,HLH,HLH,HLH	CTSP	177,729	CTSP		152,472
56	145	CRN,CRN,WWT,HLH,HLH,HLH	RT	33,770	RT		0
56	186	CRN,SOY	CTSP	42,860	CTSP		0
56	186	CRN,SOY	Cover	0	CTSP	Cover	84,902
56	201	CRN,SOY,WWT	RT	224,954	RT		0
56	201	CRN,SOY,WWT	Cover	0	RT	Cover	224,953
56	244	CSL,CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	93,596
56	246	CSL,CSL,OTS,NLH,NLH	RT	107,794	RT		0
56	246	CSL,CSL,OTS,NLH,NLH	Cover	0	RT	Cover	31,571
56	262	CSL,OTS,HLH,HLH,HLH	CTSP	134,538	CTSP		0
56	262	CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	111,249
56	366	OTS,NLH,NLH,NLH	CTSP	26,553	CTSP		60,324
		Total PA 56 Area =		2,649,214			2,649,217
57	125	CRN,CRN,OTS,NLH,NLH	RT	216,102	RT		0
57	125	CRN,CRN,OTS,NLH,NLH	Cover	0	RT	Cover	136,232
57	131	CRN,CRN,SOY	CTSP	5,131,259	CTSP		5,149,470
57	131	CRN,CRN,SOY	RT	1,786,693	RT		1,786,690
57	131	CRN,CRN,SOY	NT	246,912	NT		246,912
57	186	CRN,SOY	CTFP	425,206	CTFP		0
57	186	CRN,SOY	Cover	0	CTFP	Cover	406,998
57	218	CRN,WWT	RT	848,572	RT		0
57	218	CRN,WWT	Cover	0	RT	Cover	928,443
57	339	HLH,HLH,HLH,HLH,SRG,SOY	CTSP	632,251	CTSP		632,251
57	339	HLH,HLH,HLH,HLH,SRG,SOY	RT	309,341	RT		309,341
57	350	OTS,HLH,HLH,HLH	CTSP	252,900	CTSP		252,900
57	366	OTS,NLH,NLH,NLH	CTSP	110,116	CTSP		110,116
57	508	NLH,NLH,NLH,NLH	CTFP	197,473	CTFP		197,473
		Total PA 57 Area =		10,156,825			10,156,826
58	100	CRN	RT	2,049,830	RT		2,049,830
58	100	CRN	NT	164,984	NT		164,984
58	186	CRN,SOY	CTSP	83,817	CTSP		83,817
58	186	CRN,SOY	RT	337,128	RT		337,128
58	218	CRN,WWT	CTFP	1,275,058	CTSP		378,581
58	262	CSL,OTS,HLH,HLH,HLH	CTSP	378,581	CTFP		1,275,060
58	490	WWT	RT	1,018,680	RT		1,018,680
58	503	HLH,HLH,HLH,HLH	CTFP	169,989	CTFP		169,989
58	508	NLH,NLH,NLH,NLH	CTFP	8,250,320	CTFP		8,250,320
58	508	NLH,NLH,NLH,NLH	CTSP	31,758	CTSP		31,758
		Total PA 58 Area =		13,760,145			13,760,147
59	100	CRN	CTSP	2,468,150	CTSP		1,973,377
59	100	CRN	RT	370,376	RT		842,633
59	100	CRN	NT	71,274	NT		71,274
59	186	CRN,SOY	CTFP	853,576	CTFP		0
59	186	CRN,SOY	CTSP	0	CTSP		683,116
59	186	CRN,SOY	RT	572,148	RT		214,182
59	218	CRN,WWT	Cover	0	CTFP	Cover	640,256
59	244	CSL,CSL,OTS,HLH,HLH,HLH	CTSP	192,474	CTSP		0
59	244	CSL,CSL,OTS,HLH,HLH,HLH	Cover	0	CTSP	Cover	293,114
59	339	HLH,HLH,HLH,HLH,SRG,SOY	CTFP	202,938	CTFP		127,270
59	490	WWT	RT	352,391	RT		238,100
59	508	NLH,NLH,NLH,NLH	CTSP	361,605	CTSP		361,605
		Total PA 59 Area =		5,444,932			5,444,927

Table E.2 (contd.)

