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DAYCENT model analysis of past and contemporary soil N_2O and net greenhouse gas flux for major crops in the USA

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Abstract

The DAYCENT ecosystem model (a daily version of CENTURY) and an emission factor (EF) methodology used by the Intergovernmental Panel on Climate Change were used to estimate direct and indirect N_2O emission for major cropping systems in the USA. The EF methodology is currently used for the USA greenhouse gas inventory but process based models, such as DAYCENT, may yield more reliable results because they account for factors such as soil type, climate, and tillage intensity that are ignored by EF. Comparison of mean annual soil N_2O flux estimated by DAYCENT and EF with measured data for different cropping systems yielded r^2 values of 0.74 and 0.67, and mean deviations of −6 and +13%, respectively. At the national scale, DAYCENT simulation of total N_2O emission was ~25% lower than estimated using EF. For both models, N_2O emission was highest in the central USA followed by the northwest, southwest, southeast, and northeast regions. The models simulated roughly equivalent direct N_2O emission from fertilized crops, but EF estimated greater direct N_2O emission than DAYCENT for N-fixing crops. DAYCENT and EF estimates of the gaseous component of indirect N_2O emission ($NO + NH_3$) differed little, but DAYCENT estimated approximately twice the indirect emission from NO_3 leaching since it included the contribution of N from N-fixing crops while EF did not. DAYCENT simulations were also performed for no tillage cropping, pre-1940 crop management, and native vegetation. DAYCENT-simulated N_2O, CO_2, and CH_4 fluxes were converted to CO_2–C equivalents and combined with fuel use estimates to estimate net global warming potential (GWP_{net}). GWP_{net} for recent non-rice (*Oryza sativa* L.) major cropping was 0.43 Mg C ha^{-1} yr^{-1} under conventional tillage and 0.29 Mg C ha^{-1} yr^{-1} under no tillage, for pre-industrial cropping was 0.25 Mg C ha^{-1} yr^{-1}, and for native systems was −0.15 Mg C ha^{-1} yr^{-1}. Results from DAYCENT suggest that conversion to no tillage at the national scale could mitigate ~20% of USA agricultural emission or ~1.5% of total USA emission of greenhouse gases.

Keywords: Biogeochemical modeling; Global warming potential; Methane; Nitrous oxide; Regional analysis; Soil carbon

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1. Introduction

1.1. Nitrogen gas emissions from agricultural soils

There has been concern regarding the environmental effects of nitrogen (N) gases in the atmosphere for many years (CAST, 1976; Rodhe, 1990). Nitrous oxide (N_2O) in the troposphere absorbs terrestrial thermal radiation and thus contributes to greenhouse warming of the atmosphere. On a mass basis, N_2O is about 300 times more potent than carbon dioxide (CO_2) in this respect, and it is increasing in atmospheric concentration at the rate of 0.6–0.9 ppbv per year (Albritton and Meira Filho, 2001; CMDL, 2002). Nitrous oxide is also involved in the depletion of the ozone layer in the stratosphere, which protects the biosphere from the harmful effects of solar ultraviolet radiation (Crutzen, 1981). It has been estimated that doubling the concentration of N_2O in the atmosphere would result in a 10% decrease in the ozone layer, and this would increase the ultraviolet radiation reaching the earth by 20% (Crutzen and Ehhalt, 1977). With a relatively long atmospheric lifetime for N_2O of approximately 114 years (Albritton and Meira Filho, 2001), there are justifiable reasons for concern. A second important atmospheric gas is nitric oxide (NO), which reacts with hydroxyl radicals in the atmosphere. Hydroxyl radicals are necessary for the removal of other greenhouse gases (GHG), such as methane (CH_4) (Williams et al., 1992). Atmospheric NO can also be deposited on soils, incorporated into the N cycle, and act as a secondary source for N_2O emission. A third reactive N gas is ammonia (NH_3), which affects visibility, aerosol chemistry, acid deposition, health, and climate. Ammonia also affects the capacity of soil to act as a sink for CH_4 (Steudler et al., 1989), which is also an important GHG. Ammonia, like NO, has a short lifetime in the atmosphere and provides a secondary source for the formation of N_2O, because it can be deposited on soils.

Globally, approximately 7 (6–13) Tg of N_2O–N is emitted to the atmosphere each year as a result of human activities (Kroeze et al., 1999). The only known process for its removal from the atmosphere is reaction with excited singlet oxygen atoms (formed by photolysis of ozone) in the stratosphere. The concentration of N_2O in the atmosphere is increasing at the rate of 0.8 ppbv yr^{-1}, which translates to an atmospheric stock increase of ~5 (4–6) Tg N yr^{-1}. Assuming that the stratospheric destruction of N_2O is 12.3 (10–15) Tg N yr^{-1} then the total emission of N_2O from the biosphere is calculated as 17.2 (14–21) Tg N yr^{-1} (Albritton and Meira Filho, 2001). These estimates suggest that the bulk of emission (~10 Tg N yr^{-1}) comes from natural sources, with oceans responsible for a third, and soils two-thirds of these emissions. Although significant uncertainty remains about the quantity of N_2O emitted from specific sources, agriculture, through soil emission, biomass burning and animal production, is responsible for an estimated 80% of anthropogenic emission (Kroeze et al., 1999).

Currently the inventory of GHG emissions and sinks in the USA includes an assessment of N_2O emission from agricultural soil based on the Good Practice 2000 amendment of the IPCC (1997) (USEPA, 2002). Calculation of N_2O emission directly from crop production systems is based on an emission factor of 1.25 ± 1% of total N applied (IPCC, 1997). However, the IPCC (1997) guidelines for estimating N_2O emission from agricultural soils have a number of limitations. The guidelines consider all agricultural systems to be the same throughout the world and do not take into account different crops, soils, climate and management, all of which are known to affect nitrification–denitrification and N_2O production and emission (Mosier et al., 1998). This methodology assumes that cropped systems are in steady-state so that the entire N cycle occurs during a calendar year, i.e., N is not stored in the plant/soil system for >1 year. However, N can be stored and cycled within the plant/soil system for many years before it is harvested, lost to the atmosphere, or leached as nitrate (NO_3) into groundwater (Follett, 2001a). This lag time between N input and ultimate production of N_2O (Bakken and Bleken, 1998; Mosier and Kroeze, 2000) and an interaction between weather patterns from year to year (Dobbie et al., 1999), are likely confounding factors that are not accounted for in the IPCC (1997) methodology.

A recent compilation of measured N_2O emission suggests that a more appropriate median N_2O emission factor would be 0.9% of N applied (Bouwman et al., 2002a; Laegried and Aastveit, 2002) instead of 1.25% as used by IPCC (1997). Whatever emission factor is used, however, it is clear that N_2O emission varies