# Global Warming Potential and Eutrophication Potential of Biofuel Feedstock Crops Produced in Florida, Measured Under Different Scenarios

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## ABSTRACT

The agriculture sector is in a growing need to develop greenhouse gas (GHG) mitigation techniques to reduce the enhanced greenhouse effect. The challenge to the sector is not only to reduce net emissions but also increase production to meet growing demands for food, fiber, and biofuel. This study focuses on the changes in the GHG balance of three biofuel feedstock (biofuel sugarcane, energycane and sweet sorghum) considering changes caused by the adoption of conservationist practices such as reduced tillage, use of controlled-release fertilizers or when cultivation areas are converted from burned harvest to green harvest. Based on the Intergovernmental Panel on Climate Change (IPCC) (2006) balance and the Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) characterization factors published by the EPA, the annual emission balance includes use energy (diesel and electricity), equipment, and ancillary materials, according to the mean annual consumption of supplies per hectare. The total amounts of GWP were 2740, 1791, and 1910 kg $CO_2$e $ha^{-1}$ $y^{-1}$ for biofuel sugarcane, energycane and sweet sorghum, respectively, when produce with conventional tillage and sugarcane was burned prior to harvesting. Applying reduced tillage practices, the GHG emissions reduced on 13% for biofuel sugarcane, 23% for energycane and 8% for sweet sorghum. A similar decrease occurs when a controlled-release fertilizer practice is adopted, which helps reduce the total emission balance in 5%, 12% and 19% for biofuel sugarcane, energycane and sweet sorghum, respectively and a 31% average reduction in eutrophication potential . Moreover, the GHG emissions for biofuel sugarcane, with the adoption of green harvest, would result in a smaller GHG balance of 1924 kg $CO_2$e $ha^{-1}$ $y^{-1}$, providing an effect strategy for GHG mitigation while still providing a profitable yield in Florida.

Keywords: Sugarcane, energycane, sweet sorghum, ethanol production, global warming, inventory, mitigation, reduced tillage, controlled-release fertilizer, green harvest

## 1. INTRODUCTION

Climate change accelerated by the greenhouse gas (GHG) emissions and its effects like increased frequency and severity of extreme events and different patterns in weather and water distribution, could affect food and fiber production in several ways (Godfray *et al.*, 2011). As a result, new studies have focused on the adaptation of production systems to reduce the negative impacts associated with climate change. Especial efforts have been made to develop alternative sustainable energy sources (Lisboa et al., 2011). Replacing fossil fuels with biofuels derived from agricultural crops could mitigate the greenhouse effect by reducing GHG emissions; reductions of up to 85% have been observed in some cases (Boorjesson, 2009).

Crop-derived first-generation biofuels are becoming important biomass energy sources. For instance, they account for a proportion of liquid fuel, Several previous studies have been based on a life cycle assessment (LCA) of energy crops, including maize (Zea mays), soybean (Glycine max), wheat (Triticum aestivum), sugarcane (Saccharum officinarum) and. sugar beet (Beta vulgaris L. subsp. vulgaris) and , and sorghum (Sorghum bicolor (L.) Moench) and. These studies have shown the effects of bioethanol on the reduction of the environmental impact of factors such as GHG emissions and fossil energy consumption. Meanwhile, energy crop production for bioethanol has recently come into question with respect to its sustainability and influence on food crops. Overall, biofuels have a limited capacity to resolve energy problems unless some changes are made to increase their production and reduce their GHG emission contribution. Then, he challenge to the agricultural sector is to reduce net emissions and at the same time to increase feedstock production to meet growing demands for food, fiber, and biofuel.

A large number of different activities can contribute to other emissions that cause problems other than the greenhouse effect, such as eutrophication. $N_2O$ emissions from agricultural lands range from fertilizer application to methods of irrigation and tillage.

Flessa et al. (2002) reported that a conversion from conventional to organic farming resulted in reduced emissions per hectare of farm and field area, contributing to the reduction of greenhouse gas (GHG) emissions from agriculture.

In 2010, greenhouse gas emissions from agriculture accounted for approximately 7% of total U.S. greenhouse gas emissions. Greenhouse gas emissions from agriculture have increased by approximately 13% since 1990. The biggest driver for this increase has been the 51% growth in combined CH4 and N2O emissions from livestock manure management systems, reflecting the increased use of emission-intensive liquid systems over this time period. Emissions from other agricultural sources have either remained flat or increased by a relatively small amount since 1990.

The adoption of conservationist management practices would result in significant changes in the GHG balance due to the reduced consumption of diesel fuel in mobile sources and due to increases in soil carbon stock (Bayer & Mielniczuk, 1997). Moreover, it has been argued that when crop rotation is adopted, N-fixing crops (leguminous) could help reduce soil $N_2O$ emissions (Urquiaga et al., 2010). Due to the need to adapt existing productive systems to reduce their impact on GHG emissions, our challenge is to propose new alternatives that would result in a lower GHG emission balance. Thus, there is no universally applicable list of mitigation practices; instead, the proposed practices will need to be evaluated according to the specific climatic conditions, edaphic characteristics, social context, and historical land use and management of individual agricultural systems (IPCC, 2007b).

Several studies have shown the potential for improvements in the environmental efficiency of energy crop cultivation, and LCA has been applied to assess the improvements in energy crops. However, in these studies, the analyses of the improvements were of a broad scope. Thus, an in-depth assessment of the feasibility and practicality of improvement is necessary for an appropriate evaluation of the first-generation biofuels. There are few similar studies that have used an LCA to assess the potential for improvement in crop cultivation. The difficulty in assessing crop cultivation is attributable to the variability of the results of different studies, as most biofuel production studies that have focused on energy balance and GHG emission show a wide variety of results. According to Whitaker (2010), there are 3 sources of variability in the LCAs of energy crop production. The first is the diversity of agricultural processes and material inputs; this diversity is dependent on location, which determines the climatic and edaphic factors of cultivation.

Florida is one of the largest producers of sugarcane in the U.S. In 2009 it produced 13.3 million tons of sugarcane, harvested on 156,613 hectares, representing 46.6% of the total national production and 44.3% of the total land area dedicated to sugarcane in the U.S. (Hilliard *et al.*, 2012). To know the contribution of sugarcane biofuel production to the emission of greenhouse gases is thus important. Estimation of the greenhouse gas emissions, otherwise known as the carbon footprint, is an essential part of any sustainability study.

Previous studies show a range of CFP values for sugarcane production, for example de Figueiredo *et al.* (2010), show a value of 0.027 kg $CO_2e\ kg^{-1}$ for sugarcane produced in southern Brazil; Yuttitham *et al.* (2011) report a value of 0.49 kg $CO_2e\ kg^{-1}$ for sugarcane produced in eastern Thailand; and Murphy *et al.* (2010) report a CFP value of 0.047 kg $CO_2e\ kg^{-1}\ y^{-1}$ for the entire United States.

The objective of this study was to estimate the global warming potential (GWP) and eutrophication potential (EP) balance resulting from alternative scenarios of biofuel sugarcane, energycane and sweet sorghum produced in mineral soils in Florida and identify which production system would result in a smaller GWP and EP emissions balance. The study focused on estimating emissions in four production scenarios, including a production with conventional tillage (scenario 1), reduced tillage associated with conventional pre-harvest burning (scenario 2), controlled-release fertilizer associated with conventional tillage and pre-harvest burning and green harvest associated with conventional tillage (scenario 4).

