Life Cycle Analysis of Net Greenhouse Gas Emissions Under Different Tillage Practices in Bioenergy Sorghum Production

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Introduction

Bioenergy sorghum is a second-generation bioenergy crop with high biomass yield potential and nitrogen (N) and water use efficiency. Biomass sorghum can at least partly offset carbon dioxide (CO_2) emissions by converting atmospheric CO_2 to organic carbon (C) in crop biomass and soil, and by potentially oxidizing methane (CH_4). However, its production also emits nitrous oxide (N_2O) and requires energy [e.g., to operate farm machinery, produce inputs such as fertilizer and to convert the harvested product to usable fuels (feedstock conversion efficiency)]. Because of lower energy requirements and greater environmental benefits, such as reduced soil erosion and N leaching, conservation tillage may be better able to optimize crop productivity than conventional tillage systems. Yet, information about effects of tillage on C dynamics and greenhouse gas (GHG) emissions in bioenergy sorghum cropping systems is still unavailable. Whether conservation tillage is needed in bioenergy sorghum production and to what extent to sustain production and soil organic C (SOC) while minimizing GHG emissions needs to be studied. Field experiments can reveal short-term results, however, field experimentation is time-consuming and expensive for obtaining long-term results. The biogeochemical model DAYCENT is able to simulate plant and soil C and N dynamics and GHG fluxes, and integrates weather, soil, and crop information along with field management practices such as planting, harvest, tillage, mineral and organic fertilization, irrigation, etc. The objectives of this study were to 1) use the DAYCENT model to simulate soil GHG fluxes, SOC change, and biomass yields in bioenergy sorghum production as affected by different tillage practices and 2) conduct a life cycle analysis (LCA) of net GHG emissions by combining the outputs from DAYCENT model simulation with data from published, estimated, and field operation records.

Material and Methods

The field study associated with this research was established at the Texas A&M AgriLife Research Farm near College Station, TX (30°32'15''N, 96°25'37''W) in 2009 and used a completely randomized experimental design with five replications to compare the effects of tillage (conventional vs. reduced tillage) on bioenergy sorghum production. All plots were 9.14 m long by 4.08 m wide, with four 1.02 m rows, and received 280 kg N ha^{-1} yr^{-1} without residue return. Biomass yield and SOC data were collected from 2009 to 2014. Conventional Tillage (CT) plots were disked to a depth of 15 - 20 cm and bedded into rows after harvest and prior to planting, with additional inter-row cultivation in the spring. Plots under reduced tillage (RT) received only spring inter-row cultivation to maintain rows. DAYCENT was calibrated and validated using measured data and then used to predict yield, SOC, and GHG emissions to the end of this century, in order to calculate net GHG emissions from different tillage practices using LCA and the net GHG protocol established by Adler *et al.* (2007). Based on field observations and model simulations, net GHG emissions were divided into two categories, C sinks and C sources, where C sinks included displaced fossil fuel by biofuel produced from sorghum biomass, changes in SOC, and CH_4 oxidation, and C sources included direct and indirect N_2O emissions, and energy requirements for N fertilizer manufacture and field machinery operations.

