A Model Integration Framework for Assessing Integrated Landscape Management Strategies

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Abstract. Nitrogen application is a standard practice for maximizing productivity of an agronomic system. The challenge is that many commercial scale agricultural systems are inefficient in utilizing the nitrogen that is applied. Therefore, understanding the impact of land management practices on nitrogen use inefficiencies within the agroecosystem is critical. This paper presents an integrated model that quantifies the impact of various land management practices on specific agroecosystem units. This integrated model is composed of the Wind Erosion Prediction System (WEPS), the Revised Universal Soil Loss Equation, Version 2 (RUSLE2), the Soil Condition Index (SCI), and the daily CENTURY model, DAYCENT. The integrated model was used to determine the impact of land management strategies on greenhouse gas emissions and nitrate leaching in a 60.5 ha field in Webster County, Iowa, USA. It was found that nitrogen use efficiency can vary significantly across a field and that integrated land management strategies can reduce overall nitrogen losses.

Keywords: integrated model, soil organic carbon, greenhouse gas emissions, nitrate leaching

1 Introduction

In some agricultural systems a significant amount of nitrogen fertilizer is required for the land to reach its maximum productivity potential. However, these agricultural systems are often inefficient in their utilization of the nitrogen, and much of the nitrogen is lost through greenhouse gas emissions and nitrate leaching. The U.S. Environmental Protection Agency has determined that in 2011 agricultural systems accounted for 8% of the total greenhouse gas emissions in the United States and that 69% of the total N_2O emissions were due to agricultural practices [1]. This is significant because N_2O has a global warming potential 310 times greater than CO_2. Nitrate leaching is another concern as nitrogen leaving a field through runoff or tile drainage enters river systems and migrates into open water. This is evident in the northern Gulf of Mexico where hypoxia is occurring due to increased concentrations of nitrogen delivered from the Mississippi River system [2].

adfa, p. 1, 2011.

Nitrogen losses in agroecosystems can be attributed to several factors including land management practices, crop rotation, drainage, soil organic matter levels, and climate patterns [3]. This paper presents an integrated model composed of several agronomic models for simulating environmental processes that quantify the impact of various land management practices on specific agroecosystem units. Using the integrated model the potential of integrated landscape management strategies to improve nitrogen use efficiency and mitigate nitrogen losses from the agroecosystem are examined. Two land management scenarios are assessed: 1) a traditional Midwest row cropping rotation (corn-soybean) and 2) an integrated landscape management with a corn-soybean rotation with a rye clover cover crop and switchgrass in low production areas. The study is performed using high-fidelity soil, landscape, and grain yield data for a 60.5 ha field in Webster County, Iowa, USA.

2 Integrated Model

Agronomic models provide the ability to assess a broad range of soil, climates, and land management practices. However, these models are often disparate in nature and focused on a specific environmental process. Muth and Bryden [4] addressed the challenges of integrating agronomic models through development of a model integration framework. Initial research efforts for the integrated model were focused on sustainable residue removal with models used by the US Department of Agriculture – Natural Resources Conservation Service for developing land management plans. These models include the Wind Erosion Prediction System (WEPS) [5], Revised Universal Soil Loss Equation, Version 2 (RUSLE2) [6], and the Soil Conditioning Index (SCI) [7]. The integrated model predicted sustainable residue removal rates based on wind- and water-induced soil erosion and qualitative soil organic carbon constraints. The integrated model was used to investigate sustainable residue removal at the national scale [8] and at the subfield scale [9-10].

In this paper, this integrated model has been extended to include the biogeochemical model DAYCENT [11]. The DAYCENT model quantifies exchanges of carbon and nitrogen between the soil, vegetation, and atmosphere, enabling assessment of the impacts of land management decisions on soil organic carbon, greenhouse gas emissions, and nitrate leaching.

The data flow in the integrated model is shown in Fig. 1. The model uses high-fidelity datasets including light detection and ranging (LiDAR) for slope and elevation ($0.5m^2$), grain yield data taken from a yield monitor of a combine during grain harvest ($5m^2$), and the Soil Survey Geographic (SSURGO) Database (10m – 100m). The integrated model is initialized with the selection of an agroecosystem unit and land management practice. Soil and climate data are retrieved based on the selected location. The soil, climate, and land management data are then assembled into native file formats for each of the integrated models. The WEPS model is initialized and simulated to produce wind-induced soil erosion. The RUSLE2 model is then initialized and simulated to determine the water-induced soil erosion. The soil erosion values are then passed to the SCI model and considered in determining the qualitative