# 2. MATERIALS AND METHODS

## 2.1. Study site and biofuel feedstock cultivation

Our research considers emissions from the production activities of three biofuel feedstock: sugarcane (*Saccharum officinarum* L.), energycane a cross of commercial sugarcane (*Saccharum officinarum* L.) with *Saccharum spontaneum* L. and sweet sorghum [*Sorghum bicolor* (L.) *Moench*] cultivated in mineral soil in the Everglades Agricultural Area (EAA) of Florida. The data used in our study were obtained primarily from enterprise budgets published by the Institute of Food and Agricultural Sciences at the University of Florida (UF/IFAS) for the cropping years 2007/2008 and 2009/2010 for biofuel sugarcane (José Álvarez & Zane R Helsel, 2011; Roka *et al.*, 2009) , 2008/2009 for energycane (José Álvarez & Zane R. Helsel, 2011) and 2009/2010 for sweet sorghum (Helsel & Alvarez, 2011). The estimated area for sugarcane cultivation in Florida during 2009 was 156,613 hectares, which represents 46.6% of the total sugarcane planted in the United States (Hilliard *et al.*, 2012). At present, there is no significant commercial production of sweet sorghum in the EAA, but grain sorghum and forage sorghums for silage are produced in other parts of Florida (Helsel & Alvarez, 2011). Energycane has been grown for cellulosic ethanol production as an experimental crop in the north of Lake Okeechobee in Highlands County near the Brighton Indian Reservation.

The basis for performing the LCA and estimating the global warming potential (GWP) and eutrophication potential (EP) in this study were the practices commonly performed for cultivation of the three biofuel crops in the EAA. Sugarcane and energycane are planted between August and January and harvested at yearly intervals from October to April, and farmers generally keep four years harvest for sugarcane (one year plant crop and three ratoon crops) and six years harvest for energycane (one year plant crop and five ratoon crops). Sweet sorghum is a summer annual crop that if planted by May or earlier can produce a harvestable ratoon crop.

During the production process, for any of the three biofuel feedstock considered in this study, several pieces of equipment are used (disc harrows, laser level, combine harvester, etc.), also soil conditioners such as calcium silicate slag and agricultural lime are usually applied during land preparation together with chemical fertilizers (N, P, and K) that are applied only once as a composite fertilizer. Cropping fields in the EAA of Florida are irrigated and drained by subirrigation (seepage irrigation) and open ditch drainage. Subirrigation is defined as supplying water to the crop root zones by controlling the water table (Lang *et al.*, 2002). Herbicide and insecticide are applied three times per crop to control weeds and insects.

## 2.2. System boundaries

The GWP and EP were estimated based on the results obtained from the LCA of biofuel sugarcane, energycane and sweet sorghum produced in mineral (sandy) soils. Four stages of the life cycle of each biofuel feedstock were considered in this study, i.e. land preparation, planting, crop management, and harvesting. The system boundaries covered GWP and EP from raw materials used for cultivation, and from land preparation to harvesting (**Error! Reference source not found.**). Therefore, the results presented in this study include carbon dioxide equivalents ($CO_2$ e) and nitrogen equivalents (N-e) emissions from raw material preparation up to the biofuel feedstock produced and left in the field (consistent with the "cradle to gate" approach) (ISO, 2009).

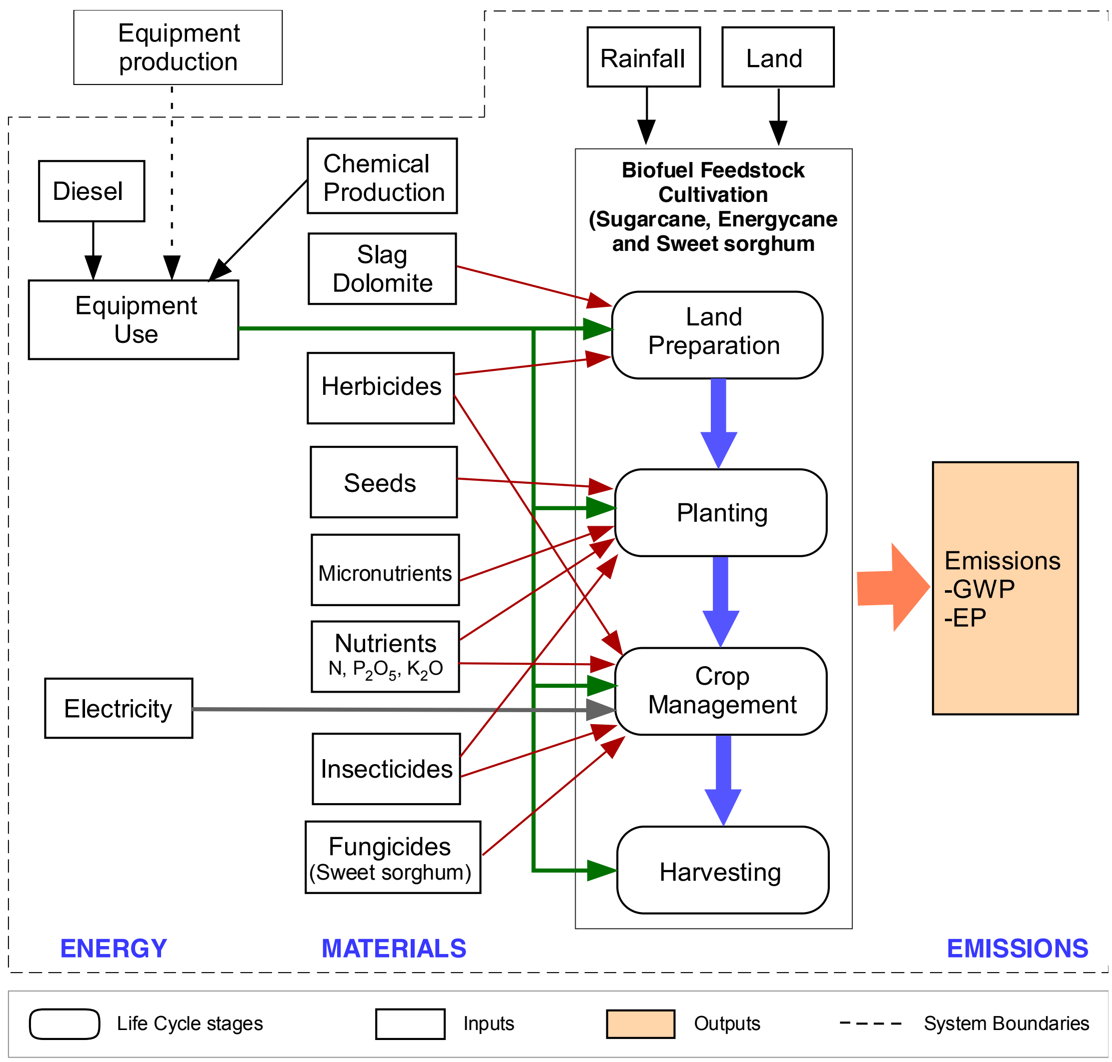


**Figure 1. The above diagram shows the system boundaries and a simplified process flow for each of the biofuel feedstock (sugarcane, energycane and sweet sorghum) life cycles, which includes land preparation, planting, crop management, and harvesting.**

## 2.3. Functional units

The functional unit, to which all inputs and outputs of analysis are related, to allow pollution emissions estimation for our study, for the GWP were defined as kilograms of carbon dioxide equivalents per hectare of biofuel feedstock produced per year (kg $CO_2$e $ha^{-1}y^{-1}$) and for the EP were defined as kilograms of nitrogen equivalents per hectare of biofuel feedstock produced per year (kg N-e $ha^{-1}y^{-1}$). The greenhouse gases considered for the GWP are carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). Each gas is converted into a $CO_2$ equivalent value using a specialized LCA software that uses GWP from the latest IPCC 100-year time horizon equivalent factors ($CO_2$, $CH_4$, and $N_2O$ having GWP of 1, 25 and 298, respectively). The gases considered for the EP are nitrogen oxides ($NO_x$), ammonium ($NH_4^+$), nitrogen N, phosphate ($PO_4^{3-}$), phosphorus (P), and chemical oxygen demand (COD). In a similar way than for GWP, to estimate EP, each gas is converted into a N equivalent value using a specialized LCA software (IPCC, 2006; PE International, 2012).

