Greencalc: A Calculator for Estimating Greenhouse Gas Emissions for the Australian Sugar Industry

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Abstract

This paper describes a calculator (GreenCalc), for estimating annual net emissions of the key greenhouse gases from the primary production (on-farm), transport and secondary production (processing of raw sugar) sectors of the Australian sugar industry. The calculator utilises various methodologies, including the agricultural production systems model APSIM, algorithms from the National Greenhouse Gas Inventory Committee (NGGIC), and various other established relationships. Use of the calculator is demonstrated via a case study for the Mossman region in north Queensland. The results for this system show that, while the primary sugarcane production sector is a net greenhouse gas sink, much of the assimilated carbon is eventually released upon bagasse combustion at the mill. Potential applications of the calculator include the estimation of current greenhouse gas emission levels and investigation of abatement strategies.

Key words

Greenhouse gas, calculator, sugarcane

Introduction

As a signatory to the Kyoto Protocol to the United Nations Framework Convention on Climate Change, Australia is required to limit the growth of greenhouse gas (GG) emissions in the target period of 2008 to 2012, to 8% above 1990 levels. For this to be achieved, Australian industries have to take substantive action to reduce their GG emissions. This includes the agricultural industry, which has a significant impact on emissions through land use change and a variety of land management practices. The clearing of land alters the balance of carbon fluxes in the pre-existing natural, undisturbed ecosystem, releasing carbon stored in both the vegetation and the soil. While the details of Government policies and programs to meet greenhouse targets, and in fact the nature of the targets themselves, are still evolving, there will be increasing demand for agricultural industries to be in a position to estimate current emission levels and assess management strategies to reduce emissions. This has provided the impetus for the development of a calculator for estimating annual net emissions of the key GG's.

Figure 1 illustrates the structure of the calculator. GreenCalc utilises the systems model, APSIM (Agricultural Production Systems sIMulator; 2, 1) to simulate various key GG related processes associated with sugarcane production. APSIM combines modules describing the specific processes within the system under investigation and provides a capability to represent a variety of management practices, soil types, genotypes and climates. The operator of GreenCalc begins by configuring APSIM to represent the production system under investigation. Key outputs arising from the subsequent model run become inputs to National Greenhouse Gas Inventory Committee (NGGIC), and various other relationships established within a spreadsheet format. These algorithms estimate CO_2, CH_4, N_2O, NO_x (NO and NO_2), CO and NMVOC (non-methane volatile organic compounds) emissions from three sectors of the Australian sugar industry, namely: (a) primary (on-farm) production, (b) transport (haulage and locomotive) and, (c) secondary (processing of raw sugar) production. The calculator does not address tertiary production emissions or ancillary emissions associated with fertiliser and fuel production.

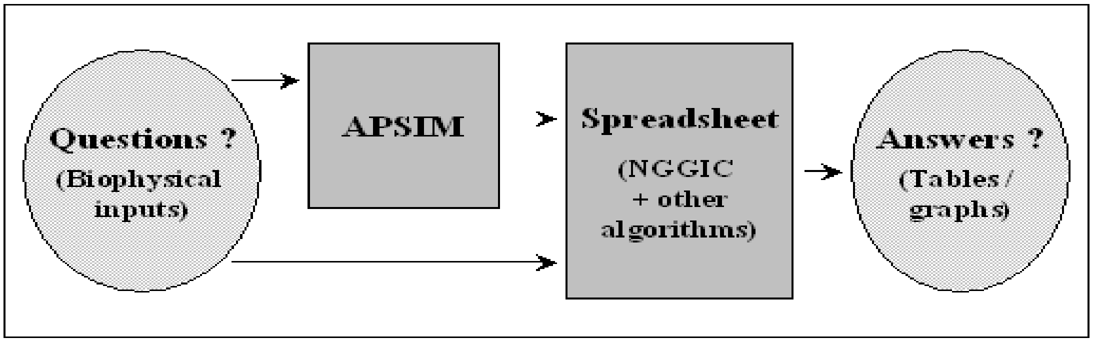

Figure 1. Structure of GreenCalc.