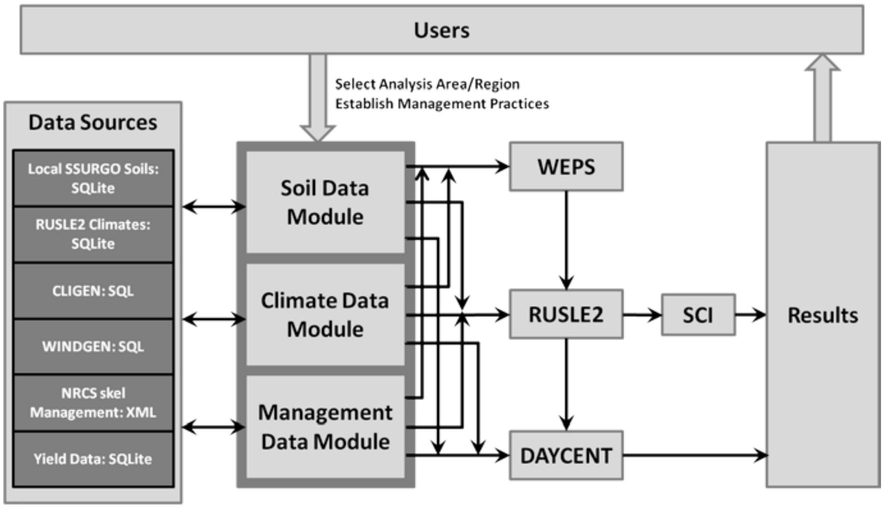

Fig. 1. Model integration framework used to assess environmental processes.

soil organic carbon value. Also considered in the SCI calculation are organic matter and field operations. The system is then determined to either be sustainable or unsustainable using total soil erosion and soil organic carbon criteria. The DAYCENT model is then initialized and simulated to predict and quantify the long-term impacts on soil organic carbon, greenhouse gas emissions, and nitrate leaching.

One of the challenges in the integrated model is using consistent yield data across all the models since WEPS and RUSLE2 use yield as an input, and DAYCENT predicts yield based on soil, climate, and land management practices. To account for this difference, a yield calibration module is utilized with DAYCENT to enable yield consistency across the integrated model. While this enables a more accurate assessment of the land management decisions, it increases the simulation time due to the parameter adjustment methodology employed by the yield calibration module and because the process occurs for each year of the simulation. The WEPS, RUSLE2, and SCI simulations are less than a minute while the DAYCENT simulation/calibration process is several minutes.

3 Methodology

3.1 Field Discretization

The differences in computational runtime between the various models impacts the fidelity the agroecosystem unit can be analyzed. The relatively quick runtime of the WEPS, RUSLE2, and SCI models enables them to be simulated at every yield data point. However, simulation of the DAYCENT model with yield calibration at every yield data point is computationally expensive. To address this challenge, a discretization methodology was developed that captures the variability of the soil, slope, and yield at a scale that is appropriate for understanding the environmental processes

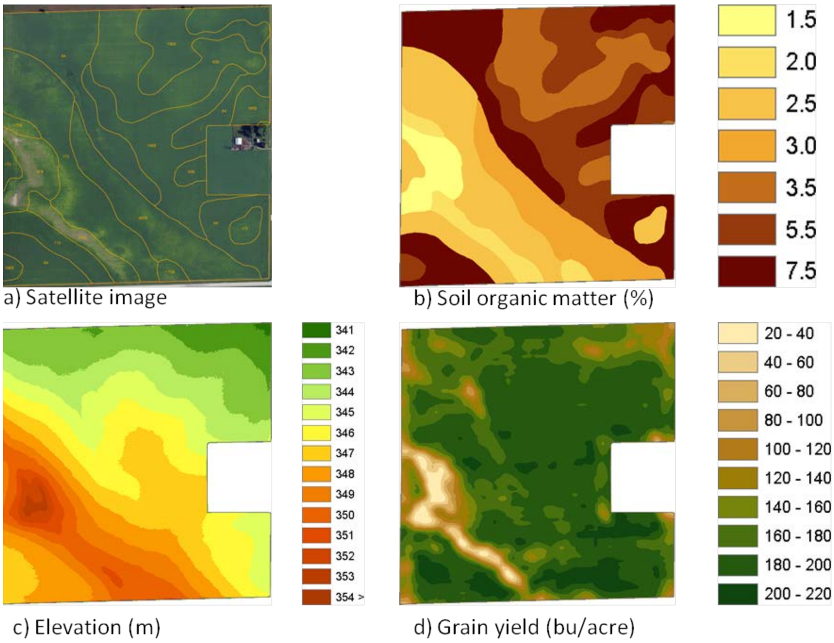

Fig. 2. Soil and grain yield characteristic for a field in Webster County, IA, USA. a) SSURGO soil map, b) soil organic matter (%), c) elevation (m), and d) grain yield (bu/acre)

while enabling utilization of the DAYCENT model. A 10 m × 10 m grid was determined to be the optimum resolution for (1) representing existing agricultural equipment used in the field and (2) aggregating the data to a level that is representative of the field.