## 2.4. Estimate of pollution emissions

In our study we assume that at any given time each of the biofuel feedstock plantations are divided into separate areas representing different stages in their biological life cycle during the same year. For biofuel sugarcane, approximately one fourth of the land is in fallow (i.e. no sugarcane or any other crop growing); and it is the area where the land preparation takes place. Another one fourth of the land area is planted with seed cane to produce both biofuel sugarcane and additional seed cane. This area represents the plant cane crop. The remaining half portion of the land is used to grow ratoon or stubble crops. Ratoon or stubble are cane plants that have re-grown from previous cane plantings and represents second, third, or fourth ratoons (Roka *et al.*, 2009; Salassi & Deliberto, 2009). For energycane, the total net area is equally distributed in seven parts: one seventh for fallow land (i.e. no crop growing), one seventh with new energycane planted and the remaining five sevenths with ratoon crops. For sweet sorghum, it is assumed that it is ratooned for an additional crop during the year; therefore, land preparation and planting are considered for one hectare but crop management and harvest for two hectares.

### 2.4.1. Scenarios description

***Scenario 1 – Business as usual***

GWP and EP emissions for the three biofuel feedstock studied were estimated based on the information collected from the growers and published in cost and returns reports (José Álvarez & Zane R Helsel, 2011; José Álvarez & Zane R. Helsel, 2011; Helsel & Alvarez, 2011; Roka *et al.*, 2009). Our analyses included the production and use of energy (diesel and electricity), the utilization of equipment, the production and application of fertilizers, herbicides, fungicides and insecticides, and in the case of biofuel sugarcane, the pre-harvesting biomass burning.

Biofuel sugarcane in Florida is burned prior to harvesting since the practice, reduces harvest cost, and facilitates subsequent land preparation. According to the Intergovernmental Panel on Climate Change (IPCC, 2006), the amount of emissions depends on the volume of burned biomass, the combustion factor, and the emission factor, which is the amount of a given gas released by a unit amount of combusted biomass. Estimation of GHG emissions due to burning was included in our model based on the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) using the following equation:

$$L_{fire} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$$

Where $L_{fire}$ is the amount of GHG emissions from fire (tones of each: $CO_2$, CO, $CH_4$, $N_2O$, and $NO_X$); A represents the area burned (ha); $M_B$ is the biomass available for combustion (Mt $ha^{-1}$); $C_f$ is the combustion factor (dimensionless) and $G_{ef}$ is the emission factor, expressed in g $kg^{-1}$ of biomass burned, taken from Andreae and Merlet (2001) and also used in the IPCC guidelines. Carbon monoxide and VOCs are expected to be quickly converted to $CO_2$, and its associated carbon will be reabsorbed in the next growth cycle of the sugarcane crop. Therefore, the net contribution to greenhouse gases for these three gases is assumed to be zero (Murphy *et al.*, 2010). $CO_2$ emissions from biomass burning were not accounted for because it was assumed that $CO_2$ is re-absorbed when sugarcane plants are regrown in the next cropping season. Also, diesel used during fertilizers and pesticides application, tillage, and irrigation was included as energy expenditure.

### *Scenario 2 – Reduced tillage*

Weed's control, ruts caused by harvest elimination, elimination of residue from the previous crop, and fertilizer incorporation for biofuel feedstocks production are achieved using tillage. In a previous study (Izursa *et al.*, 2013) we observed that to produce biofuel sugarcane in mineral and organic soils the use of equipment during tillage is one the most important source of emissions. Although, some form of reduced tillage has been implemented in most agronomic crops, sugarcane growers (and for the purpose of our study energycane and sweet sorghum growers) due to concerns over negative effect on crop growth and on weed control have been slow to adopt reduced tillage practices (Wilson E Judice *et al.*, 2006). The assumption for this scenario is to model a reduced use of equipment for all three biofuel feedstock crops.

### *Scenario 3 – Controlled-release Nitrogen*

To model our third scenario we consider the use of slow-release N fertilizers instead of the conventional one. We are considering this approach because it has been considered, lately, that there is a fundamental flaw in how N fertilizer is applied. Farmers don't apply N as the crop needs it. Also, in some cases, applying all N during land preparation does not result in optimal use of N and because of the excessive amount applied is subject to environmental losses. These losses, by volatilization, denitrification, leaching, and/or runoff are in part responsible for the water and soil eutrophication.

Considering the use of controlled-released nitrogen fertilizers, we modeled biofuel feedstock production with the use of 2/3 of the traditional amount for either biofuel sugarcane or energycane and one half of the traditional amount for sweet sorghum, keeping all the other inputs like in the business as usual scenario.

### *Scenario 4 – Green harvesting*

Traditionally, biofuel sugarcane in Florida is burn before harvesting to remove leaves, weeds and other trash which impede harvesting and milling. However, according to Gilbert *et al.* (2010) there is a generalized pressure on the sugarcane industry to implement green cane harvesting systems. Green cane harvesting allows the farmers to recycle nitrogen in the plant by leaving trash cuttings from harvesting in the field. In our study, we consider this scenario for the biofuel sugarcane since burning prior harvesting is practiced only for this crop. All the operations during land preparation, planting and crop management remain the same as in our business as usual scenario but in the harvesting phase we eliminate the pre-harvest burning.

The impact potentials for all the scenarios were calculated using TRACI (Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts) characterization factors published by the U.S. Environmental Protection Agency (Bare, 2011). Since the soils are being cultivated for several years, the emissions from land use change to biofuel sugarcane were not considered in this study. Biofuel sugarcane yield for the purpose of our study was presumed to be left on the field, in loader containers.

In cases where primary data were not available, secondary data from literature and previous LCA studies were used. To model the environmental emissions of ancillary processes, existing datasets were used for the analysis (PE International, 2012).

# 3. Results

## 3.1. General characteristics of the biofuel feedstock crops

The amount of energy (diesel and electricity) and ancillary materials utilized and the amount of other resource inputs during the production operations of biofuel feedstocks and for the different scenarios are shown in **Error! Reference source not found.**. The average yields for each crop were 69,000; 66,000; and 45,000 kg $ha^{-1}y^{-1}$ for biofuel sugarcane, energy cane and sweet sorghum, respectively.

