NJAS - Wageningen Journal of Life Sciences 76 (2016) 43–53

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

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

Energy inputs and greenhouse gas emissions associated with small-scale farmer sugarcane cropping systems and subsequent bioethanol production in Japan

Takahiro Nakashima [a], Shoko Ishikawa [b,*]

[a] Farm Management Division, NARO Agricultural Research Center, 3-1-1 Kannondai, Tsukuba, Ibaraki, 305-8666, Japan
[b] Crop Production Systems Division, NARO Agricultural Research Center, 3-1-1 Kannondai, Tsukuba, Ibaraki, 305-8666, Japan

ARTICLE INFO

Article history:
Received 3 January 2014
Received in revised form 21 July 2015
Accepted 24 November 2015
Available online 21 December 2015

Keywords:
Life cycle assessment
sugarcane
small-scale farming
high latitude
bioethanol

ABSTRACT

Fossil fuel energy consumption and greenhouse gas emissions were estimated in cropping systems of sugarcane (*Saccharum officinarum* L.) and the subsequent production of ethanol in order to evaluate the feasibility of bioethanol production by small-scale farmers in the Tanegashima Island, one of the major areas of sugarcane production in Japan. The current cropping system and an alternative system were compared using Life Cycle Assessment and the results are discussed in relation to a comparable study in Brazil. Results showed that energy inputs and greenhouse gas emissions amounted to 6.89-7.22 MJ L^{-1} and 0.617-0.667 kg CO_2-eq L^{-1} of ethanol respectively. The process of fertilizer production consumed the most energy and emitted the greatest amount of greenhouse gas among all components considered. Fertilizer production was followed by manufacturing agricultural machinery, field operations for harvest and the transport of sugarcane to the mills. The replacement of chemical fertilizers with organic materials therefore provides the greatest scope to reduce energy consumption and greenhouse gas emissions. The energy output/input ratio of the bioethanol production was calculated to vary between 3.2 and 3.5; this range is considerably lower than the value of 8.3 obtained from sugarcane in Brazil, but these positive values still indicate that small-scale farmers could act as viable energy producers in this region of Japan.

1. Introduction

Sugarcane (*Saccharum officinarum* L.), one of the most productive photosynthesizers among cultivated crops, is primarily produced in areas of the tropics and subtropics with appreciable amounts of precipitation [1]. With long daylight hours and high average temperature, sugarcane can produce substrates such as sucrose, glucose and fructose that are highly suitable for bioethanol production without needing the process of saccharification [2]. Abundant arable land and cheap labor resources found in some of the major sugarcane producing countries are considered to have played an important role in establishing energy efficient production systems of raw sugar and subsequently efficient bioethanol production. The increased production and utilization of bioethanol in Brazil, for example, has been promoted by a policy called the National Alcohol Program (Pro-Alcool) which mandated the use of bioethanol in transportation. Later the policy was followed by measures such as an end-user support in the form of a tax exemption for biofuels and subsidies to purchase flex-fuel vehicles [3–5]. This trend of policy initiatives related to biofuels has recently stretched to a wider range of crops produced in higher latitudes as a consequence of increased world-wide concerns over energy security and global warming [6].

The environmental strength of biofuels lie in the fact that all of the carbon in plant organs and tissues can be obtained from atmospheric CO_2 by photosynthesis. It must however be remembered that the system of biofuel production from sugarcane is neither fossil-fuel-free nor greenhouse-gasses-free. External inputs such as fertilizers and field operations using machinery consume fossil fuels and release CO_2. In addition, it is possible that field soils especially after fertilization could release greenhouse gasses (e.g. N_2O and CH_4) which can be worse than CO_2 in terms of global warming as has been suggested by a number of researchers [6,7]. Thus, in order to assess the feasibility of a given biofuel system, one needs to assess possible greenhouse gas emissions from the system as a

* Corresponding author. Tel.: +81 298 388909; fax: +81 298 388484.
E-mail addresses: tnakasim@affrc.go.jp (T. Nakashima), shokoish@affrc.go.jp (S. Ishikawa).

http://dx.doi.org/10.1016/j.njas.2015.11.003
1573-5214/

whole including all processes from feedstock production on farm to fermentation and distillation in sugar mills. Life cycle assessment (LCA) [8,9] has served as a useful tool in this respect and some researchers have already shown that sugarcane-derived ethanol in major producing countries has an environmental advantage in terms of greenhouse gas emissions as well as consumption of fossil-fuel energy compared with other first-generation biofuel systems such as those based on maize [10–12].

A stable supply of low-cost bioethanol has been referred to as a goal to pursue by the Japanese government [13]. Already, much effort has been made to establish a sugarcane-based ethanol production system suitable to Japan where the major sugarcane production area consists of a series of small islands, i.e., the Southwest Islands (the 24-31°N latitude and 123-131°E longitude) where family-run farms of 1-2 hectares are dominant and occurrence of typhoon is quite common [14]. Before installing commercial-scale ethanol production capabilities to existing mills, the consumption of fossil energy and emission of greenhouse gases in the Southwest Islands needs to be evaluated.

Obviously small-scale sugarcane farming is not exclusive to Japan; a substantial number of sugarcane farmers in the world produce on small fields. For example, in South Africa, although medium and large-scale farmers dominate in terms of area and amount of sugarcane produced, 95% of sugarcane farmers are classified as small-scale farmers [15]. The importance of small-scale sugarcane producers to the biofuel industry in Asia has also been identified [16]. The present study on small-scale sugarcane production in Japan therefore has potential implications for the future of small-scale farmers globally. The importance of small-scale farming both in developing and developed countries was recently emphasized by the FAO who designated 2014 as the International Year of Family Farming (IYFF) [17].