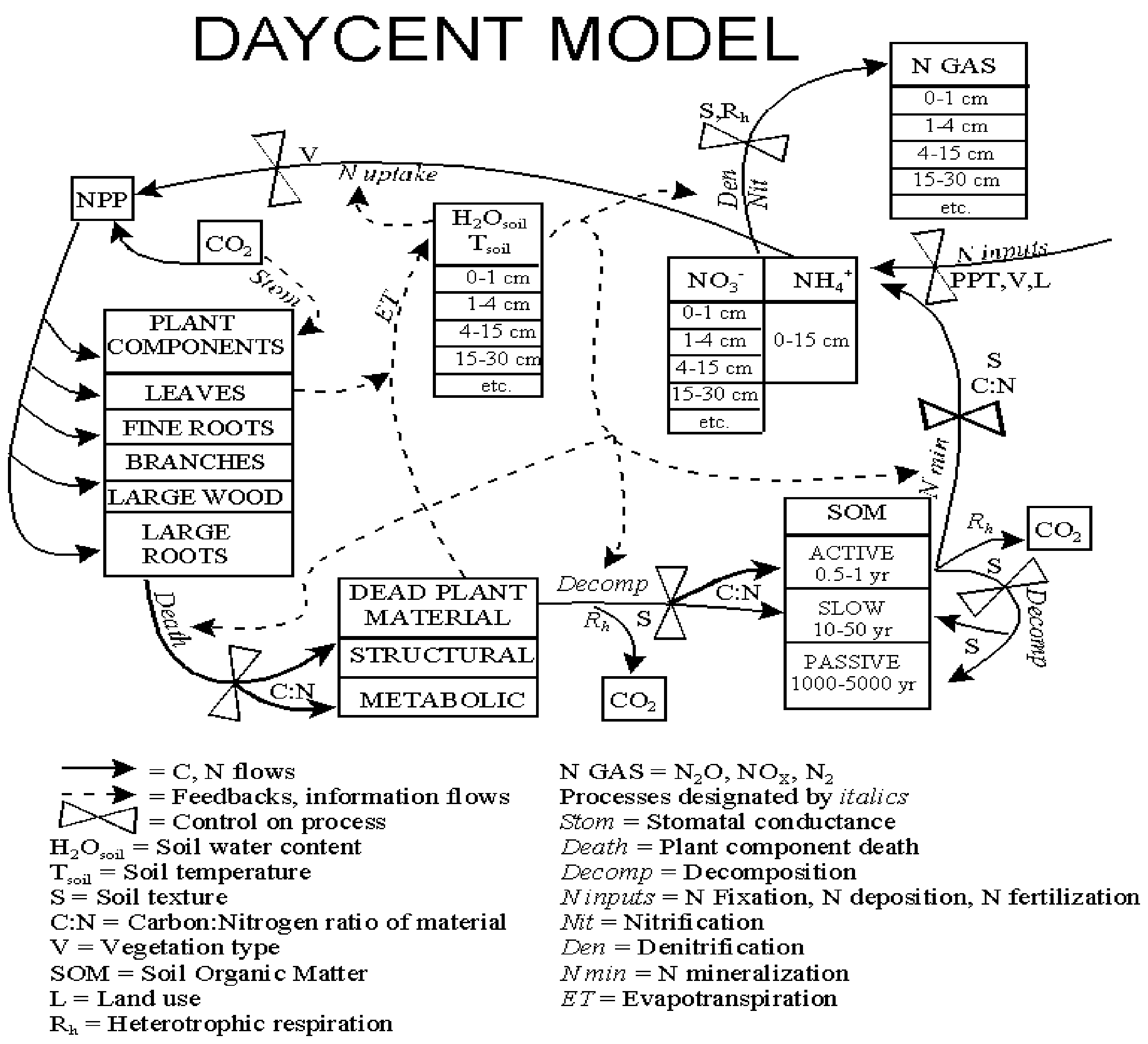

Fig. 1. Conceptual diagram of the DAYCENT ecosystem model (Del Grosso *et al.*, 2001)