PA #	CR #	CROP ROTATION	BASELINE TILLAGE TYPE	BASELINE ROTATION ACRES	COVER-CROPS TILLAGE TYPE		COVER-CROPS ROTATION ACRES
60	131	CRN,CRN,SOY	CTSP	91,638	CTSP		91,638
60	131	CRN,CRN,SOY	Cover	0	NT	Cover	238,917
60	186	CRN,SOY	CTSP	788,444	CTSP		0
60	186	CRN,SOY	Cover	0	CTSP	Cover	749,430
60	186	CRN,SOY	RT	1,271,970	RT		1,489,750
60	186	CRN,SOY	NT	238,916	NT		0
60	201	CRN,SOY,WWT	CTSP	1,292,619	CTSP		0
60	201	CRN,SOY,WWT	Cover	0	CTSP	Cover	1,331,630
60	201	CRN,SOY,WWT	RT	1,656,246	RT		29,900
60	201	CRN,SOY,WWT	Cover	0	RT	Cover	1,408,560
60	503	HLH,HLH,HLH,HLH	CTSP	490,083	CTSP		490,083
60	508	NLH,NLH,NLH,NLH	CTFP	3,145,170	CTFP		3,145,170
		Total PA 60 Area =		8,975,086			8,975,078
61	131	CRN,CRN,SOY	CTFP	21,072	CTFP		21,071
61	186	CRN,SOY	CTFP	206,940	CTFP		0
61	186	CRN,SOY	Cover	0	CTFP	Cover	208,028
61	186	CRN,SOY	NT	8,992	NT		0
61	186	CRN,SOY	Cover	0	NT	Cover	8,975
61	246	CSL,CSL,OTS,NLH,NLH	Cover	0	NT	Cover	8,416
61	350	OTS,HLH,HLH,HLH	CTSP	3,301	CTSP		3,301
61	458	SOY,WWT,SOY	CTFP	177,462	CTFP		1,897
61	458	SOY,WWT,SOY	Cover	0	CTFP	Cover	180,816
61	503	HLH,HLH,HLH,HLH	CTSP	50,128	CTSP		50,128
61	508	NLH,NLH,NLH,NLH	CTFP	387,714	CTFP		381,374
61	508	NLH,NLH,NLH,NLH	NT	8,400	NT		0
		Total PA 61 Area =		864,009			864,007
63	186	CRN,SOY	CTSP	42,041	CTSP		42,041
63	186	CRN,SOY	RT	918,236	RT		918,236
63	186	CRN,SOY	NT	192,202	NT		192,202
63	218	CRN,WWT	CTFP	1,338,510	CTFP		1,338,510
63	218	CRN,WWT	CTSP	99,701	CTSP		99,701
63	490	WWT	RT	1,204,860	RT		1,204,860
63	503	HLH,HLH,HLH,HLH	CTFP	13,162,800	CTFP		13,162,800
63	508	NLH,NLH,NLH,NLH	CTSP	514,543	CTSP		514,543
		Total PA 63 Area =		17,472,893			17,472,893
64	100	CRN	NT	56,076	NT		56,076
64	131	CRN,CRN,SOY	CTSP	2,226,539	CTSP		2,443,560
64	131	CRN,CRN,SOY	RT	674,106	RT		32,799
64	218	CRN,WWT	CTFP	690,688	CTFP		0
64	218	CRN,WWT	Cover	0	RT	Cover	762,644
64	366	OTS,NLH,NLH,NLH	CTSP	50,603	CTSP		50,602
64	458	SOY,WWT,SOY	Cover	0	CTFP	Cover	473,664
64	490	WWT	RT	272,811	RT		151,473
64	503	HLH,HLH,HLH,HLH	CTSP	173,778	CTSP		173,778
		Total PA 64 Area =		4,144,601			4,144,596

Table E.3 Soil Physical Properties, Percentage Weights, and Ranks for all Climate Divisions