**Table 1. Some characteristics of biofuel sugarcane production in mineral and organic soils in Florida**

| Characteristics | Biofuel feedstock | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Biofuel Sugarcane | | | | Energycane | | | | Sweet sorghum | | | |
| | Scenario 1 Business as usual | Scenario 2 Reduced tillage | Scenario 3 Control-release N | Scenario 4 Green harvest | Scenario 1 Business as usual | Scenario 2 Reduced tillage | Scenario 3 Control-release N | Scenario 4 Green harvest | Scenario 1 Business as usual | Scenario 2 Reduced tillage | Scenario 3 Control-release N | Scenario 4 Green harvest |
| **Diesel for machine use (L $ha^{-1}$)** | | | | | | | | | | | | |
| Land Preparation | 115 | 71 | 115 | 115 | 115 | 71 | 115 | 115 | 42 | 28 | 42 | 42 |
| Planting | 164 | 89 | 164 | 164 | 164 | 89 | 164 | 164 | 45 | 23 | 45 | 45 |
| Crop Management | 289 | 182 | 289 | 289 | 289 | 182 | 289 | 289 | 137 | 105 | 137 | 137 |
| Harvesting | 89 | 88 | 89 | 89 | 89 | 88 | 89 | 89 | 76 | 62 | 76 | 76 |
| **Electricity (kWh $ha^{-1}$)** | 118 | 118 | 118 | 118 | 118 | 118 | 118 | 118 | 118 | 118 | 118 | 118 |
| **Soil conditioners (kg $ha^{-1}$)** | | | | | | | | | | | | |
| Calcium Silicate Slag | 3,363 | 3,363 | 3,363 | 3,363 | 3,363 | 3,363 | 3,363 | 3,363 | 0 | 0 | 0 | 0 |
| Dolomite | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 | 2,242 |
| **Synthetic fertilizers (kg $ha^{-1}$)** | | | | | | | | | | | | |
| Nitrogen (N) | 207 | 207 | 138 | 207 | 207 | 207 | 138 | 207 | 202 | 202 | 101 | 202 |
| Phosphate ($P_2O_5$) | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 135 | 135 | 135 | 135 |
| Potash ($K_2O$) | 214 | 214 | 214 | 214 | 214 | 214 | 214 | 214 | 202 | 202 | 202 | 202 |
| Micronutrients | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 34 | 34 | 34 | 34 |
| **Pesticides (kg $ha^{-1}$)** | | | | | | | | | | | | |
| Herbicides | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 11.7 | 11.7 | 11.7 | 11.7 |
| Insecticide | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 11 | 11 | 11 | 11 |
| Fungicides | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.24 | 2.24 | 2.24 | 2.24 |
| **Pre-harvest burn (%)** | 75 | 0 | 75 | 75 | 0 | 0 | 75 | 0 | 0 | 0 | 0 | 0 |

Energy required for irrigation pumps were diesel and electricity. The average irrigation rate in this region, for each feedstock crop was 7,290 $m^3$ $ha^{-1}$ $y^{-1}$.

## 3.2. Contributions of Global Warming and Eutrophication Potentials

### 3.2.1. GWP in a "Business as usual" scenario

GHG emissions, expressed as GWP from use of equipment for production of biofuel feedstock crops in mineral soils are one of the largest contributors. Although sweet sorghum does not require as much use of equipment to produce one hectare, it shows a higher number because it is produced two times during one crop year, hence equipment is used more times for crop management and harvesting. (Figure 2). In all three crops, almost half of the emissions for equipment use correspond to crop management (40% for sweet sorghum, 59 for energycane and 55% for sugarcane) because most of the crop management activities are performed during this phase.

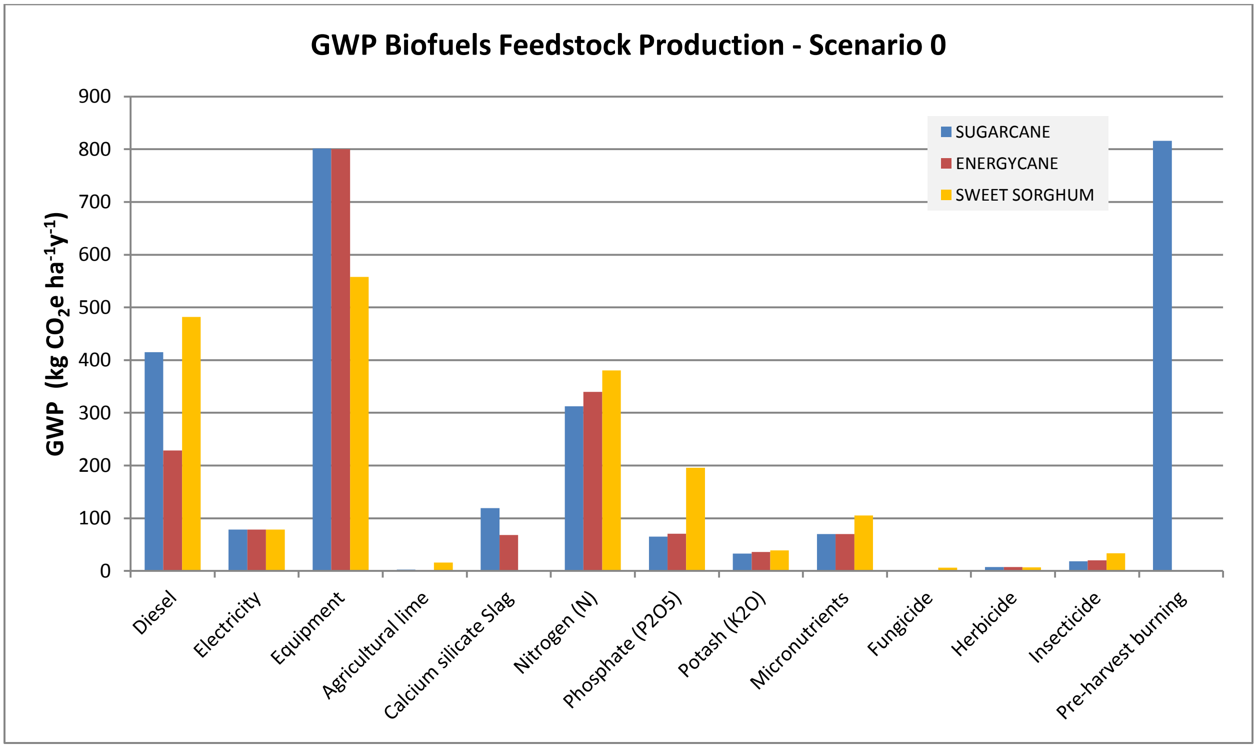


**Figure 2. GWP from biofuel feedstock (sugarcane, energycane and sweet sorghum) produced in mineral soils in Florida. Scenario 1, "business as usual", expressed in kilograms of dioxide equivalents per hectare**

According to the enterprise budgets, two soil conditioners (carbon silicate slag and agricultural lime) are used to produce biofuel sugarcane, energycane and sweet sorghum in Florida. In the case of Sweet sorghum, calcium silicate is not used. Soil conditioners are applied during land preparation and for the amount to be applied it is advised to follow the soil tests' recommendations. For our study we consider the average amounts of 3,363 kg $ha^{-1}$ $y^{-1}$ and 2,242 kg $ha^{-1}$ $y^{-1}$ for slag and agricultural lime, respectively (**Error! Reference source not found.**). GWP emissions from the use of soil conditioners add 121.8 kg $CO_2e$ $ha^{-1}$ $y^{-1}$ for biofuel sugarcane, 69.6 kg $CO_2e$ $ha^{-1}$ $y^{-1}$ for energycane and 15.6 kg $CO_2e$ $ha^{-1}$ $y^{-1}$ for sweet sorghum.

The fertilizers applied during biofuel feedstock crops production are nitrogen (N), phosphate ($P_2O_5$), potash ($K_2O$), and micronutrients. According to Rice and Gilbert (2006), Florida soils are deficient in some micro-elements: boron (B), copper (Cu), iron (Fe), manganese (Mn), silicon (Si), and zinc (Zn). The amounts of fertilizers we used in our study are the ones recommended in the enterprise budgets: 207 kg ha$^{-1}$ of N, 56 kg ha$^{-1}$ of $P_2O_5$, 214 kg ha$^{-1}$ of $K_2O$, and 95 kg ha$^{-1}$ of micronutrients for biofuel sugarcane and energycane and 202 kg ha$^{-1}$ of N, 135 kg ha$^{-1}$ of $P_2O_5$, 202 kg ha$^{-1}$ of $K_2O$, and 33.6 kg ha$^{-1}$ of micronutrients for sweet sorghum (**Error! Reference source not found.**). For an approximate amount of each element in the micronutrients mixture, we used a recommendation from the Tamil Nadu Agricultural University in its Agritech Portal (2008).