Results

Model Calibration and Validation

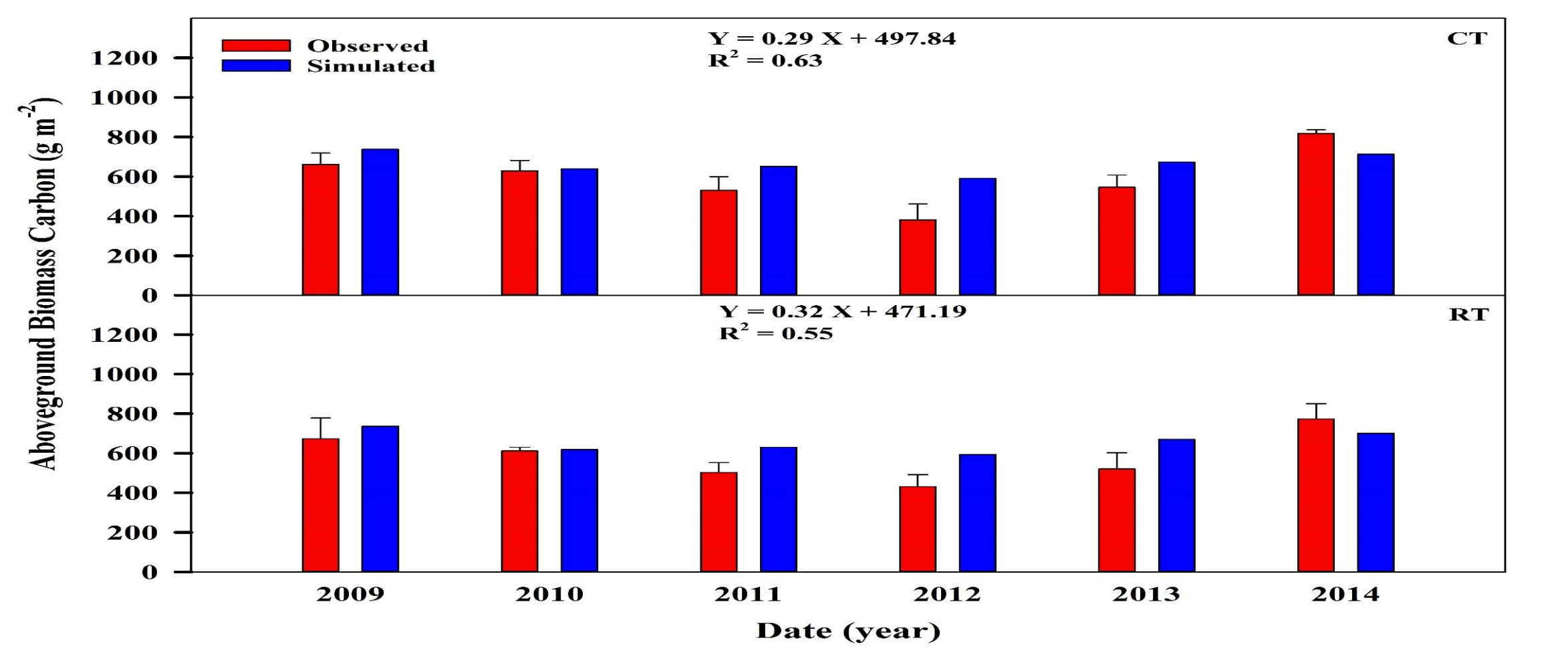

Fig. 2. Observed and Simulated Yearly Aboveground Biomass C in Different Tillage Practices