CD-221	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	4	0.10
Loam	41	41	18	1.42	0.30	0.12	2	0.24
Loamy Sand/Sand	85	10	5	1.56	0.13	0.05	5	0.08
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.20
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	6	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.31

CD-222	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	4	0.14
Loamy Sand/Sand	88	8	4	1.57	0.12	0.04	2	0.27
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.15
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	5	0.09
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.35

CD-223	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	4	0.13
Loamy Sand/Sand	87	9	4	1.56	0.12	0.04	1	0.41
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.16
Silty Clay/Silty Clay Loam	7	58	36	1.35	0.37	0.21	5	0.10
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.20

CD-231	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.01
Loam	41	41	18	1.42	0.30	0.12	2	0.26
Loamy Sand/Sand	87	9	5	1.56	0.13	0.05	4	0.08
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.19
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.46

CD-232	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.01
Loam	41	41	18	1.42	0.30	0.12	2	0.28
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.04
Sandy Clay Loam/Sandy Loam	60	27	14	1.50	0.24	0.10	3	0.07
Silty Clay/Silty Clay Loam	7	58	36	1.35	0.37	0.21	4	0.05
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.55

CD-241	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	39	1.33	0.36	0.21	5	0.03
Loam	41	41	18	1.42	0.30	0.12	4	0.06
Sandy Clay Loam/Sandy Loam	61	27	13	1.52	0.23	0.09	3	0.23
Silty Clay/Silty Clay Loam	7	55	38	1.34	0.38	0.22	2	0.29
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.39

CD-242	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	25	40	36	1.36	0.35	0.19	4	0.05
Loam	41	41	18	1.42	0.30	0.12	5	0.04
Loamy Sand/Sand	82	12	6	1.54	0.14	0.05	2	0.37
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.13
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	6	0.03
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.38

CD-251	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.02
Loam	41	41	18	1.42	0.30	0.12	2	0.19
Loamy Sand/Sand	89	7	4	1.57	0.12	0.04	1	0.42
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.13
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	5	0.08
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.16

Table E.3 (contd.)

CD-252	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	17	37	46	1.26	0.41	0.24	5	0.06
Loam	41	41	18	1.42	0.30	0.12	6	0.10
Loamy Sand/Sand	83	12	5	1.55	0.13	0.05	3	0.16
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.36
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	4	0.14
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.18

CD-253	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	2	0.28
Loamy Sand/Sand	86	9	5	1.56	0.13	0.05	1	0.48
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.18
Silty Clay/Silty Clay Loam	6	52	42	1.31	0.40	0.24	4	0.03
Silt Loam	12	68	20	1.43	0.33	0.13	5	0.03

CD-261	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	3	0.12
Loamy Sand/Sand	87	9	4	1.56	0.12	0.04	1	0.56
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.21
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	4	0.06
Silt Loam	12	68	20	1.43	0.33	0.13	5	0.05

CD-262	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	6	0.02
Loam	41	41	18	1.42	0.30	0.12	3	0.15
Loamy Sand/Sand	87	9	4	1.56	0.12	0.04	1	0.55
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.23
Silty Clay/Silty Clay Loam	7	56	37	1.34	0.38	0.22	4	0.03
Silt Loam	12	68	20	1.43	0.33	0.13	5	0.02

CD-271	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.02
Loam	41	41	18	1.42	0.30	0.12	5	0.03
Loamy Sand/Sand	82	12	6	1.54	0.14	0.05	4	0.11
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.42
Silty Clay/Silty Clay Loam	6	54	40	1.32	0.39	0.23	2	0.29
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.13

CD-272	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	13	36	52	1.20	0.44	0.27	2	0.22
Loam	41	41	18	1.42	0.30	0.12	6	0.07
Loamy Sand/Sand	83	11	5	1.55	0.13	0.05	5	0.09
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.32
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	4	0.15
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.15

CD-281	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	40	1.32	0.37	0.21	4	0.08
Loam	41	41	18	1.42	0.30	0.12	5	0.07
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.09
Silty Clay/Silty Clay Loam	7	56	37	1.34	0.38	0.22	2	0.27
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.48

CD-282	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	5	0.04
Loam	41	41	18	1.42	0.30	0.12	3	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.07
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	2	0.10
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.68

Table E.3 (contd.)

