Renewable Energy 63 (2014) 634–641

Contents lists available at ScienceDirect

Renewable Energy

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

Change in carbon footprint of canola production in the Canadian Prairies from 1986 to 2006

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ARTICLE INFO

Article history:
Received 11 April 2013
Accepted 8 October 2013
Available online 2 November 2013

Keywords:
Biodiesel feedstock
Canadian Prairies
Canola
Fertilizer
Farm operations
Greenhouse gas emissions

ABSTRACT

Accounting for greenhouse gas (GHG) emissions at the production stage of a bioenergy crop is essential for evaluating its eco-efficiency. The objective of this study was to calculate the change in GHG emissions for canola (*Brassica napus* L.) production on the Canadian Prairies from 1986 to 2006. Net GHG emissions in the sub-humid and semi-arid climatic zones were estimated for fallow-seeded and stubble-seeded canola in intensive-, reduced- and no-tillage systems, with consideration given to emissions associated with synthetic nitrogen (N) fertilizer input, mineralized N from crop residues, N leaching and volatilization, farm operations, the manufacturing and transportation of fertilizer, agrochemicals and farm machinery, and emission and removal of CO_2 associated with changes in land use (LUC) and land management (LMC). The GHG emissions on an area basis were higher in stubble-seeded canola than in fallow-seeded canola but, the opposite was true on a grain dry matter (DM) basis. Nitrous oxide emissions associated with canola production, CO_2 emissions associated with farm energy use and the manufacturing of synthetic N fertilizer and its transportation contributed 49% of the GHG emissions in 1986 which increased to 66% in 2006. Average CO_2 emissions due to LUC decreased from 27% of total GHG emissions in 1986 to 8% in 2006 and soil C sequestration due to LMC increased from 8% to 37%, respectively. These changes caused a reduction in net GHG emission intensities of 40% on an area basis and of 65% on a grain DM basis. Despite the reduction in GHG emission intensities, GHG emissions associated with canola in the Prairies increased from 3.4 Tg CO_2 equiv in 1986 to 3.8 Tg CO_2 equiv in 2006 because of the more than doubling of canola production.

1. Introduction

Globally, bioenergy is gaining popularity as a sustainable energy source for many countries in response to the issues of rising fuel prices, growing energy demands, global climate change and domestic energy security [1]. The production of biofuels is frequently presented as a possible option to reduce the atmospheric carbon dioxide (CO_2) concentration because the carbon (C) in biofuels is captured from the atmosphere rather than released from fossil storage. The emissions of greenhouse gases (GHG) from biofuels are often estimated to be less than the GHG emissions from comparable petroleum fuels [2–5], and thus the replacement of conventional fossil fuels by biofuels could have a significant benefit in the context of climate change [6]. The GHG emissions vary with the type of feedstock crop for biofuel production [7] and the total GHG emissions from biofuels can sometimes be greater than those from petroleum fuels when GHG emissions from all stages of the biorefinery process and changes in land use (LUC) and management (LMC) are included in the calculation [8–11]. Thus, increasing biofuel feedstock production with reduced environmental burden is a challenge for sustainable biofuel production programs [12].

Canada has become an increasingly important producer of canola (*Brassica napus* L.) [13]. For instance, in the Prairie Provinces of Canada (Alberta, Saskatchewan and Manitoba), canola production increased from 1.8 Tg in 1981 to 11.8 Tg in 2010 [14]. Substantial growth in canola production is forecasted for the Prairies, with a production target of 15 Tg by 2015, of which 18% is expected to be used to produce over 1 billion L of biodiesel [15,16]. Though yield improvement and the efficient use of crop inputs are resulting in higher canola production each year, the targeted increase in

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http://dx.doi.org/10.1016/j.renene.2013.10.022

production is only attainable if farmers devote more land to canola production. From the early 1960s to the mid-1990s, summerfallow area, spring wheat (*Triticum aestivum* L.) and oats (*Avena sativa* L.) have undergone the most significant declines in the Canadian Prairies while canola has increased dramatically [17].

Summerfallowing, the practice of leaving agricultural land without crop or weeds for one growing season to replenish and conserve soil moisture in semi-arid areas and to control diseases and mineralize nutrients from soil organic matter in sub-humid areas, has been commonly used in the Canadian Prairies since the beginning of the 20th century. The area under summerfallow generally increased until 1976, peaking at 11 Mha. Since then, the area under summerfallow has decreased substantially, mainly because of increasing use of soil conservation practices [18] such as reduced tillage (RT) and no-tillage (NT) [19].

Crop rotations have also changed in response to economic benefits. For example, because of canola's high economic value, more farmers are planting canola in a three-year rotation rather than a four-year rotation, and summerfallow has been virtually eliminated in some areas, especially in the sub-humid zone (Lafond, 2012 personal communication). Though canola yield after fallow is 1.3–1.5 times higher than canola grown after stubble [20–22], there has been an increasing trend to plant canola on stubble to maximize annual economic returns. Recently it was found that 56% of canola in Manitoba was cropped in a two-year rotation, and a number of farmers now plant canola on canola, though the yields are less as compared to a more diverse rotation [23].