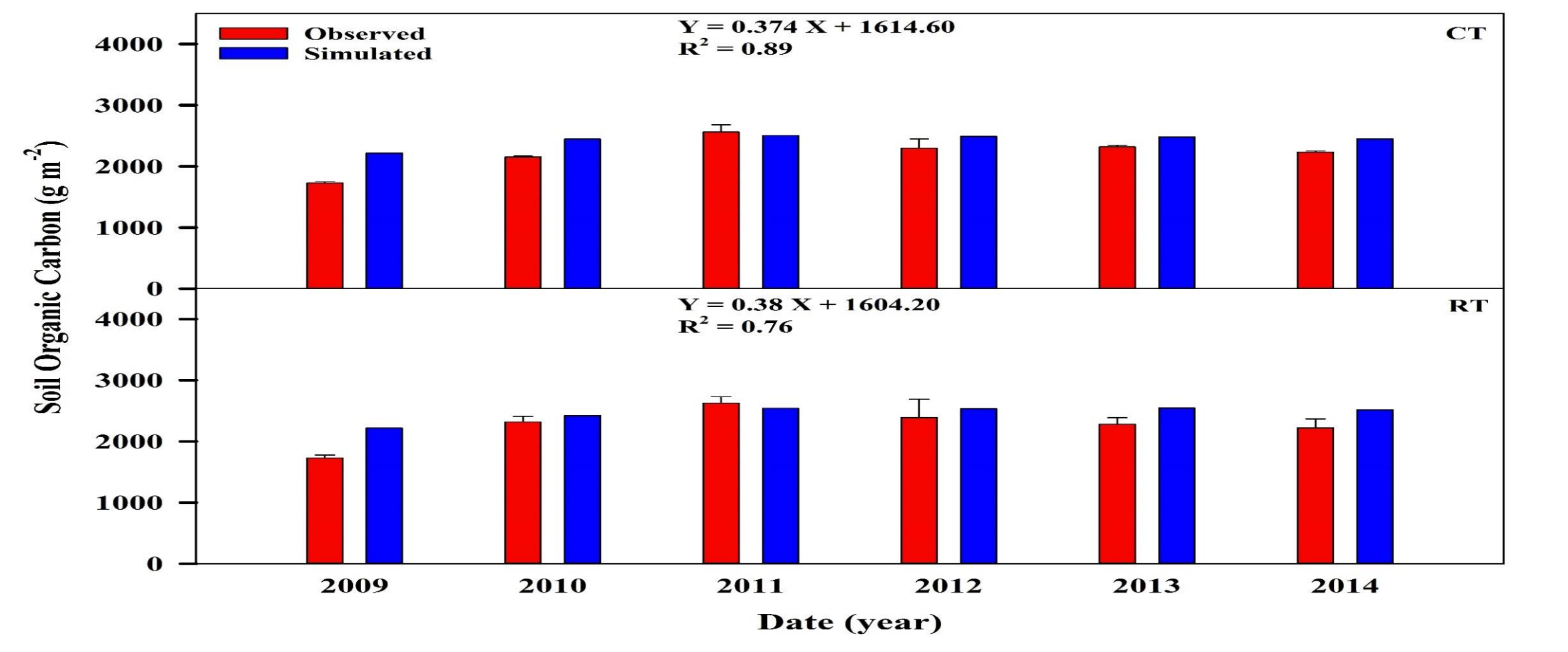

Fig. 3. Observed and Simulated Yearly SOC at 0-20 cm depth in Different Tillage Practices