CD-311	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.03
Loam	41	41	18	1.42	0.30	0.12	3	0.09
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.05
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	2	0.12
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.67
CD-312	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.09
Loam	41	41	18	1.42	0.30	0.12	4	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.02
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.16
Silty Clay/Silty Clay Loam	7	56	38	1.34	0.38	0.22	2	0.19
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.44
CD-313	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.03
Loam	41	41	18	1.42	0.30	0.12	2	0.28
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.16
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	4	0.16
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.36
CD-314	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.01
Loam	41	41	18	1.42	0.30	0.12	4	0.10
Loamy Sand/Sand	92	5	3	1.58	0.11	0.04	5	0.06
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.14
Silty Clay/Silty Clay Loam	7	58	35	1.35	0.37	0.21	3	0.11
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.58
CD-321	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	5	0.03
Loam	41	41	18	1.42	0.30	0.12	4	0.05
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.37
Silty Clay/Silty Clay Loam	7	54	40	1.33	0.39	0.23	3	0.18
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.37
								1.00
CD-322	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.02
Loam	41	41	18	1.42	0.30	0.12	3	0.11
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.08
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	2	0.14
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.64
CD-323	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Loam	41	41	18	1.42	0.30	0.12	4	0.14
Loamy Sand/Sand	92	5	3	1.58	0.11	0.04	5	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.16
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	2	0.16
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.53
CD-341	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	6	0.02
Loam	41	41	18	1.42	0.30	0.12	3	0.15
Loamy Sand/Sand	91	6	3	1.58	0.11	0.04	5	0.10
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.29
Silty Clay/Silty Clay Loam	7	57	37	1.34	0.38	0.22	4	0.14
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.30

Table E.3 (contd.)

CD-342	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	23	39	38	1.34	0.36	0.20	6	0.07
Loam	41	41	18	1.42	0.30	0.12	5	0.11
Loamy Sand/Sand	85	10	5	1.55	0.13	0.05	4	0.12
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.16
Silty Clay/Silty Clay Loam	7	59	35	1.36	0.37	0.21	3	0.16
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.38

CD-351	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.01
Loam	41	41	18	1.42	0.30	0.12	5	0.07
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	4	0.14
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.37
Silty Clay/Silty Clay Loam	6	52	42	1.31	0.40	0.24	2	0.24
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.17

CD-352	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.01
Loam	41	41	18	1.42	0.30	0.12	3	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.03
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.08
Silty Clay/Silty Clay Loam	7	55	38	1.33	0.38	0.22	1	0.40
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.38

CD-353	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.01
Loam	41	41	18	1.42	0.30	0.12	3	0.10
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.09
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.37	0.21	2	0.21
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.59

CD-391	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	4	0.11
Loamy Sand/Sand	83	11	5	1.55	0.13	0.05	3	0.14
Sandy Clay Loam/Sandy Loam	60	27	13	1.51	0.24	0.10	2	0.17
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	5	0.02
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.56

CD-392	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	41	1.31	0.38	0.22	5	0.09
Loam	41	41	18	1.42	0.30	0.12	3	0.14
Loamy Sand/Sand	83	12	6	1.55	0.14	0.05	6	0.07
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.24
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	4	0.13
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.33

CD-393	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.11
Loam	41	41	18	1.42	0.30	0.12	1	0.31
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	59	27	15	1.50	0.25	0.11	3	0.18
Silty Clay/Silty Clay Loam	7	57	36	1.35	0.37	0.21	4	0.13
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.26

CD-401	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.01
Loam	41	41	18	1.42	0.30	0.12	2	0.17
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.07
Silty Clay/Silty Clay Loam	6	48	46	1.28	0.42	0.26	4	0.02
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.73

Table E.3 (contd.)