As a result, the GWP emissions from N, P, and K were estimated at 410 kg $CO_2$e ha$^{-1}$ y$^{-1}$ for biofuel sugarcane, 446 kg $CO_2$e ha$^{-1}$ y$^{-1}$ for energycane and 615 kg $CO_2$e ha$^{-1}$ y$^{-1}$ from sweet sorghum production. GWP emissions from micronutrients, were 70 kg $CO_2$e ha$^{-1}$ y$^{-1}$ from biofuel sugarcane, 70 kg $CO_2$e ha$^{-1}$ y$^{-1}$ from energycane and 105 kg $CO_2$e ha$^{-1}$ y$^{-1}$ from sweet sorghum production.

According to our data sources, two pre-emergence herbicides, two post-emergence herbicides, and one insecticide are reported as being used to produce each of the biofuel feedstock. Funcide is also used for sweet sorghum. Herbicides are mainly applied when land is being prepared and during crop management activities. During this last phase, insecticide and fungicide are also applied.

GWP emissions from pesticides (herbicides, insecticides and fungicides combined) were estimated at 26, 28 and 46 kg $CO_2$e ha$^{-1}$ y$^{-1}$ during the production of biofuel sugarcane, energycane and sweet sorghum, respectively. To help reducing emissions from pesticides' applications, alternative management strategies should be used, for example, apply them only when protection or control are necessary; also, the pesticide selected should be the most effective that ensures a proper control of the problem and the least potential adverse effects to the environment.

From the three biofuel feedstock crop used in our study, pre-harvest burning occurs in Florida only when biofuel sugarcane is produced. Considering the fraction of area to be harvested (0.75 ha – section 2.4) and the amount of biomass burned, it was estimated that the total GWP emissions are 816 kg $CO_2$e ha$^{-1}$ y$^{-1}$. Pre-harvest burning represents 30% of total greenhouse gas emissions for biofuel sugarcane produced in Florida.

### 3.2.2. Contribution of GWP when reduced tillage is applied (Scenario 2)

Because a large part of the GWP emissions come from use of equipment, we explored an alternative, modeling a scenario considering that reduced tillage is practiced. This practice, also recommended as part of a conservation management system, helps to reduce erosion, maintains and/or improves soil organic matter, conserves soil moisture and improves overall soil health.

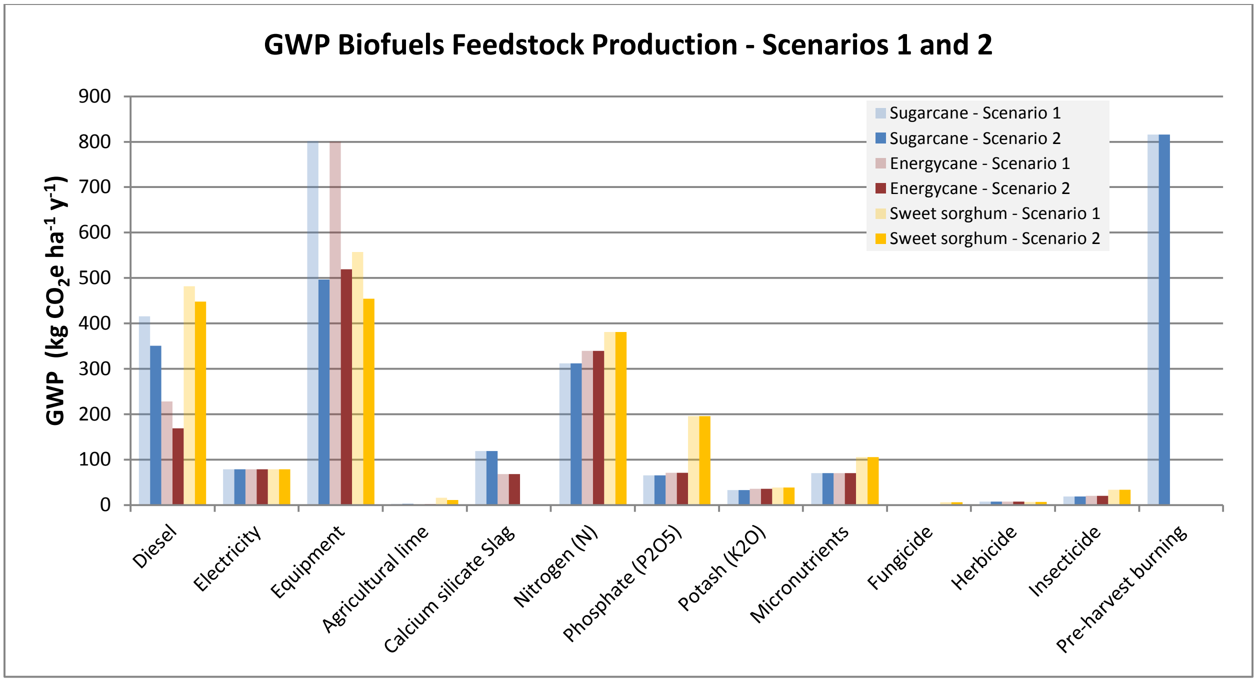


**Figure 3. GWP from biofuel feedstock (sugarcane, energycane and sweet sorghum) produced in mineral soils in Florida. Comparison of scenario 2 "reduced tillage" versus scenario 1 "business as usual" (faded colors), expressed in kilograms of dioxide equivalents per hectare per year**

To apply the reduced tillage scenario in our model, instead of the 657 liters ha$^{-1}$ y$^{-1}$ used to produce biofuel an energycane and the 300 liters ha$^{-1}$ y$^{-1}$ used during sweet sorghum production under a business as usual scenario, we assumed the use of 430 liters ha$^{-1}$ y$^{-1}$ for biofuel sugarcane and energycane, each and 217 liters ha$^{-1}$ y$^{-1}$ for sweet sorghum (**Error! Reference source not found.**).

As a result, we observe that there are some differences in the GWP emissions, only from the use of diesel and equipment. Emissions from diesel are now 351, 169, and 448 kg $CO_2$e ha$^{-1}$ y$^{-1}$ for biofuel sugarcane, energycane and sweet sorghum, respectively; which in average are 16% less than the emissions from diesel in the business as usual scenario.

The largest difference comparing scenarios 1 and 2 are from the emissions of equipment use. Emissions are 31% lower when applying reduced tillage: 496, 519 and 454 kg $CO_2$e ha$^{-1}$ y$^{-1}$ for biofuel sugarcane, energycane and sweet sorghum (Figure 3).

### 3.2.3. Contribution of EP when controlled-release nitrogen is applied

Results from modeling our assumption that controlled-release nitrogen is used can be seen in Figure 4.