Crop management, tillage practices, energy use and nutrient inputs vary with soil types and ultimately impact crop yields [24] and GHG emissions [25]. For example, NT systems not only reduce CO_2 emissions from farm fieldwork but can have an impact on nitrous oxide (N_2O) emissions and soil C sequestration [26,27]. Reduced tillage provides environmental benefits of reduced soil erosion, conserved soil moisture and improved soil structure [28]. A survey by Thomas [29] found that 26–33% of canola producers in Alberta had adopted RT by 1991. For the whole Prairies, the adoption of conservation tillage (CT), such as RT and NT, was 26% for RT and 50% for NT in 2005.

Changes in land use and land management affect the rate of soil C accumulation and influence the net GHG emissions, thus these changes have a significant role on the environmental profile of biofuels [30–33]. Significant losses of soil organic carbon (SOC) have been reported for LUC from forest and/or permanent grassland to cultivated land while the reverse process usually increases SOC [32,33]. Furthermore, there are possibilities to regain the lost SOC through better land management [34]. Land management changes from annual to perennial crops, from IT to CT, and from a crop-fallow rotation to continuous cropping all increase soil C, whereas the reverse practices have the opposite effects [30,34]. Thus, it is important to include soil C changes due to LUC and LMC in order to obtain an accurate estimate of the net GHG emissions associated with the production of crops [11,33,35].

Several studies have estimated the environmental footprint of canola production in Canada. For example, Smith et al. [36] estimated the energy budget for biodiesel produced from soybean (*Glycine max*) and canola oil and found that the energy input per unit of oil produced was lower for canola. Dyer et al. [37] estimated the GHG emissions for all the major field crops in Canada and found that canola production had the largest footprint when expressed in terms of emissions per unit of grain dry matter (DM). Gan et al. [38] estimated the C footprint of three varieties of canola and two varieties of mustard (*Brassica juncea* L.) at different locations in Saskatchewan and found that the C footprint was mainly a function of the rate of N fertilizer application. Moreover, Pelletier et al. [39] estimated 33% less GHG emissions when transitioning from conventional to organic agriculture. Most of these studies are for specific location and they did not include changes in soil C due to LUC and LMC. There is then a need to determine the historical trend in the C footprint so that the changes in GHG emissions associated with increased canola production can be assessed.

The objective of this study was to estimate the change in the C footprint of canola production in the Canadian Prairies from 1986 to 2006 for fallow-seeded and stubble-seeded fields under different tillage systems. This assessment considered GHG emissions for all stages of canola production from cradle to farm gate. The main sources of GHG emissions considered were (1) direct and indirect N_2O emissions from agricultural land, (2) CO_2 emissions from N fertilizer manufacturing and transportation, (3) CO_2 emissions from farming operations (tillage, seeding, fertilizer application, chemical spraying, swathing, harvesting), and (4) CO_2 emissions or removals from land use and land management changes [37].

2. Material and methods

2.1. Study area

This study included the sub-humid and semi-arid zones of Prairie Provinces (Manitoba, Saskatchewan and Alberta) which are the main canola-producing regions in Canada (Fig. 1). These correspond to the 'moist cool temperate' (sub-humid) and 'dry cool temperate' (semi-arid) climatic zones, as defined by the Intergovernmental Panel on Climate Change (IPCC) [40]. The sub-humid zone contains Gray, Dark Gray, and Black Chernozem soils, while the semi-arid zone contains Brown and Dark Brown Chernozem soils [41]. The canola area in the Prairie Provinces increased from 2.9 Mha in 1986 to 5.5 Mha in 2006 (Table 1), while the area under summerfallow decreased from 5.7 Mha in 1986 to 2.4 Mha [14].

2.2. Data sources and analyses

Annual crop area, grain yield and area under summerfallow for the period from 1976 to 2010 for the Census of Agriculture Region (CAR) were obtained from Statistics Canada [14]. These CAR data were transposed to the climatic zones using a method described by Campbell et al. [19]. To remove the impact of annual variations on crop yield, five-year average yields were used for the periods from 1984 to 1988 (representing the average yield for 1986) and from 2004 to 2008 (representing the average yield for 2006) (Table 1).

Yield-ratios of fallow-seeded to stubble-seeded canola were determined based on published literature [20–22]. These were found to be 1.3 and 1.5 times higher in the sub-humid and semi-arid zones, respectively. These factors were used to derive the yield for fallow-seeded and stubble-seeded canola (Table 1), based on their proportionate area, from the yields derived from the Statistics Canada's dataset [14]. In order to give credit to the non-productive area of fallow period, one half of the yield in fallow-seeded canola was taken as the 'effective yield' to estimate GHG emission intensities on a grain DM basis.

Coefficients to estimate fallow-seeded and stubble-seeded canola areas in the two climatic zones were estimated using data from a survey taken in Saskatchewan between 1997 and 2002 [42]. These coefficients were then extrapolated to 1986 and 2006 and used with the canola area reported by Statistics Canada to estimate the fallow-seeded and stubble-seeded canola areas in each climatic zone (Table 1).

The rates of synthetic N fertilizer application for fallow-seeded and stubble-seeded canola were derived from provincial government's crop planning guides [43–47]. The fertilizer application rate for Saskatchewan in 1986 was estimated by extrapolating the rate from 2010 to 1990; the mid-point of the recommended range of