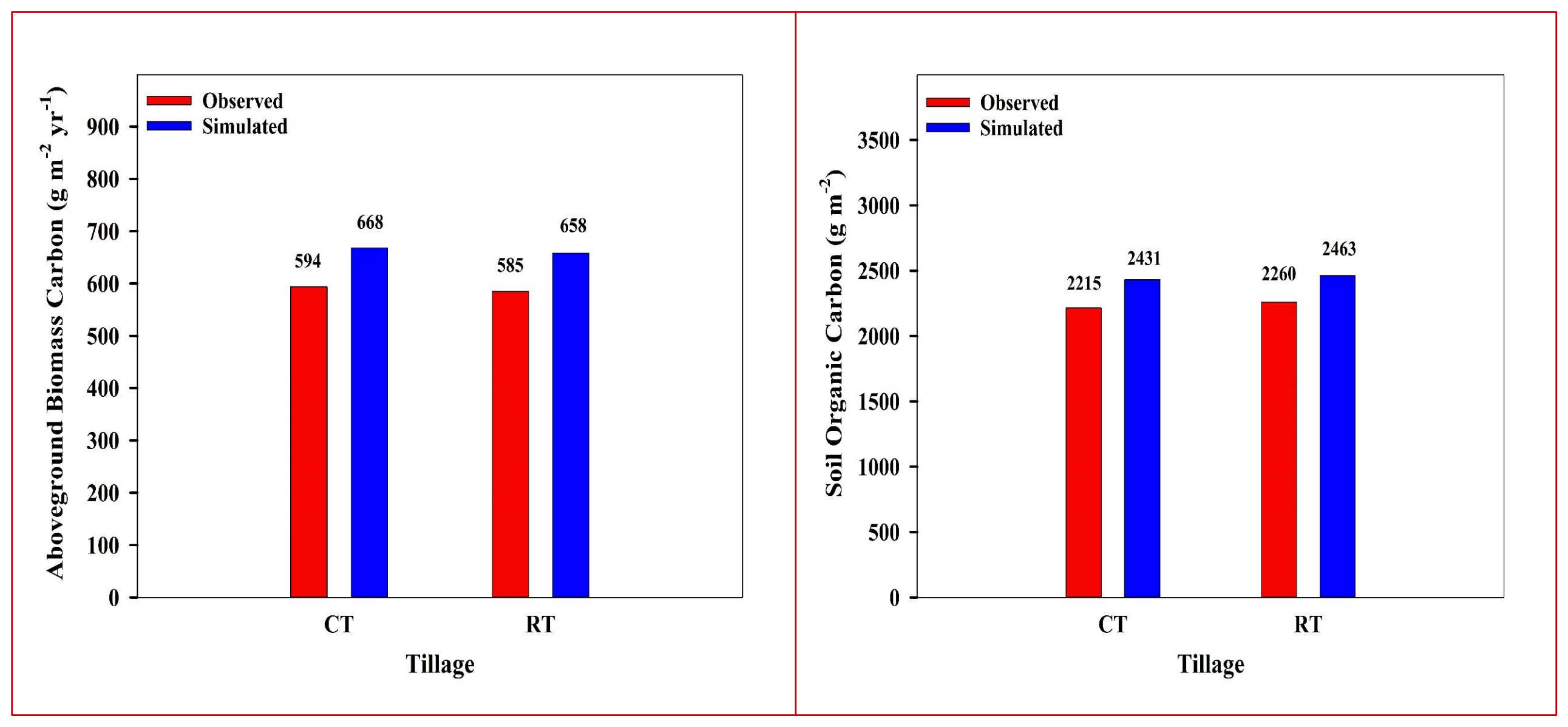

Fig. 4. Average Observed and Simulated Aboveground Biomass C (left) and SOC at 0-20 cm depth (right) in Different Tillage Practices

Fig. 5. Aboveground Biomass Harvesting (left) and Soil Cores Sampling (right)

Model Projection

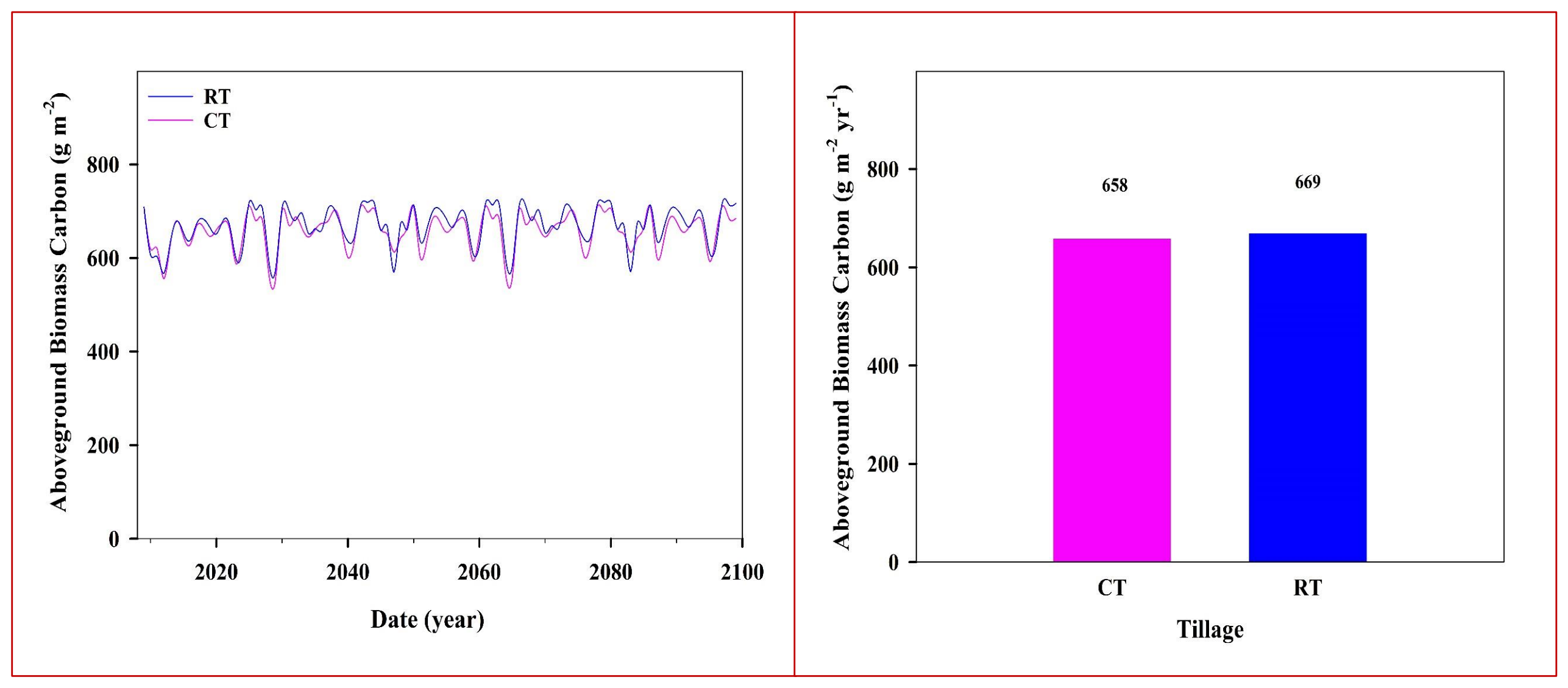

Fig. 6. Projected Yearly (left) and Average (right) Aboveground Biomass C in Different Tillage Practices