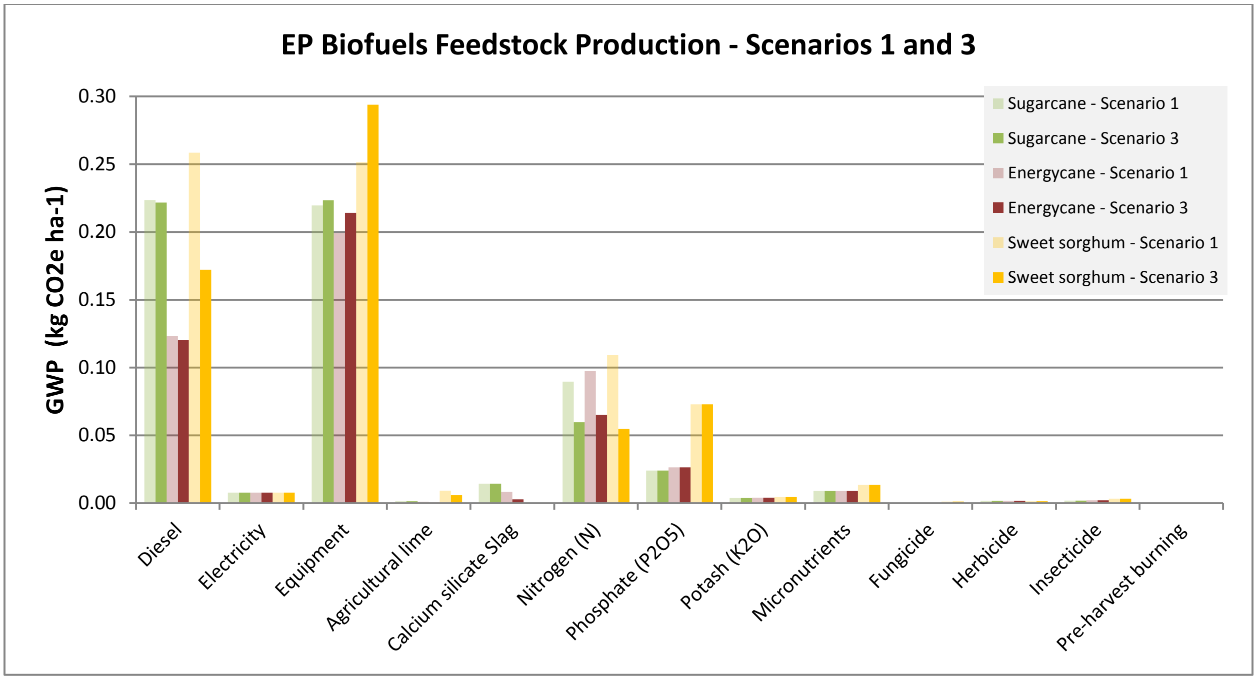


**Figure 4. EP from biofuel feedstock (sugarcane, energycane and sweet sorghum) produced in mineral soils in Florida. Comparison of scenario 3 "Controlled-release Nitrogen" versus scenario 1 "business as usual" (faded colors), expressed in kilograms of nitrogen equivalents per hectare per year**

For modeling our "controlled-release Nitrogen" scenario we assumed the use of 138 kg N $ha^{-1}$ for biofuel sugarcane and energycane, which represents 2/3 of the conventional amount used and 101 kg N $ha^{-1}$ for sweet sorghum, which is one half of the amount of N used in the business as usual scenario (**Error! Reference source not found.**).

The results as shown in Figure 4 depict changes in EP emissions from use of diesel, use of equipment and mainly EP emissions coming from nitrogen. Considering the controlled-release nitrogen scenario, emissions from diesel are 0.222, 0.120, and 0.172 kg N-e $ha^{-1}$ $y^{-1}$ for biofuel sugarcane, energycane and sweet sorghum, respectively. These values are in average are 12% less than the emissions from diesel in the business as usual scenario. However, the values for the emissions from equipment use are 9% higher with the new scenario, presumably because the amount of equipment used is the same but the material (nitrogen) applied is less. And the emissions from nitrogen application are 31% lower comparing to the business as usual scenario. The emissions from nitrogen with the controlled-release technique are: 0.06, 0.07, and 0.06 kg N-e $ha^{-1}$ $y^{-1}$ for biofuel sugarcane, energycane and sweet sorghum, respectively (Figure 3).

### 3.2.4. Contribution of GWP when green harvesting is practiced

The pre-harvest biomass burning practiced for biofuel sugarcane crops in Florida, considering the normal practices (scenario 1) contributes with 30% (816 kg $CO_2e$ $ha^{-1}$ $y^{-1}$) of the total emissions (Figure 5). For cultivation of energycane and sweet sorghum as biofuel feedstock, this practice is not implemented.

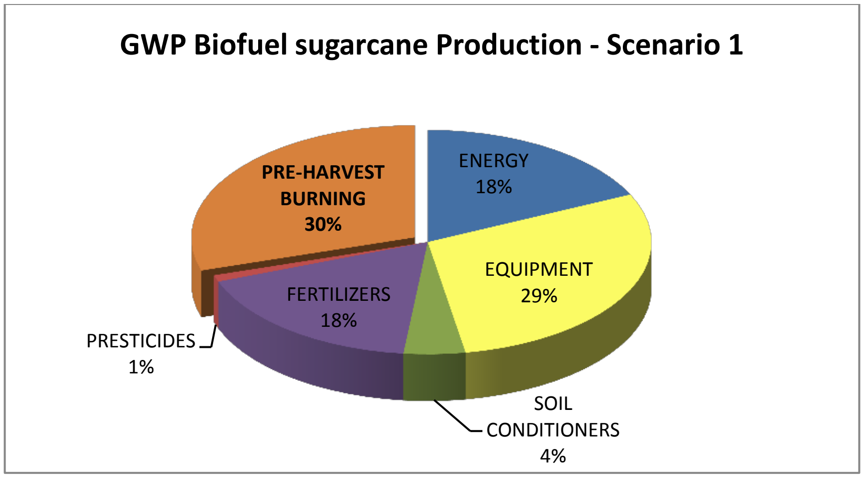


**Figure 5. Percentage of GWP emissions from biofuel sugarcane produced in mineral soils in Florida. Considering pre-harvest biomass burning as part of the scenario 1 "business as usual", expressed in kilograms of dioxide equivalents per hectare per year**

Results of modeling the fourth scenario, where pre-harvest burning is not considered, show that the main contributor is the use of equipment (42%). Other important sources of emission are energy (26%) and the use of fertilizers (25%) (Figure 6).

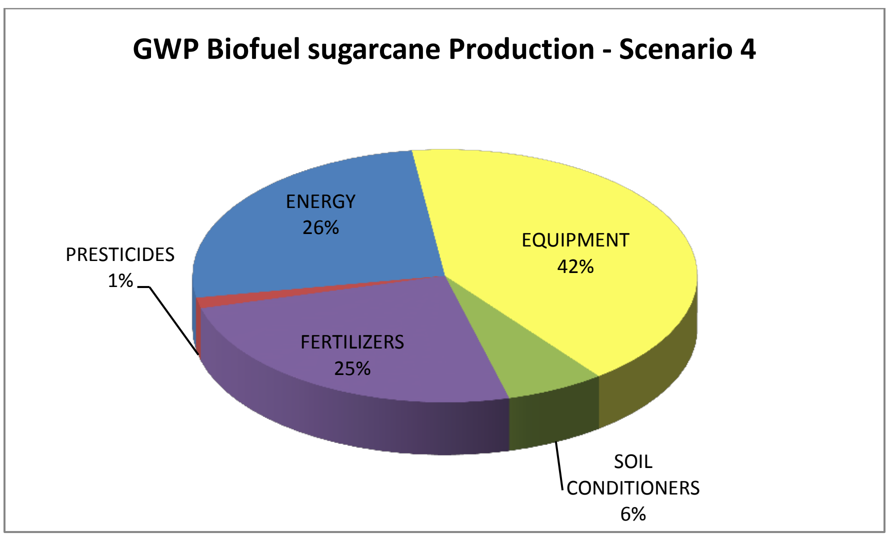


**Figure 6. Percentage of GWP emissions from biofuel sugarcane produced in mineral soils in Florida. Without considering pre-harvest biomass burning, as part of the scenario 4 "green harvest", expressed in kilograms of dioxide equivalents per hectare per year**

### 3.2.5. Summary of GWP emissions from biofuel feedstock crops cultivation

The total emissions of $CO_2$e to produce one ha of biofuel three biofuel feedstock in show that the way as these feedstock crop are being produced (or would be produced commercially; i.e. energycane and sweet sorghum) has the highest emissions (Table 2).