Key GreenCalc processes and methodologies

Crop/soil/residue system. APSIM is used to estimate the net uptake/assimilation of CO_2 by the crop and subsequent partitioning to the various biomass pools, the breakdown (decomposition with CO_2 evolution) and incorporation of crop and land clearing residues ('slash') into the soil, and the transformation of soil C and N between the various soil organic matter pools and related emissions of CO_2 and denitrification gases. Outputs of yield and residue weight at harvest are utilised in other parts of the calculator. APSIM simulations are run over an extended period using historical climate data to capture some of the long-term changes and the effect of temporal climate variability on these processes.

In GreenCalc, a factor is applied to the seasonal denitrification total generated from APSIM, which captures the proportion of denitrification gases in the form of the greenhouse gas, N_2O. This factor is user-defined with a default setting based on the work of (9) and (8). APSIM does not capture processes associated with soil CH_4 uptake and release. In GreenCalc, net annual methane uptake (Gg CH_4/ha/year) is user-defined with the default setting based on the findings from a study that measured net CH_4 emissions in a sugarcane production system (9).

Burning of slash, sugarcane crop and crop residues. In Australia, sugarcane is harvested either in a 'green' condition or following the burning of the crop. Similarly, crop residues remaining after harvest may be either burnt or allowed to decompose over the course of the cropping cycle, prior to incorporation into the soil profile at the completion of the cycle. In GreenCalc, algorithms developed by the NGGIC (5, 6) are employed to estimate emissions of CO_2, CH_4, NOx, N_2O, CO and NMVOC from the burning of the crop, crop residues and slash. These algorithms require inputs of fuel load (Gg DM/ha), supplied either as a direct user-defined value in the case of slash, or generated by APSIM in the case of crop biomass. This is then multiplied by the burning efficiency (ie fraction of fuel that is burnt), the carbon mass fraction, the C:N ratio (in the case of nitrogen gases only), and a fuel-specific emission factor for the gas (X) in question (Gg X / GgC or GgN burnt).

Fuel combustion in mobile sources. Fuel combustion emissions are associated with tractor related farm activities, harvesting and locomotive transport of the sugarcane from the farm to the mill. In all cases, the principle fuel used is automotive diesel oil (ADO). In GreenCalc, calculation of emissions associated with fuel combustion in mobile sources is based on methodologies developed by the NGGIC (4). These emissions consist of CO_2 associated with oxidation of fuel carbon content during fuel combustion, and CH_4, N_2O, NOx, CO, NMVOC's resulting from incomplete fuel combustion. Non-CO_2 emissions are calculated by multiplying activity data by the energy density of the fuel type (MJ/L) and an emission factor for the gas in question, which is specific to the type of fuel and vehicle (g/MJ). CO_2 emissions are calculated in a similar manner but with an additional oxidation factor multiplier. The balance of fuel is assumed to be converted to solid products such as soot/ash. Emissions associated with tractor related fuel consumption are taken to be independent of crop production with activity expressed in terms of L/ha. Fuel consumption by the harvester, haulout vehicles and locomotive is dependent on crop yield with activity expressed in terms of L/t harvested cane. Crop yield is estimated by APSIM. Fugitive losses from non-petrol fuel types are considered to be negligible and are ignored in the calculator.

Mill fuel combustion. The generation of steam and electricity required for the operation of sugar mills comes primarily from the combustion of bagasse, the fibrous by-product of sugar extraction. NGGIC algorithms (7) are employed to estimate emissions of CO_2, CH_4, NOx, N_2O, CO and NMVOC (Gg/ha harvested cane). The methodology is similar to that described above for the burning of crop residues and slash and is based on the amount of bagasse from a hectare of sugarcane crop, calculated as the product of APSIM cane yield (kg/ha), the fraction of bagasse in harvested cane and the gross calorific value of bagasse (PJ/kg). Specific emission factors (Gg/PJ) are applied for each GG.

Co-generation credit. Surplus power from the burning of bagasse in Queensland sugar mills is fed into the electricity grid under an agreement with the Queensland Electricity Commission, and represents a potential greenhouse 'credit'. The net emission of carbon dioxide when generating power in industrial boilers at moderate steam conditions from the combustion of biomass is 120 g/kWh, compared with 950 g/kWh when burning coal in utility boilers with elevated steam conditions (3). Clearly, significant reductions in CO_2 emissions are possible by replacing coal fired thermal power with electricity generated from biomass. In GreenCalc, the amount of power contributed to the electricity grid each year (kWh/year) is multiplied by the rates of CO_2 production for biomass and thermal based electricity production (g/kWh) to estimate the respective CO_2 emission totals. The difference between these totals is a measure of the potential greenhouse credit.