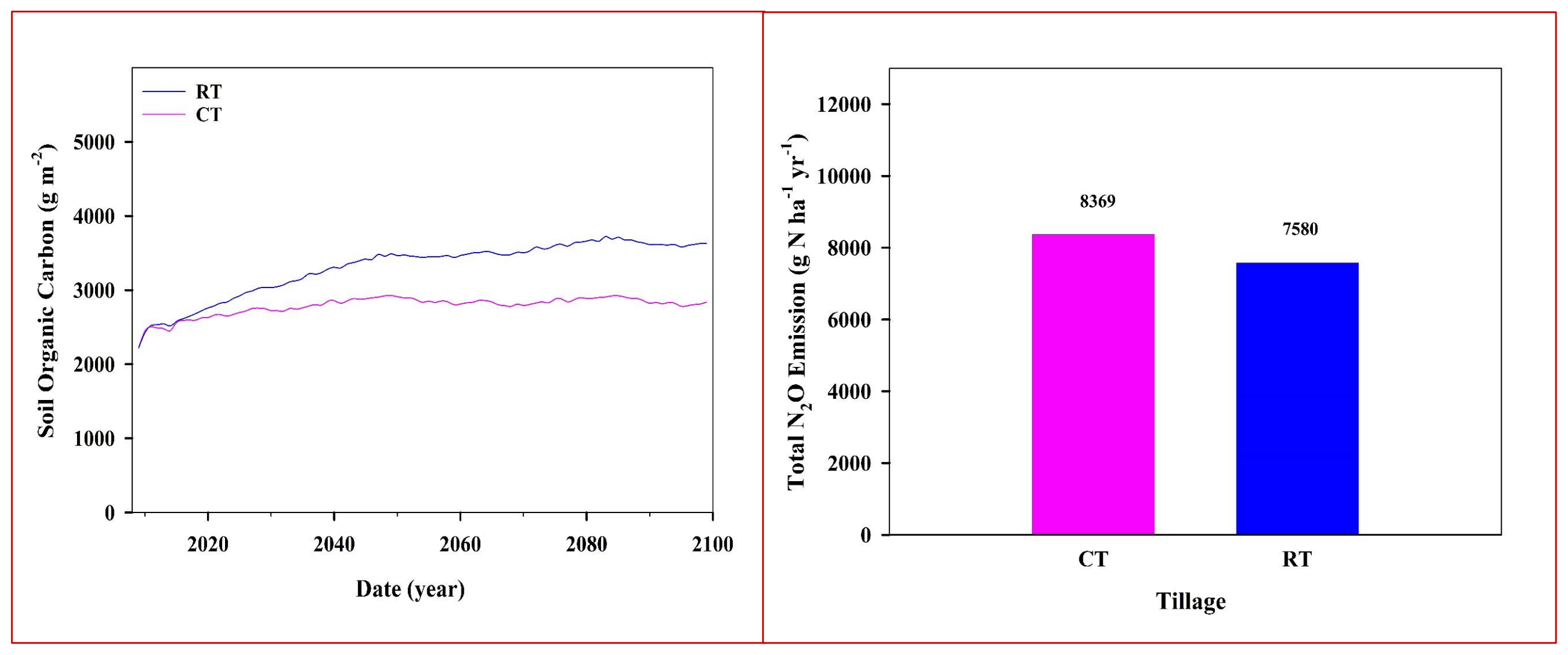

Fig. 7. Projected SOC Change at 0-20 cm depth (left) and Average N_2O Emissions in Different Tillage Practices