On the other hand, the lowest contributions for each crop are when the following scenarios are applied: for sugarcane the scenario 4 (green harvest), that reduces in 30% the $CO_2$ contributions; for energycane the best production scenario is when “reduced tillage” is practiced since it helps to reduce the $CO_2$ emissions in 23%; and for sweet sorghum, the “controlled- release nitrogen” is the best scenario because it reduces its emissions in 19%.

**Table 2. Summary of GWP emissions from biofuel sugarcane, energycane and sweet sorghum production in mineral soils in Florida. Expressed in kg $CO_2$e $ha^{-1}$ $y^{-1}$**

| Emission source | SUGARCANE | | | | ENERGYCANE | | | | SWEET SORGHUM | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** |
| Energy | 494 | 430 | 490 | 494 | 307 | 248 | 355 | 307 | 560 | 527 | 398 | 560 |
| Equipment | 802 | 496 | 784 | 802 | 800 | 519 | 784 | 800 | 558 | 454 | 574 | 558 |
| Soil Conditioners | 122 | 122 | 122 | 122 | 70 | 70 | 7 | 70 | 16 | 11 | 11 | 16 |
| Fertilizers | 480 | 480 | 376 | 480 | 586 | 516 | 403 | 586 | 736 | 720 | 530 | 736 |
| Pesticides | 26 | 26 | 26 | 26 | 28 | 28 | 28 | 28 | 40 | 46 | 40 | 40 |
| Pre-harvest burning | 816 | 816 | 816 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **2,740** | **2,370** | **2,615** | **1,924** | **1,791** | **1,381** | **1,577** | **1,791** | **1,910** | **1,759** | **1,553** | **1,910** |

## 4. Discussion

Our analysis considered a baseline scenario, where all the practices for biofuel feedstock production are currently performed in Florida. We worked with four different scenarios in our model making modifications to inputs like: reduce equipment use through strip tillage methods, reduce the amount of nitrogen using new products in the market that allow slow-release fertilizers and avoid pre-harvest biomass burning.

Uchida and Hayashi (2012) Sorghum Normal cultivation, conventional varieties Yield: 100 t/ha Low-input cultivationk, high-yield varietiesl Yield: 125 t/ham Sugarcane Ratooning 2 times, conventional varieties Yield: 60e70 t/ha Ratooning 5 timesp, high-biomass varieties Yield: 90e120 t/haq They found that the improvements in the cultivation practices for sorghum and sugarcane were associated with significant reductions in all of the environmental impact categories when compared to conventional cultivation methods.

Scenario 1

The CFP of biofuel sugarcane found in this study was 0.044 kg $CO_2$e $kg^{-1}y^{-1}$ for mineral soils and 0.46 kg $CO_2$e $kg^{-1}$ $y^{-1}$ for organic soils. For tomato production in Florida GHG emissions ranged from 0.19 to 0.27 kg $CO_2$e kg $fruit^{-1}$ with N fertilizer accounting for between 17.7% and 22.8% (Jones *et al.*, 2012). Thus, the range of CFP for biofuels sugarcane is considerably wider than that of tomato due to the use of widely different soils, since Florida tomato production is on mineral soils only.

For example, the CFP for sugar production in southern Brazil was 0.027 kg $CO_2$e $kg^{-1}$ sugarcane produced (de Figueiredo *et al.*, 2010) and in eastern Thailand, a value of 0.49 kg $CO_2$e $kg^{-1}$ sugarcane was also reported (Yuttitham *et al.*, 2011). Murphy *et al.* (2010) reported a value of 17,609 kg $CO_2$e $ha^{-1}$, representing an average biomass yield of 73 tons per hectare for the whole continental U.S., which is different from the 3,008 and 39,301 kg $CO_2$e $ha^{-1}$ that we found in our study for biofuel sugarcane production in mineral and organic soils, respectively. These authors also stated that *"the practice of growing sugarcane on the organic soils of the Florida Everglades is by far the most significant contributor to greenhouse gas emissions in the growing of sugarcane in the continental U.S."*.

There are other studies (Contreras *et al.*, 2009; Nguyen *et al.*, 2010; Ramjeawon, 2008) that highlight the benefits of using sugarcane by-products such as bagasse and molasses for bio-energy productions, and their potential to reduce GHG emissions. We do not consider this option for GHG emissions reduction in this study. This is because according to our study's system boundaries, carbon emissions include raw material preparation up to the produced biofuel sugarcane and left in the field (consistent with the "cradle to gate" approach).

Scenario 2

Another option could be to reduce the tillage process. Mechanical tillage loosens the soil and prepares it for additional farming operations. However, tillage operations aerate the soil, which promotes microbial growth and as a result it enhances subsidence. Another important effect caused by tillage is the loss of soil structure. For this reason, reduced or no-till operations can be put in practice to reduce biofuel sugarcane CFP, not only reducing the use of equipment and diesel fuel, but reducing subsidence and hereafter GHG emissions.

(W. E. Judice *et al.*, 2006) The effect of weed control and tillage programs on sugarcane growth and yield and on economics was evaluated they found that Elimination of a single tillage operation reduced cost $16.28/ha, and herbicide applied as a band rather than broadcast reduced cost $30.49/ha.

Scenario 3

Nitrogen (N) is the most limiting nutrient for crop growth, especially on coarse-textured, low-organic-matter soils. Under typical Florida conditions, N is readily lost by leaching (Scholberg et al. 2000b). Commercial growers in south Florida typically apply N fertilizer in amounts of 300–400 kg N $ha^{-1}$ of tomato (Scholberg et al. 2000a). The high rate of N applied may reduce N-use efficiency in tomato production and contribute to ground and surface water pollution.

Increasing fertilizer-use efficiency and preventing fertilizer losses to the environment are important goals of crop management. Slow-release fertilizers may contribute to achieving these objectives. Urea–formaldehyde is one type of slow-release N fertilizer, which is formed by the reaction of formaldehyde with excess urea under controlled conditions (pH, temperature, molar proportions, reaction time, etc.); it yields a mixture of methylene ureas with different long-chain and ring polymers. The proportion of the different methylene ureas in the mixture influences the release of N and its efficiency of use (Trenkel 1997). (Fan & Li, 2009)

(Yang *et al.*, 2012) controlled release urea (CRU) Although the CRU at 200 kg N ha–1 supplied one-third less N than the urea at 300 kg N ha–1, the CRU produced 3 to 5.9% more grain than the urea. Placing the

CRU with rice seeds without additional fertilizer application during the entire growing season significantly increased N availability in soils and improved rice growth and led to use of less N fertilizers for greater rice grain yield.