3.2 Case Study

The integrated model was applied to a 60.5 ha field in Webster County, Iowa, USA. Fig. 2 shows the high-fidelity data utilized to assess the field. Fig. 2a shows a satellite image of the field with the SSURGO soil map overlaid. The field is composed of seven soil types. The variation in soil type is noticeable from the satellite image. Fig. 2b shows the soil organic matter levels of the various soil types found in the field. Soil organic matter retains and recycles nutrients, improves soil structure, enhances water exchange characteristics, and sustains microbial life in the soil [12] and provides an indicator of productivity [13]. Fig. 2c shows the field elevation using LiDAR data. Slope values required by the integrated model are determined using this elevation data. Fig. 2d shows the 2010 corn grain yield distribution using yield data gathered during harvest from the grain combine. More than 24,000 yield data points were taken during the 2010 grain harvest. Corn grain yield varies across the field from 1.25

Mg/ha (20 bushel/acre) on the high elevation areas to almost 15 Mg/ha (220 bushel/acre) in the lower elevation areas. The field was discretized into 6048 grid cells, as shown in Fig. 3. Grain yield and slope data points were averaged within each grid cell to generate a representative value. In addition, the dominant soil type was determined based on area coverage within the grid cell. These values were used within the integrated model by DAYCENT.

The integrated model was used to compare the impacts of two land management scenarios—a traditional Midwest row crop rotation and an integrated landscape management strategy on nitrogen use efficiency in the agroecosystem. The traditional row crop rotation is a corn-soybean rotation assuming 2010 corn grain yield and 1.48 Mg/ha soybean yield. A fertilizer application of 0.235 Mg_N/ha was applied during the spring in the corn year. A reduced tillage regime and no residue harvest are also assumed. For the integrated landscape management scenario, sections of the field with low productivity are taken out of row crop production and replaced with switchgrass. Switchgrass has been identified as a potential biomass resource for biofuel production and can potentially improve carbon sequestration, nutrient recovery from runoff, and soil remediation [14-15]. Approximately 35% of the field is converted from traditional row crops to switchgrass. The areas selected are based on the productivity of the land and the ability to manage the land with existing equipment without inconveniencing the farmer. The switchgrass stand is assumed to have a two-year establishment period followed by productive years where 80% of the biomass is harvested in the fall. Each year a fertilizer application of 0.101 Mg_N/ha is applied. The remaining area of the field still in row crop production assumes the same fertilizer application and reduced tillage with the addition of a rye clover cover crop. In addition, residue was removed from the row crop area at the highest sustainable rate. Each scenario is simulated for 10 years to compare the impacts of the two land management scenarios on nitrogen use efficiency and losses.

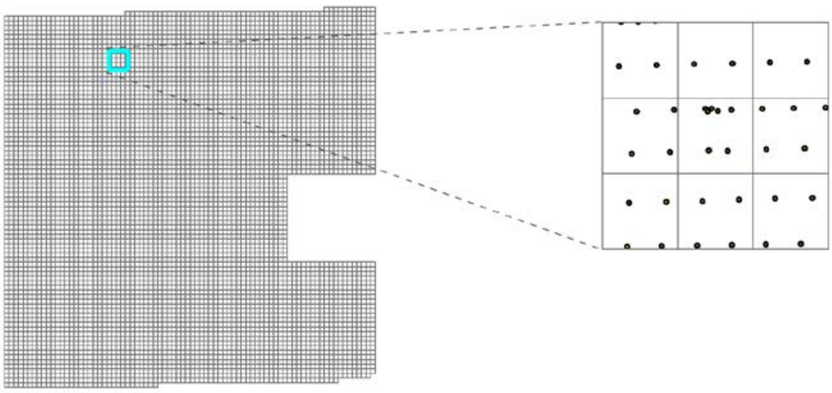

Fig. 3. Discretized field with an expanded view of a 30m x 30m section of the field with grain yield data points.