Case Study: Mossman region

Introduction. APSIM was configured to represent a typical farm system in the Mossman region. The cropping cycle began with the planting of cultivar Q124 on September 5 and included 4 subsequent ratoon crops. Crop residues were burnt after harvest with a burning efficiency of 65%. Production was rainfed and nitrogen fertiliser rates were set to be non-limiting for crop growth.. A reference 'silt loam' soil was used with 114 mm plant available water to a depth of 150 cm. Simulations were conducted over a 10 year period using historical climate data for South Mossman (16.57?S, 145.37?E) (Courtesy of Bureau of Meteorology and Queensland Centre for Climate Applications). At-harvest yield, residue, seasonal denitrification and net CO_2 uptake totals were fed into GreenCalc to investigate temporal variability and long-term trends in system greenhouse gas emissions. Other key inputs to GreenCalc were: tractor fuel usage of 310 L/ha; harvester fuel usage of 1.05 L/t; haulout fuel usage of 0.73 L/t; and locomotive fuel usage of 0.49 L/t.

Results and discussion. Figure 2 shows CO_2 equivalent totals for the various sectors of the sugarcane industry at Mossman (-ve values correspond to GG sources and +ve values to GG sinks). The results for this system show that while the primary sugarcane production sector is a net sink of GG, a substantial fraction of the carbon assimilated in the crop is eventually released upon combustion of bagasse at the mill. In terms of GG co-generation credit, Mossman currently contributes between 2500-3000 MWh to the grid over the crushing season (R. Sutherland pers. comm.). This power largely displaces coal-based power supplied from the southern states. There is an estimated 20% transmission loss associated with the delivery of this power to the Mossman region. Hence, the actual displacement is between 3000–3600 MWh/year. This generates a total potential greenhouse gas credit of 2.49–3.00 $GgCO_2$/year. The mill is currently considering upgrading its boiler and turbine alternator equipment in order to increase power export to ~100000 MWh/year (R. Sutherland pers. comm.).

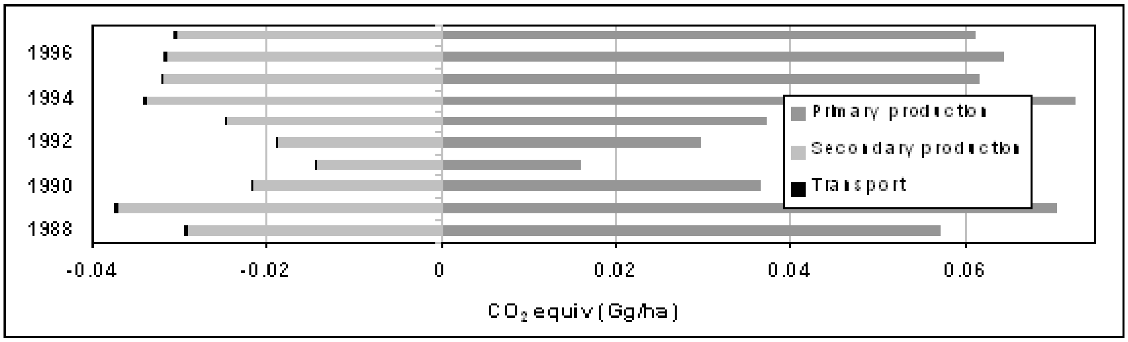

Figure 2. Annual GG emissions (CO_2 equivalent) for the period 1988-1997, for the primary production, transport and secondary production sectors of the Mossman sugarcane industry. Negative emissions are CO_2 sources and positive emissions are CO_2 sinks.

Conclusion

GreenCalc has potential applications in the estimation of current GG emission levels, the identification of benchmark emission levels, and the investigation of abatement strategies for various sectors of the sugarcane industry. GreenCalc provides a framework in which to incorporate current and future GG estimation methodologies. While GreenCalc has been configured to calculate emissions in the sugar industry, much of the functionality is generic in nature and could be readily adapted to other agricultural industries. For example, the modular structure of APSIM permits the replacement of the sugarcane module with other crop modules. A number of research gaps have been identified for future development of GreenCalc, including: validation of APSIM's denitrification methodology and prediction of the component gases, and further studies in the area of soil CH_4 uptake and release in sugarcane production systems.

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