CD-402	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	13	36	51	1.21	0.43	0.26	2	0.14
Loam	41	41	18	1.42	0.30	0.12	4	0.08
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.03
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	5	0.04
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	3	0.12
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.59

CD-403	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	39	1.33	0.36	0.21	5	0.06
Loam	41	41	18	1.42	0.30	0.12	4	0.07
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.03
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.17
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	2	0.32
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.35

CD-411	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.03
Loam	41	41	18	1.42	0.30	0.12	2	0.24
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.23
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	4	0.09
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.40

CD-412	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	6	0.02
Loam	41	41	18	1.42	0.30	0.12	4	0.16
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.12
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.18
Silty Clay/Silty Clay Loam	7	57	36	1.35	0.37	0.21	2	0.21
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.31

CD-413	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.02
Loam	41	41	18	1.42	0.30	0.12	2	0.34
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.20
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	4	0.04
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.39

CD-414	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	16	37	47	1.25	0.41	0.25	4	0.10
Loam	41	41	18	1.42	0.30	0.12	5	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.22
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	3	0.14
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.43

CD-415	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.01
Loam	41	41	18	1.42	0.30	0.12	2	0.33
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.13
Silty Clay/Silty Clay Loam	6	51	43	1.30	0.41	0.25	3	0.13
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.40

CD-416	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	18	37	45	1.27	0.40	0.24	5	0.05
Loam	41	41	18	1.42	0.30	0.12	3	0.15
Loamy Sand/Sand	89	7	4	1.57	0.12	0.04	6	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.10
Silty Clay/Silty Clay Loam	6	52	42	1.31	0.40	0.24	1	0.35
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.31

Table E.3 (contd.)

CD-421	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.01
Loam	41	41	18	1.42	0.30	0.12	4	0.09
Loamy Sand/Sand	83	12	6	1.55	0.14	0.05	3	0.12
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	5	0.06
Silty Clay/Silty Clay Loam	7	57	36	1.35	0.37	0.21	2	0.23
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.49

CD-422	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	14	36	50	1.22	0.43	0.26	5	0.06
Loam	41	41	18	1.42	0.30	0.12	2	0.18
Loamy Sand/Sand	87	9	5	1.56	0.13	0.05	6	0.02
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.08
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	3	0.12
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.54

CD-431	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	4	0.10
Loam	41	41	18	1.42	0.30	0.12	3	0.13
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.02
Silty Clay/Silty Clay Loam	7	59	34	1.37	0.36	0.20	2	0.20
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.55

CD-432	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	3	0.09
Loam	41	41	18	1.42	0.30	0.12	5	0.06
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.15
Silty Clay/Silty Clay Loam	7	57	37	1.34	0.38	0.22	4	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.63

CD-433	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	18	37	45	1.27	0.40	0.24	5	0.05
Loam	41	41	18	1.42	0.30	0.12	3	0.14
Loamy Sand/Sand	92	5	3	1.58	0.11	0.04	6	0.02
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.24
Silty Clay/Silty Clay Loam	7	56	38	1.34	0.38	0.22	4	0.11
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.44

CD-441	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Loam	41	41	18	1.42	0.30	0.12	2	0.15
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.08
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	4	0.02
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.75

CD-442	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	41	1.31	0.38	0.22	5	0.09
Loam	41	41	18	1.42	0.30	0.12	3	0.17
Loamy Sand/Sand	83	11	5	1.55	0.13	0.05	4	0.09
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.23
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	6	0.06
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.36

CD-443	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	3	0.14
Loam	41	41	18	1.42	0.30	0.12	6	0.01
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	4	0.12
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.32
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	5	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.34

Table E.3 (contd.)

CD-444	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	14	36	50	1.22	0.43	0.26	3	0.16
Loam	41	41	18	1.42	0.30	0.12	2	0.16
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	4	0.14
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	5	0.14
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	6	0.13
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.27

CD-471	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.01
Loam	41	41	18	1.42	0.30	0.12	4	0.17
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.06
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.31
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	3	0.19
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.26

CD-472	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.01
Loam	41	41	18	1.42	0.30	0.12	3	0.12
Loamy Sand/Sand	82	12	6	1.55	0.14	0.05	5	0.08
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.10
Silty Clay/Silty Clay Loam	7	56	38	1.34	0.38	0.22	1	0.47
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.22

