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RZWQM2 simulated management practices to mitigate climate change impacts on nitrogen losses and corn production

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ABSTRACT

Gaseous and aqueous nitrogen (N) losses from corn (maize) production systems are concerns under projected climate change. In the present study, the Root Zone Water Quality Model (RZWQM2) was used to test the ability of agricultural management practices (N application rate, corn cultivar, planting date, tillage and controlled drainage) to mitigate future climate change effects on N losses and corn yield in a subsurface drained field in Iowa, USA. Under a future downscaled climate scenario, the simulated non-constant N_2O emission factor (EF), yield-scaled global warming potential and N loss through drainage increased with increasing fertilization above an optimal N rate of 120 kg N ha^{-1}. This rate represents the optimal tradeoff point between environmental issues and economic returns. While yields of the cultivar IB1068 DEKALB declined with climate change, yields of cultivar, IB 0090 GL 482 in the future climate were greater than historical yields of IB 1068 DEKALB.

1. Introduction

Despite some beneficial effects (such as increase in C_3 crop production and water use efficiency (Hatfield et al., 2011), and decrease in stomatal conductance (Bernacchi et al., 2007)) of an elevated atmospheric CO_2 concentration (CO_2) on corn (*Zea mays* L.) yield, a 3.8% global decline in corn yield over the last three decades has been attributed to climate change (Lobell et al., 2011). Our previous simulation of the potential effects of climate change on corn yield in 2050s in Iowa showed an even more severe (14.7%) decline (Wang et al., 2015) due to a shorter corn life length under increased temperature. Many potential adaptation methods have been investigated (e.g., elongating crop life length, developing temperature-tolerant corn cultivars, and optimizing planting date (Islam et al., 2012; Lobell and Field, 2007; Tao and Zhang, 2011)).

Beyond food security, environmental concerns regarding the response of agricultural systems to climate change include the increased potential for N loss through either N_2O emissions or nitrate-nitrogen (NO_3-N) losses to surface and groundwater. The former can contribute to more global warming and depletion of stratospheric ozone (Ravishankara et al., 2009), while the latter can lead to eutrophication and resulting hypoxia of freshwater and marine bodies (Hufnagl-Eichiner et al., 2011). Accounting for about 85% of global N_2O fluxes, agriculture is the main anthropogenic source of N_2O (IPCC, 2007). American agriculture is a major producer of greenhouse gases (GHG), with an estimated 500 Gg having been emitted in 2007 alone. This represented 7% of total global GHG emissions (EPA, 2009). Agricultural soil fertilization with nitrogenous compounds accounts for almost 80% of total agriculture–-driven N_2O emissions (EPA, 2009) Larsen et al. (2007) reported that as the fifth largest GHG-emitting sector, agriculture contributed 7% of total GHG emissions in the US Midwest, representing an equivalent of over 100 Tg of CO_2. Given the dominance of corn and other N fertilizer intensive crops, N_2O is the most heavily emitted GHG in this region.

Widely used in predicting N_2O emissions, N_2O emission factor (EF-percent of N applied during fertilization released as N_2O-N) can be defaulted as 0.8% for animal manure and 1.0% for synthetic fertilizer (Shcherbak et al., 2014). While normally based on a linear fertilizer N to N_2O emission relationship (Tier 1 approach given uncertainties of 0.3–3%, (IPCC, 2006)), a number of studies have shown the relationship to be better described by an exponential function (Hoben et al., 2011; Millar et al., 2010) or quadratic (Ma et al., 2010) relationships. The present study, is seeking to analyze

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the nonlinear response of N_2O emissions to fertilizer N application rate. Such N_2O emissions can be classified as occurring through direct (e.g., from supplemental soil-applied fertilizer) or indirect pathways (e.g., from NO_3-N losses arising from runoff and subsurface drainage brought on by supplemental irrigation or rain water). In this study, NO_3-N loss was assumed to be an indirect source of N_2O, and was calculated accordingly (IPCC, 2006).

N_2O emissions expressed with respect to crop yield can be more representative of the consequences of poor soil N management than such emissions simply expressed per cropped area. Yield-scaled N_2O emissions have been widely reported in recent studies showing that emissions were at their lowest when crops were grown at the N rate of maximum return, situated within a range of high and low N rate profitability (Hoben et al., 2011; Linquist et al., 2012; Ma et al., 2010; Millar et al., 2010; Van Groenigen et al., 2010).

Agricultural systems modeling has become a useful tool in evaluating the potential effectiveness of management practices on adaptation to and mitigation of the agroenvironmental consequences of climate change. The Root Zone Water Quality Model (RZWQM2), coupled with DSSAT (Decision Support System for Agrotechnology Transfer) crop models, is widely used to simulate crop production and NO_3-N losses through drainage under different potential management practices and weather conditions. The potential management practices which have been evaluated for Midwest sites, particularly Iowa (Ma et al., 2007a, 2007b; Saseendran et al., 2007), and include N application rate and timing (Lawlor et al., 2008; Ma et al., 2008; Qi et al., 2012), tillage (Ma et al., 2007a), drainage water management (Jaynes, 2012; Ma et al., 2007a), and planting date (Ko et al., 2012). The model has recently been evaluated using four algorithms for modeling N_2O emissions from 2003 to 2006 in Colorado, USA (Fang et al., 2015). Based on this analysis, RZWQM2 modeling of N_2O emissions was modified using algorithms from the NOE (Nitrous Oxide Emissions) and DAYCENT models.