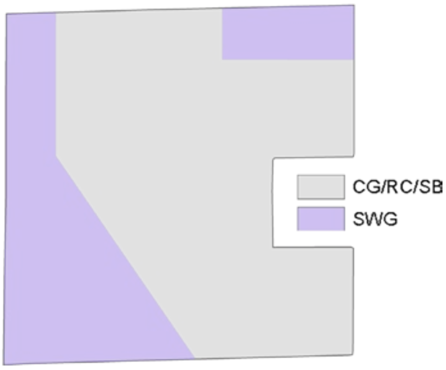

Fig. 4. Field representation of integrated landscape management

4 Results

Fig. 5 shows the losses that occur in each of the land management strategies. Fig. 5a,b show the agroecosystem unit losses due to N_2O gas fluxes. It can be seen that when calculating the N_2O flux that the integrated model is sensitive to soil texture. Soils with higher organic matter tend to have higher N_2O flux. Although crop rotation selection can reduce N_2O emissions, the general trend of higher organic matter lead-

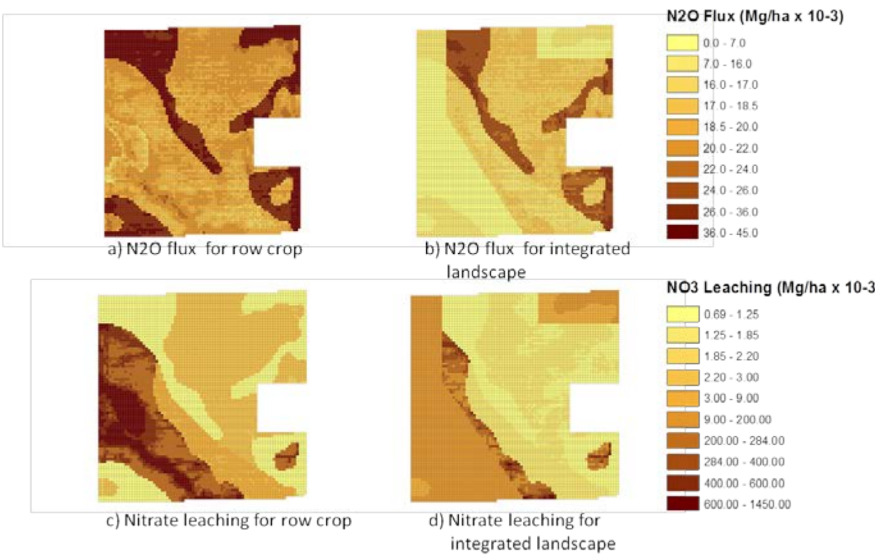

Fig. 5. Nitrogen losses for the row crop and integrated landscape managements

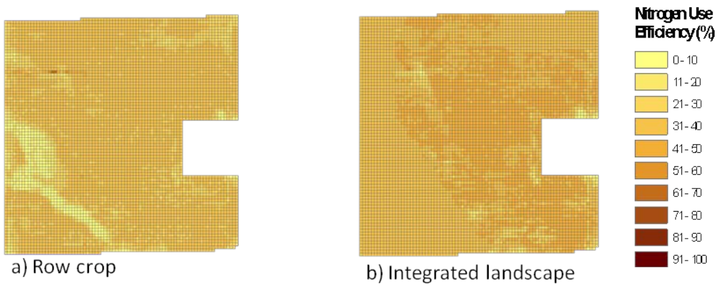

Fig. 6. Nitrogen use efficiency for the row crop and integrated landscape managements

ing to high N_2O emissions is consistent. The integrated land management strategy reduces the greenhouse gas emissions relative to the traditional row crop system from the field from 1.46 Mg_N to 0.87 Mg_N over 10 years. Fig. 5c,d show the nitrogen losses due to nitrate leaching. Implementation of switchgrass reduces total nitrate leaching relative to the traditional row crop management by 4.83 Mg_N over 10 years, a 63% decrease.

Fig. 6a and 6b show the nitrogen use efficiency in the agroecosystem unit for both land management scenarios. As shown the integrated landscape significantly increases the efficiency of nitrogen use in the low production areas. Overall, the integrated land management strategy increases nitrogen use efficiency by 6% relative to the traditional row crop scenario, reducing nitrogen losses relative to the traditional row crop scenario by 6.48 Mg_N over a ten-year period.

5 Conclusions

The integrated model was used to investigate a traditional row crop rotation and an integrated landscape management scenario in a field with diverse soil and topographical characteristics. The integrated landscape management replaced low production areas in a traditional row crop rotation with switchgrass and added a rye cover crop where the traditional row crop was maintained. The integrated landscape improved nutrient use efficiency resulting in reduced nitrogen loss from the agroecosystem unit. The integrated land management strategy reduced N_2O emissions and nitrate leaching by 40% and 63%, respectively, resulting in a net nitrogen loss reduction of 0.11 Mg_N/ha. In addition, these nitrogen losses have an economic value associated with them and as markets for energy feedstocks begin to grow, the integrated model can enable decisions towards determining land management strategies that improve the economics, environment, and total biomass production.

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