Renewable Energy 66 (2014) 454–460

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Evaluating agricultural management practices to improve the environmental footprint of corn-derived ethanol

Xiaobo Xue [a], YuLei Pang [b], Amy E. Landis [c,*]

[a] Department of Civil and Environmental Engineering, University of Pittsburgh, 3700 O'Hara Street, Pittsburgh, PA 15260, USA
[b] Department of Mathematics and Statistics, Texas Tech University, 2500 Broadway, Lubbock, TX 79401, USA
[c] School of Sustainable Engineering and the Built Environment, Arizona State University, 501 E. Tyler Mall, Tempe, AZ 85287, USA

ARTICLE INFO

Article history:
Received 13 February 2013
Accepted 27 December 2013
Available online 24 January 2014

Keywords:
Agricultural best management practices
Energy
Global warming
Eutrophication
Life cycle assessment (LCA)
Ethanol

ABSTRACT

This study examines three agriculture management practices with the aim of improving the environmental performance of corn-derived products such as bioethanol. Corn production is energy intensive and contributes to water quality degradation and global warming, thus affecting the environmental impact of corn-derived ethanol. Life Cycle Assessment (LCA) is used to quantify and compare the environmental impacts of three management strategies: tillage, fertilizer choices and the use of buffer strips to sequester nutrients. Detailed energy, carbon, nitrogen and phosphorus inventories are compiled to represent corn production scenarios within the US Corn Belt. The LCA was developed using GREET 1.8 (Greenhouse Gases, Regulated Emissions, and Energy use in Transportation) and emission factors with statistical analyses to estimate energy consumption, associated air emissions, and aqueous nutrient runoff potentials. Results show that using manure fertilizers as opposed to synthetic fertilizers requires less energy, however the use of manure generates more CH_4, N_2O, CO_2 and results in more variable concentrations of nitrogen and phosphorus leaching from farmlands. No tillage emits less greenhouse gas emissions, sequesters more soil organic carbon and slightly reduces nutrient runoff compared with conventional tillage practices. Building buffer strips of certain widths is an efficient way to reduce N and P discharge to surrounding waters with minimal effect on the energy or global warming profile. Based on the results of the LCA studies, replacing conventional tillage with no till, and installing buffer strips can improve environmental performances of corn derived ethanol.

1. Introduction

Currently, most ethanol production in the United States uses corn as the feedstock. Production of corn-based ethanol has grown from less than 3 billion gallons in 2003 to over 10 billion gallons in 2012. Increasing demands for biofuel and animal feed may continue to drive large expansion of corn farming [1]. The United States Department of Agriculture predicts corn acreage in United States will maintain more than 85 million acres till year 2018 [2]. However, corn farming is energy intensive and contributes to global warming and water quality degradation [3–8].

Modern agriculture relies on high chemical application and use of farming equipment. Fertilizers are used to increase crop yield and can potentially disrupt natural nitrogen and phosphorus cycles, resulting in hypoxia and eutrophication. Agriculture production in the Corn Belt of the US contributes the highest fluxes of nitrogen and phosphorus to the Mississippi River Basin and is considered one of primary contributors to the growing hypoxic zone in the Gulf of Mexico [9,10]. To minimize and control this hypoxic area, agriculture management practices in the Corn Belt will need to play an important role to reduce nutrient load.

Furthermore, operating farming equipment (such as tractors etc.) and producing associated chemicals rely on the combustion of fossil fuels that release green house gases and consequently influence climate change. Previous studies show that farming equipment usage and associated processes annually consume a large amount of the total fossil energy use [11]. Syntheses of commercial fertilizers are also energy demanding processes [12]. In the US, corn production uses more than 40% of the nation's commercial fertilizer (about 330 million pounds of nitrogen fertilizers), mainly in the Midwestern Corn Belt region in 2008 [13]. As corn farming increases, increased use of fertilizers and farming operations

* Corresponding author. Tel.: +1 480 965 4028; fax: +1 480 965 0557.
E-mail address: Amy.Landis@asu.edu (A.E. Landis).

0960-1481/$ – see front matter
http://dx.doi.org/10.1016/j.renene.2013.12.026

increases energy consumption and generates considerable greenhouse gases. Direct agricultural practices and indirect supporting activities lead to environmental quality impairment.

Indeed, integrating and optimizing farming practices will enable the mitigation of environmental degradation and reduce biobased products' environmental footprints [14–16]. Specifically, we focus on three agricultural management practices in this study: tillage, fertilizer type and buffer strips as possible strategies to alleviate corn derived products' environmental impacts resulting from agriculture.