The primary consideration for mitigating N(2)O emissions from agricultural lands is to match the supply of mineral N ( from fertiliser applications, legume-fixed N, organic matter, or manures) to its spatial and temporal needs by crops/pastures/trees. Thus, when appropriate, mineral N supply should be regulated through slow-release (urease and/or nitrification inhibitors, physical coatings, or high C/N ratio materials) or split fertiliser application. Also, N use could be maximised by balancing other nutrient supplies to plants

Scenario 4

Two contrasting harvest systems are practiced in the sugarcane fields of southern Brazil: manual harvest, which is based on the prior burning of the sugarcane field, and mechanized harvest, which does not involve pre-burning (also known as green harvest) and leaves a large amount of crop residue on the soil surface. (Bordonal *et al.*, 2012)

(Bordonal *et al.*, 2012) 2651.9 and 2316.4 kg CO2eq ha1 yr 1 for BH and GH, respectively production in sugarcane in southern Brazil is cropped in a 5 to 6- year cycle of yearly harvests . Due to the input from long-term crop residues associated with the conversion from BH to GH, the emission balance in GH decreased to 1428.3 kg CO2eq ha 1 yr. A second decrease occurs when a reduced tillage strategy is adopted instead of conventional tillage during the replanting season in the GH plot, which helps reduce the total emission balance to 1180.3 kg CO2eq ha 1 yr. Also, harvesting green sugarcane without or at least reducing the pre-harvest burning will return considerable organic matter back to the soil. To put this option in practice, additional consideration must be given not only to crop residue management but also consider the extra energy and material flows associated with growing nitrogen fixing crops as part of crop rotation. The green material can produce a cool soil and direct emergent plant shading for the next ratoon that potentially could decrease the biofuel sugarcane growth rate. This would need to be adjusted, since it may represent another source for the CFP increase.

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# References

Álvarez, J., & Helsel, Z. R. (2011). Economic Feasibility of Biofuel Crops in Florida : Sugarcane on Mineral Soils 1. *IFAS Publication number SC090. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-9. Retrieved from http://edis.ifas.ufl.edu/sc090

Álvarez, J., & Helsel, Z. R. (2011). Economic Feasibility of Biofuel Crops in Florida: Energycane on Mineral Soils. *IFAS Publication number SC090. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-7. Retrieved from http://edis.ifas.ufl.edu/sc090

Andreae, M. O., & Merlet, P. (2001). Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles, 15*, 955.

Bare, J. (2011). TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. [Article]. *Clean Technologies and Environmental Policy, 13*(5), 687-696.

Bordonal, R. D., de Figueiredo, E. B., & La Scala, N. (2012). Greenhouse gas balance due to the conversion of sugarcane areas from burned to green harvest, considering other conservationist management practices. [Article]. *Global Change Biology Bioenergy, 4*(6), 846-858.

Contreras, A. M., Rosa, E., Perez, M., Van Langenhove, H., & Dewulf, J. (2009). Comparative Life Cycle Assessment of four alternatives for using by-products of cane sugar production. *Journal of Cleaner Production, 17*(8), 772-779.

de Figueiredo, E. B., Panosso, A. R., Romão, R., & La Scala, N. (2010). Greenhouse gas emission associated with sugar production in southern Brazil. *Carbon balance and management, 5*, 3.

Fan, X. H., & Li, Y. C. (2009). Effects of Slow-Release Fertilizers on Tomato Growth and Nitrogen Leaching. [Article]. *Communications in Soil Science and Plant Analysis, 40*(21-22), 3452-3468.

Gilbert, R. A., Kingston, G., Morgan, K., Rice, R. W., Baucum, L., Shine, J. M. et al. (2010). Effect of harvest method on microclimate and sugarcane yield in Florida and Costa Rica. *Proc. Int. Soc. Sugar Cane Technol., 27*, 1-10.

Godfray, H. C. J., Pretty, J., Thomas, S. M., Warham, E. J., & Beddington, J. R. (2011). Linking Policy on Climate and Food. *Science, 331*(6020), 1013-1014.

Helsel, Z. R., & Alvarez, J. (2011). Economic potential of sweet sorghum for ethanol production in South Florida. *IFAS Publication number FE896. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-8. Retrieved from http://edis.ifas.ufl.edu/fe896

Hilliard, P., Coley, A., Pendarvis, S., Ray, T., Duncan, P., & Simms, P. (2012). *Agricultural Statistics 2011* (No. 9780160905452). Washington, DC: Department of Agriculture. National Agricultural Statistics Service.

IPCC (2006). Agriculture, Forestry and Other Land Use, Volume 4 in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, NGGIP Publications. , *Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories* (pp. 1-59).

ISO (2009). Environmental management The ISO 14000 family of International Standards. Geneva, Switzerland.

Izursa, J.-l., Hanlon, E. A., Amponsah, N. Y., & Capece, J. C. (2013). Carbon Footprint of Biofuel Sugarcane Produced in Mineral and Organic Soils in Florida - Manuscript submitted for publication. 1-18.

Jones, C. D., Fraisse, C. W., & Ozores-Hampton, M. (2012). Quantification of greenhouse gas emissions from open field-grown Florida tomato production. *Agricultural Systems, 113*(0), 64-72.

Judice, W. E., Griffin, J. L., Jones, C. A., Etheredge, L. M., & Salassi, M. E. (2006). Weed control and economics using reduced tillage programs in sugarcane. *Weed Technology, 20*(2), 319-325.

Judice, W. E., Griffin, J. L., Jones, C. A., Etheredge, L. M., Salassi, M. E., Judice, W. E. et al. (2006). Weed Control and Economics Using Reduced Tillage Programs in Sugarcane '.

Lang, T. A., Daroub, S. H., & Lentini, R. S. (2002). Water Management for Florida Sugarcane Production. *IFAS Publication number SSAGR231. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-11. Retrieved from http://edis.ifas.ufl.edu/pdffiles/SC/SC03100.pdf

Murphy, C. F., O'Donnell, M., Alhajeri, N., McDonald-Buller, E., Strank, S., Werst, M. et al. (2010). *Analysis of Innovative Feedstock Sources and Production Technologies for Renewable Fuels*: EPA Project Number XA-8337950 1-0, Final Report to EPA.

Nguyen, T. L. T., Gheewala, S. H., & Sagisaka, M. (2010). Greenhouse gas savings potential of sugar cane bio-energy systems. *Journal of Cleaner Production, 18*(5), 412-418.

PE International (2012). GaBi 5 Software-System and Databases for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen, 1992 - 2012.

Ramjeawon, T. (2008). Life cycle assessment of electricity generation from bagasse in Mauritius. *Journal of Cleaner Production, 16*(16), 1727-1734.

Rice, R. W., & Gilbert, R. A. (2006). Nutritional requirements for Florida sugarcane. *IFAS Publication number SS-AGR-228/SC028. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-8. Retrieved from http://edis.ifas.ufl.edu/sc028

Roka, F., Alvarez, J., & Baucum, L. (2009). Projected Costs and Returns for Sugarcane Production on Mineral Soils of South Florida, 2007-2008. *IFAS Publication number SC087. Gainesville: University of Florida Institute of Food and Agricultural Sciences* 1-16. Retrieved from https://edis.ifas.ufl.edu/sc087

Salassi, M. E., & Deliberto, M. A. (2009). Sugarcane Production in Louisiana: 2009 Projected Commodity Costs and Returns. *Agricultural Economics & Agribusiness*, 1-41.

TNAU Agritech Portal (2008). Nutrient Management: Sugarcane. Retrieved from http://agritech.tnau.ac.in/agriculture/agri_nutrientmgt_sugarcane.html

Uchida, S., & Hayashi, K. (2012). Comparative life cycle assessment of improved and conventional cultivation practices for energy crops in Japan. *Biomass and Bioenergy, 36*(0), 302-315.

Yang, Y. C., Zhang, M., Li, Y. C., Fan, X. H., & Geng, Y. Q. (2012). Controlled Release Urea Improved Nitrogen Use Efficiency, Activities of Leaf Enzymes, and Rice Yield. [Article]. *Soil Science Society of America Journal, 76*(6), 2307-2317.

Yuttitham, M., Gheewala, S. H., & Chidthaisong, A. (2011). Carbon footprint of sugar produced from sugarcane in eastern Thailand. *Journal of Cleaner Production, 19*(17-18), 2119-2127.