In the present study, fossil fuel energy inputs and the associated greenhouse gas emissions were assessed in the current and an alternative system of sugarcane production in fields of the Tanegashima Island, one of the major sugarcane producing areas in the Southwest Islands. An attempt was made to assess the production of ethanol for sugarcane in mills/refineries by making comparisons with the study conducted by Uchida et al. [18,19] on comparative LCA of improved and conventional cultivation practices for energy crops in Japan. This study provides specific evidence on which stakeholders can base decisions affecting the economic and environmentally sustainable production of bioethanol from sugarcane in the Southwest Islands of Japan, and generic information of significance to small-scale sugarcane production in other countries.

2. Materials and methods

The analytical method employed in the present study was LCA. The goal of the present LCA was to assess fossil energy inputs and the associated greenhouse gas emissions in ethanol production from sugarcane in the study area, with a special focus on sugarcane production in the field.

2.1. Study area

The study area, Tanegashima Island (Nishinoomote; 30°44'N 131°00'E), is located at the north end of the Southwest Islands occupying an area of approximately 445 km^2 and is home to 31,865 people [20] (a detailed description of characteristics of the area can be found elsewhere [21]). As is often the case with the Southwest Islands, a considerable part of agricultural income comes from sugarcane farming. The climate is temperate with the average temperature being 19.6 °C and precipitation 2,345 mm $year^{-1}$ on average during 1984 to 2010 [22]. Low temperatures adversely affect stalk growth and sugar accumulation of sugarcane. Nonetheless, farmers in the Tanegashima Island have achieved stalk yields as high as 73.6 Mg ha^{-1} $year^{-1}$ on average over the past decade [23], partly due to the unique and well-established practice of mulching cane [24] (Section 2.2.1) and the application of a considerable amount of chemical fertilizer (150kg-N, 120kg-P_2O_5, 120kg-K_2O ha^{-1} $year^{-1}$) as well as 20 Mg ha^{-1} of cattle manure before the cane is planted [25]. The soil type representing the region is Andosol, a well-drained soil of volcanic origin which is suitable to agriculture.

2.2. System description

2.2.1. Sugarcane production in fields

To reflect the diversity of sugarcane production practiced in the study area, two types of operational production system (OS), labor-intensive (OS1) and capital-intensive (OS2) were identified (Table S-1 in Supplementary data). OS1 represented field operations conducted either manually or by using light machinery. The process of planting was defined as the sequence of manual preparation of two-budded seed setts followed by furrowing, basal dressing, insecticide application and soil covering, all of which were powered by a hand tractor/tiller. Harvesting was separated into three separate manual processes, i.e., manual top cutting, manual green and whole-cane harvesting and leaf stripping of mainly senesced leaves in the field. OS2 employed more mechanized operations compared with the former and in particular the use of sugarcane specific machinery. Planting was conducted by a whole stalk cutting planter (SPKR-902, Bunmei Noki Co., Ltd., Kagoshima) powered by a wheel tractor and the crop was harvested by a self-propelled chopping harvester (58.5 kw; MCH-15WE2, Matsumoto Kiko Co., Ltd., Kagoshima). Another major difference between the two systems was that the latter included the process of breaking subsoil between furrows after harvest to prevent soil compaction caused by the weight of harvesters [25] (see Table S-1 in Supplementary data for other differences between the systems). Field operations common to both systems were soil preparation using a plow and a rotary harrow before planting, mulching newly planted canes using a mulcher pulled by a hand tractor, and a series of ratooning operations using a stubble shaver (LC-OS, Bunmei Noki Co., Ltd., Kagoshima) and a root cutting plow (MHD-1, Matsumoto Kiko Co., Ltd., Kagoshima) that molds soil into rectangular shapes along furrows to facilitate tillering followed by mulching [25]. Ratooning is a procedure where the crop is allowed to regrow once or several times so that two or more harvests can be taken from the original planting after the initial and subsequent harvests [1]. Mulching, which is recommended in the region to protect canes from cold weather during early growth stages, was performed using transparent polyethylene sheet 0.02 mm thick and 45 cm wide (plant cane) and 60 cm wide (ratoon). The mulch is removed manually before the operation of intertillage [25]. The operation of mulching has been reported to increase stalk yield by 15-30% [26] and is employed in 61.1% of the plant cane area and in 14.9% of the ratoon cane area [23].

By combining the two operational systems with two cultivars (NiF8 and KY01-2044), four cropping systems (CS) of sugarcane production were generated (Table 1). NiF8, a sugar cultivar, was released in 1992 by the Tanegashima Experimental Station (NARO-Kyushu Okinawa Agricultural Research Center) and has been commonly grown in the Tanegashima Island (94.1% of harvested fields was planted with NiF8 in 2010 [23]). The cultivation scheme commonly observed with NiF8 in the island is a plant cane and two ratoons, i.e., three crops in three years [23]. OS1 and OS2 combined with NiF8 were defined as CS1 and CS2 respectively (Table 1). The fresh-basis stalk yield of NiF8 employed in the present study was 75.2 and 72.9 Mg ha^{-1} $year^{-1}$ in CS1 and CS2 respectively. The slight reduction (3%) in stalk yield in CS2 was due to losses as consequence