CD-473	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	6	0.06
Loam	41	41	18	1.42	0.30	0.12	1	0.24
Loamy Sand/Sand	82	12	6	1.54	0.14	0.05	5	0.15
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.18
Silty Clay/Silty Clay Loam	6	53	41	1.32	0.39	0.23	2	0.19
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.18

CD-474	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.01
Loam	41	41	18	1.42	0.30	0.12	4	0.19
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.05
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.26
Silty Clay/Silty Clay Loam	6	53	41	1.32	0.40	0.24	3	0.22
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.27

CD-531	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	6	0.01
Loam	41	41	18	1.42	0.30	0.12	4	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.03
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.24
Silty Clay/Silty Clay Loam	7	58	35	1.36	0.37	0.21	3	0.15
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.47

CD-532	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	5	0.08
Loam	41	41	18	1.42	0.30	0.12	2	0.21
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.03
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.09
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	3	0.14
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.45

CD-533	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.02
Loam	41	41	18	1.42	0.30	0.12	2	0.13
Sandy Clay Loam/Sandy Loam	59	27	14	1.50	0.24	0.10	3	0.13
Silty Clay/Silty Clay Loam	6	53	41	1.32	0.40	0.24	4	0.05
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.67

Table E.3 (contd.)

CD-561	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.06
Loam	41	41	18	1.42	0.30	0.12	4	0.13
Loamy Sand/Sand	83	12	6	1.55	0.14	0.05	3	0.21
Sandy Clay Loam/Sandy Loam	61	27	13	1.52	0.23	0.09	2	0.23
Silty Clay/Silty Clay Loam	6	48	46	1.28	0.42	0.26	6	0.02
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.35

CD-562	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.03
Loam	41	41	18	1.42	0.30	0.12	2	0.18
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.17
Silty Clay/Silty Clay Loam	6	50	44	1.29	0.41	0.25	4	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.54
								1.00

CD-571	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.02
Loam	41	41	18	1.42	0.30	0.12	3	0.13
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.02
Sandy Clay Loam/Sandy Loam	60	27	13	1.51	0.24	0.10	1	0.45
Silty Clay/Silty Clay Loam	6	49	45	1.29	0.41	0.25	4	0.10
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.28
								1.00

CD-572	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.03
Loam	41	41	18	1.42	0.30	0.12	3	0.16
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.41
Silty Clay/Silty Clay Loam	6	49	45	1.29	0.42	0.26	4	0.13
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.27

CD-573	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	39	1.33	0.36	0.21	5	0.03
Loam	41	41	18	1.42	0.30	0.12	3	0.21
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.48
Silty Clay/Silty Clay Loam	6	50	44	1.29	0.41	0.25	4	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.21

CD-581	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	6	0.02
Loam	41	41	18	1.42	0.30	0.12	5	0.10
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	2	0.21
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.18
Silty Clay/Silty Clay Loam	7	59	34	1.36	0.36	0.20	1	0.30
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.19

CD-582	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	39	1.33	0.36	0.21	4	0.03
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.01
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.06
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	1	0.75
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.15

CD-583	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	22	39	39	1.33	0.36	0.21	5	0.03
Loam	41	41	18	1.42	0.30	0.12	3	0.07
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.04
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	2	0.28
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.58

Table E.3 (contd.)