Tillage is often practiced as the first step in the preparation for a soil bed to be made suitable for seed germination and seedling development. According to the amount of plow surfaces and crop residues, there are three typical tillage methods: conventional tillage, reduced tillage, and conservation tillage [17]. Conventional tillage involves plowing the entire soil surface and leaving less than 15% of crop residue to cover the soil surface after planting. Reduced tillage utilizes a chisel plow to mix soil and crop residue, leaving 15%–30% residue coverage on soil. Conservation tillage includes ridge tillage, no tillage etc. This study evaluated the environmental impacts of corn produced with conventional and no tillage practices. Compared to conventional tillage, no tillage often has more environmental advantages including surface runoff reduction and soil erosion mitigation [18]. The no tillage method uses crop residue mulch to provide a protection against raindrop impact, thereby increasing soil organic carbon and decreasing decomposition of soil organic matter and oxidization of soil organic carbon. Other possible environmental benefits include energy and emissions savings resulting from less fuel consumption for operating farming equipment and associated air emissions [19,20].

The choice of fertilizer types can affect the energy profile, greenhouse gas emissions, and aqueous emissions attributed to the environmental footprint of agricultural products [21,22]. Both synthetic fertilizers and animal manures are used to enrich soil nutrition within Corn Belt agriculture [23]. Compared to manures, most commercial synthetic fertilizers contain higher nutrient concentrations by weight, more appropriate nutrient ratios (i.e. N:P:K ratios), and are more readily available to crops when applied to the soil. High gaseous carbon and nitrogen fluxes that result from handling and applying manures are concerns for the use of manure as a source of fertilizer [24,25]. However, manure has the potential to adjust the soil carbon cycle and maintain soil fertility. Reusing manures, which are usually waste products of animal raising systems, is often explored as an economic and sustainable alternative to synthetic fertilizers [16,26].

Establishment of buffer strips is used as an important component of integrated farming nutrient management plans [27–29]. Installing riparian buffer zones is a recognized agroforestry practice that not only provides phytoremediation for nonpoint source pollutants but also increases biodiversity of terrestrial ecosystems. It can also moderate flood damage, control nutrient leaching, sequester carbon, and recharge groundwater. Riparian zones generally consist of two types: grass strips and wooded buffers. Woody vegetated strips can include shrubs and have advantages in controlling bank erosion and providing biological abundance, while grass strips might be more acceptable in keeping with the original character of the landscape. Both woody vegetation and grass strips can uptake of nutrients to improve water quality [30–32].

Alternative agricultural management strategies have been studied widely in the agricultural literature, primarily focusing on narrow aspects of agriculture management, such as their effects on yields, nutrient leaching etc. However, the overall environmental impacts from agriculture and related management strategies, and thus their implications on the environmental footprint of bioproducts have not been explored adequately. With the growth of biofuels and biobased products, Life Cycle Assessments (LCAs) applied to agricultural activities can be a useful method to quantify environmental impacts. LCA is a systematic approach to analyze and quantify the environmental impacts of a product or process over its entire life cycle. Comparative LCAs among possible products or processes can help to determine the environmentally preferable alternative. Guidelines for performing LCAs are delineated by American National Standards Institute (ANSI) and International Organization of Standardization's (ISO) 14040 series [33,34]. LCA is an iterative four-stage process including goal and scope definitions, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation. Currently, agricultural LCAs have been mainly carried out for either single crops or individual production processes [3,35–39]. The comparative analysis of farming practices, which is important to identify environmentally preferred practices and reduce negative environmental impacts resulting from corn farming, is still lacking from life cycle perspectives.

This study aims to quantify energy consumption, air emissions, and aqueous nutrient emissions under different corn farming management scenarios. The inventory includes global warming emissions, aqueous nutrients (N, P) and energy usage. Comparative LCA results of the three farming practices discussed above are presented. Moreover, this article provides detailed and comparative analysis of environmental impacts to identify farming practices that improve environmental performances of corn derived ethanol.

2. Materials and methods

2.1. System boundary

The agricultural system boundary, material and energy flows accounted for in the LCA are depicted in Fig. 1. The system boundaries include on-field production practices (tillage practices and fertilizer application), integrated farming practices (buffer strips), associated equipment and chemical manufacturing, transportation processes, and also power generation. Energy usage, atmospheric and aqueous emissions are calculated during every stage.

Geographically, this system reflects the farming scenarios in US Corn Belt states, which produced more than 75% of total U.S. corn in 2008. US Corn Belt states include Iowa, Illinois, Nebraska, Minnesota, Indiana, Ohio, South Dakota, Wisconsin, and Missouri. Data was collected from literature that included experimental data, on-field survey data, and geological modeling estimation results between 1990 and 2007.

2.2. Models

A description of the models used to develop the LCI is discussed in this section. Energy flows and associated EPA criteria air emissions are calculated with GREET 1.8 (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model while nutrient outputs are estimated through the development of LCA models using emission factors. Variability of agricultural systems is accounted for using statistical analyses and Monte Carlo Analysis (MCA).

2.2.1. GREET 1.8 model

GREET 1.8 was developed by Argonne National Laboratories and was utilized within this study to compile an LCI of on-farm and upstream energy use and air emissions. GREET consists of a comprehensive spreadsheet-based database that calculates energy consumption and emissions of criteria air pollutants (VOC, carbon monoxide, nitrogen oxides, particular matter, sulfur oxides, carbon