Life Cycle Analysis of Net Greenhouse Gas Emissions

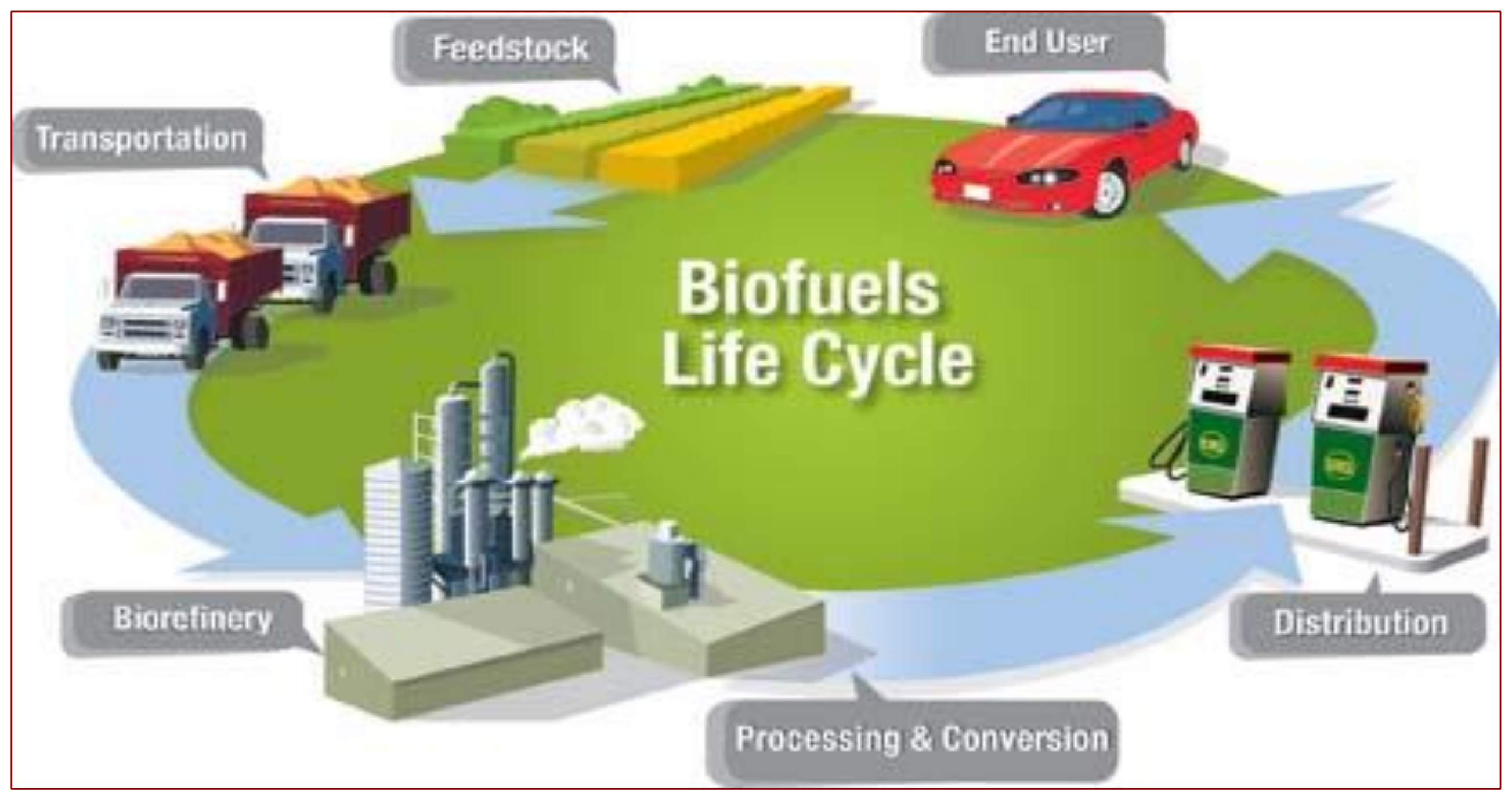

Fig. 8. Biofuel Life Cycle Analysis by *U.S. Department of Energy*

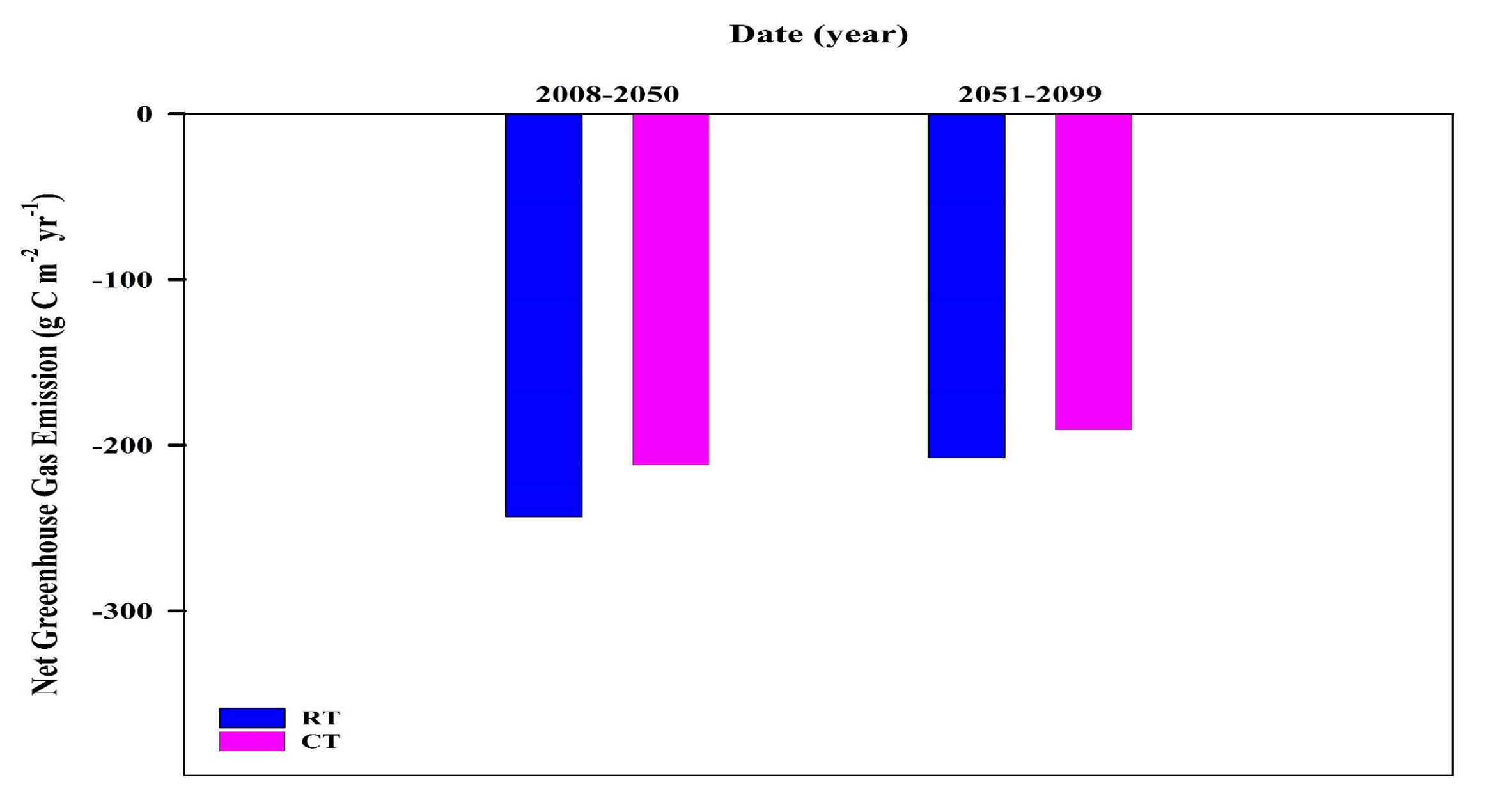

Fig. 9. Net GHG Emissions Before and After SOC Equilibrium in Different Tillage Practices

Conclusions

- DAYCENT simulated aboveground biomass C and SOC change reasonably well, correctly reflecting the variation caused by seasonal change and tillage practice.
- Aboveground biomass C was higher in conventional compared to reduced tillage at the beginning, but the trend was reversed in the long run due to increased mineralized N released from larger SOC pool in reduced till treatment.
- Both tillage practices increased SOC until the middle of the century, with higher SOC content in reduced till treatment.
- Higher N_2O emission was predicted for conventional compared to reduced till, mainly due to intense, short-term mineralized N release caused by more frequent cultivations in conventional tillage.
- Accounting for C sinks and C sources, both tillage practices were promising for reducing GHG emissions under bioenergy sorghum production.
- Reduced tillage may have a greater potential due to higher biomass production, higher SOC sequestration, lower N_2O emissions, and less field machinery use.

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