As reduced corn N uptake leads to greater losses of NO_3-N through subsurface drainage (Wang et al., 2015), climate change adaptation and mitigation relating to corn yield and N loss are the focus of the present study. Since N fertilization rate not only directly influences corn yield but also provides a transparent and quantitative proxy for calculating N_2O emissions (Millar et al., 2010), different N fertilization rates were simulated. Further management practices to increase corn yield include selecting well-adapted corn cultivars and varying planting date (Beiragi, 2011; Van Roekel and Coulter, 2011). Tillage management (Ma et al., 2007a) and controlled drainage (Jaynes, 2012) can also influence N loss and corn yield. The current study addressed the question as to whether, in response to climate change, a sustainable balance between corn yield and N losses could be achieved by altering one or more management practices. The study's specific objectives were therefore to: (i) compare RZWQM2 simulated N_2O emissions with other observed or predicted values; 2) determine the relationship between N application rate and N_2O emissions; and 3) simulate the effect of management practices (i.e. N application rate, corn cultivars, planting date, tillage and controlled drainage management) on corn yield and N_2O emission under climate change scenarios using RZWQM2.

2. Materials and methods

2.1. Study area

The field study was located near Gilmore City in Pocahontas County, north-central Iowa. Predominant soils are Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Webster (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) clay loams with 3%–5% organic matter and with a slop of 0.5%–1.5%. The total experimental area was 3.8 ha, including 78 individual plots. Each plot was 0.05 ha with 38 in length and, 15 in width. Subsurface drain pipes were installed through the center and borders parallel to the long dimension with 7.6 m spacing and at 1.06 m depth. More details about treatments are in (Lawlor et al., 2008).

2.2. Climate data

The future climate data were obtained from the North American Regional Climate Change Assessment Program (NARCCAP, Mearns et al. (2007)). NARCCAP provides high resolution climate change simulation data allowing investigation of the uncertainty of regional scale projections of future climate and thereafter, generation of climate change scenarios for impacts assessment research (Mearns et al., 2009, 2012). Projections were generated by dynamically downscaling global climate model (GCM) output to 50-km using different regional climate models (RCM). The projections were then downscaled to Gilmore City, IA (experimental location) using the delta method (Mearns et al., 2014). The HRM3_hadcm3 simulation from NARCCAP was used for this study; that is, the simulation using the HRM3 regional model and the HADCM3 GCM (see Mearns et al., 2012 or www.narccap.ucar.edu for more details on this simulation). Only this one simulation of the twelve available NARCCAP simulations was used in this study, due to limited computational resources and the desire to focus on RZWQM2 sensitivity tests. A previous study examined multi-model sensitivities using NARCCAP data (Wang et al., 2015). In this study, the corn yield was lowest under HRM3_hadcm3 scenario due to the highest number of days exceeding 34 °C and N_2O emissions were also highest. Therefore, we chose this simulation to represent the most extreme scenario produced by the NARCCAP ensemble. NARCCAP data were chosen for use over climate change projections from various GCMs (e.g. those produced for the Coupled Model Intercomparison Project 5 – CMIP5), as the resolution of the NARCCAP data is still higher than that from most GCMs (approx. 100-km). The higher resolution often leads to better simulation of regional- and local-scale atmospheric processes (Mearns et al., 2014).

The RZWQM2 model uses daily meteorological variables as inputs (precipitation, maximum and minimum air temperature, short wave radiation, wind speed, relative humidity and CO_2). These variables are available from NARCCAP at three hourly time intervals from 1971 to 1999 for a baseline/current climate period and 2041–2069 for the future climate. However, to remove the effect of potential climate model bias on RZWQM2 simulations, the NARCCAP simulation output was aggregated into monthly means, and the monthly mean difference between the future and baseline climate periods were applied to weather station data from Gilmore City, IA using the commonly applied delta approach (Mearns et al., 2014). This study essentially perturbs observed mean climate of the location to a future scenario state. Since only the mean is adjusted, potential changes in the frequency of future weather events, which may affect the distribution of the input variables, are not considered with this method.

Observations from the Gilmore City site are only available from 1989 to 2009. This is different from the baseline period used in NARCCAP (1971–1999). Therefore, the monthly mean differences were scaled using the midpoints of the data sets by a factor of 55/70 [(2055–2000)/(2055–1985)], which also adjusts the future weather data to 2045 to 2064. CO_2 in RZWQM2 was assumed to increase to 548 ppm in 2055. The CO_2 values were drawn from values given in the IPCC online data document at http://www.ipcc-