CD-584	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	23	39	38	1.34	0.36	0.20	3	0.07
Loam	41	41	18	1.42	0.30	0.12	5	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.09
Silty Clay/Silty Clay Loam	7	55	38	1.33	0.38	0.22	4	0.05
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.75
CD-591	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	3	0.16
Loam	41	41	18	1.42	0.30	0.12	2	0.16
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	4	0.05
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	5	0.02
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.61
CD-592	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	12	35	53	1.19	0.44	0.27	1	0.33
Loam	41	41	18	1.42	0.30	0.12	4	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	3	0.28
Silty Clay/Silty Clay Loam	7	60	33	1.37	0.36	0.20	5	0.03
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.32
CD-601	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	4	0.10
Loam	41	41	18	1.42	0.30	0.12	1	0.47
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	5	0.09
Silty Clay/Silty Clay Loam	7	56	38	1.34	0.38	0.22	3	0.11
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.23
CD-602	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	13	36	52	1.20	0.44	0.27	3	0.20
Loam	41	41	18	1.42	0.30	0.12	5	0.15
Sandy Clay Loam/Sandy Loam	59	27	14	1.50	0.25	0.11	2	0.20
Silty Clay/Silty Clay Loam	7	54	39	1.33	0.39	0.23	4	0.17
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.28
CD-603	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	5	0.02
Loam	41	41	18	1.42	0.30	0.12	3	0.18
Sandy Clay Loam/Sandy Loam	60	27	13	1.51	0.24	0.10	2	0.25
Silty Clay/Silty Clay Loam	7	56	37	1.34	0.38	0.22	4	0.10
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.45
CD-611	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	5	0.01
Loam	41	41	18	1.42	0.30	0.12	1	0.39
Sandy Clay Loam/Sandy Loam	58	26	16	1.48	0.26	0.12	4	0.03
Silty Clay/Silty Clay Loam	7	57	36	1.35	0.37	0.21	3	0.19
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.38
CD-612	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	14	36	50	1.22	0.43	0.26	5	0.12
Loam	41	41	18	1.42	0.30	0.12	4	0.14
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	1	0.27
Sandy Clay Loam/Sandy Loam	60	27	13	1.51	0.24	0.10	3	0.16
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	6	0.07
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.24

Table E.3 (contd.)

CD-631	% SAND	% SILT	% CLAY	BD	FC	WP	Rank	Weight
Clay/Clay Loam	23	39	38	1.34	0.36	0.20	3	0.07
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	4	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	1	0.58
Silt Loam	12	68	20	1.43	0.33	0.13	2	0.31
CD-632	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	21	39	40	1.32	0.37	0.21	4	0.05
Loam	41	41	18	1.42	0.30	0.12	6	0.02
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	5	0.04
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.12
Silty Clay/Silty Clay Loam	7	58	36	1.35	0.37	0.21	3	0.05
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.72
CD-633	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	20	38	43	1.30	0.39	0.23	4	0.04
Loam	41	41	18	1.42	0.30	0.12	3	0.09
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.02
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.26
Silty Clay/Silty Clay Loam	7	57	36	1.35	0.38	0.22	5	0.04
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.55
CD-634	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	15	37	48	1.24	0.42	0.25	6	0.04
Loam	41	41	18	1.42	0.30	0.12	3	0.06
Loamy Sand/Sand	83	12	6	1.55	0.14	0.05	4	0.06
Sandy Clay Loam/Sandy Loam	61	27	12	1.52	0.23	0.09	2	0.26
Silty Clay/Silty Clay Loam	6	51	43	1.30	0.40	0.25	5	0.04
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.54
CD-641	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	4	0.08
Loam	41	41	18	1.42	0.30	0.12	5	0.02
Sandy Clay Loam/Sandy Loam	60	27	14	1.50	0.24	0.10	2	0.34
Silty Clay/Silty Clay Loam	7	55	39	1.33	0.39	0.23	3	0.09
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.47
CD-642	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	28	41	31	1.41	0.32	0.17	5	0.03
Loam	41	41	18	1.42	0.30	0.12	3	0.16
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	6	0.02
Sandy Clay Loam/Sandy Loam	61	27	13	1.52	0.23	0.09	2	0.23
Silty Clay/Silty Clay Loam	7	56	38	1.34	0.38	0.22	4	0.08
Silt Loam	12	68	20	1.43	0.33	0.13	1	0.48
CD-643	**% SAND**	**% SILT**	**% CLAY**	**BD**	**FC**	**WP**	**Rank**	**Weight**
Clay/Clay Loam	11	35	54	1.18	0.45	0.28	5	0.01
Loam	41	41	18	1.42	0.30	0.12	2	0.34
Loamy Sand/Sand	81	13	6	1.54	0.14	0.05	1	0.39
Silty Clay/Silty Clay Loam	7	58	36	1.35	0.37	0.21	4	0.05
Silt Loam	12	68	20	1.43	0.33	0.13	3	0.21

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