Renewable and Sustainable Energy Reviews 78 (2017) 807–820

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Combined application of Life Cycle Assessment and Adaptive Neuro-Fuzzy Inference System for modeling energy and environmental emissions of oilseed production

Seyed Hashem Mousavi-Avval[a,*], Shahin Rafiee[a], Mohammad Sharifi[a], Soleiman Hosseinpour[a], Ajay Shah[b]

[a] Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran
[b] Department of Food, Agricultural and Biological Engineering, The Ohio State University, Wooster, Ohio, United States

A R T I C L E I N F O

Keywords:
Multi-level ANFIS
Energy consumption
Economic
LCA, Canola

A B S T R A C T

In this study energy and economic analyses and environmental Life Cycle Assessment (LCA) of canola production in Mazandaran province of Iran were conducted and then an intelligent system of three level Adaptive Neuro-Fuzzy Inference System (ANFIS) was implemented to predict three mentioned indices based on energy consumption from different inputs. The functional unit was considered to be one hectare of canola production. Energy use efficiency and energy productivity were found to be 3.73 and 0.14 kg MJ^{-1}, respectively. The LCA results indicated that total emissions of canola production was 2488.72 pPt ha^{-1}, from which off-farm emissions and on-farm emissions contributed as 1780.43 and 708.29 pPt ha^{-1}, respectively. Emissions due to production and application of chemical fertilizers, especially nitrogen, had the pivotal role on environmental burdens. Coefficients of determination for predicting output energy, benefit to cost ratio and environmental emissions final score (EEFS) were estimated to be 0.90, 0.87 and 0.92, respectively. It is concluded that chemical fertilizer is one of the main energy consuming inputs and emission sources, in particular, for impact categories of global warming, acidification and eutrophication. Optimization of fertilizer application in canola production in the region is generally beneficial from energy, economic and environmental points of view. It is proposed that implementation of multi-level ANFIS is a useful tool in helping to predict the energy, economic and environmental indices of agricultural production systems.

1. Introduction

At present, food sector represents one of the world's largest industrial sectors. So, the sustainability of food chains is a theme of great interest and several studies have been conducted and focused on the related issues. Many of these studies have concluded that agricultural phase is the most polluting phase in many cases of a food production systems [1]. So, the study of agricultural systems and their relevant impacts to the environment are of high importance [2]. Nowadays, canola is known as the second dominant oilseed crop in Iran. In 2014, Iran harvested 340,000 metric tons (t) of canola grain from 160,000 ha farming area with an average production yield of 2.12 t ha^{-1} [3]. Mazandaran province is the most important center of canola production in the country as about 11% of total harvested farming area and 12% of total canola production in Iran comes from this province [4].

To enable useful decisions for developing energy efficient, economically productive and environmentally friendly farming systems, assessment tools are required that allow for comprehensive environmental impact assessments of different farming systems [5]. Life Cycle Assessment (LCA) is a comprehensive, structured and internationally standardized methodology for analyzing the environmental profile in the life cycle of a product or process, and providing insight into ways to mitigate the impacts [6]. Energy and economic analyses as well as LCA of agricultural productions have already been the subject of several studies [7–10].

Recently, mathematical models have been widely applied to find the relationship between inputs and outputs of a production process. In our previous study [11], we examined energy use patterns and the relationship between energy inputs and yield for canola production in Golestan province of Iran. This approach requires an exact definition of the mathematical model equations. In comparison to the mathematical regression models, artificial neural networks (ANNs), on the other hand, are the computational techniques used to find the relationship

* Corresponding author.
E-mail addresses: moosavi.13848@gmail.com, sh.mousavi@ut.ac.ir (S.H. Mousavi-Avval).

http://dx.doi.org/10.1016/j.rser.2017.05.002
Received 16 July 2015; Received in revised form 20 April 2017; Accepted 2 May 2017
1364-0321/

between inputs and outputs by training with examples, and hence, require no assumptions about the form of the fitting function; so they are known to be less time-consuming and more suitable in modeling of complex systems of agricultural productions [12]. Many authors have investigated the applicability of ANNs in different fields of researches [13–15]. Rahman and Bala [16] employed ANNs to estimate the jute production in Bangladesh. Grzesiak et al. [17] applied the ANNs to estimate the milk yield in dairy cows in Canada.

Fuzzy logic is an infinite-valued extension of the traditional logic. By using fuzzy logic, fuzzy inference systems (FISs) can properly describe the complex and non-linear phenomena with the precise rules. The rules are typically in if–then format with different matching degrees for a given operational situation. In a study conducted by Sefeedpari et al. [18], fuzzy logic was combined with data envelopment analysis to solve the ranking problem of dairy farms for milk production in Iran.

Adaptive Neuro-Fuzzy Inference System (ANFIS), a combination of ANNs and FISs, has many advantages of fuzziness. Fuzzy methods provide linguistic labels for complex system modeling [19]. In literature, ANFIS has been widely used in different field of researches. For instance, Naderloo et al. [20] applied ANFIS for prediction of crop yield with considering energy consumption from different inputs. In a research by Arkhipov et al. [21], ANFIS was developed for evaluation of ecological conditions using bio-indicators. In another study, Fahimifard et al. [22] applied ANFIS to predict agricultural economic variables. Khoshnevisan et al. [19] applied multi-level ANFIS to forecast greenhouse strawberry yield on the basis of different combination of energy inputs.

Reviewing the literature demonstrates that there has been no comprehensive study on the application of multi-level ANFIS in oilseed production. Also, by considering the importance of canola as an oilseed crop which currently has been introduced to Iranian conditions, it can be considered a reference oilseed crop for the energy, economic and environmental assessments. Accordingly, the main objectives of this study are: (1) investigating the canola production from energy and economic points of view, (2) assessing environmental profile of canola production via a LCA approach, (3) developing a multi-level ANFIS model to predict the individual energy, economic and environmental indicators, and (4) evaluating the proposed model using the comparative analysis with other familiar techniques such as ANNs.

2. Materials and methods

2.1. Data acquisition

The study area included 416.6 ha consisting of 150 individual rainfed winter canola fields in Mazandaran province, Iran. Mazandaran province is located in the north of Iran within 36° 30' and 38° 08' north latitude, and 53° 57' and 56° 22' east longitude. Data used in this paper were obtained mainly by visiting the farms, and also through personal interviews with 150 farmers as representatives of the canola producers in the region, using simple random sampling method. Data included descriptive and quantitative information on inputs and costs in different production operations.

2.2. Conceptual framework for energy, economic and environmental assessments

For energy analysis, inputs were in the form of chemicals, chemical fertilizers, farmyard manure (FYM), diesel fuel, human labor and machine power. The conversion factors for farm machinery and equipment [23], diesel fuel, human labor, chemical fertilizers [23], FYM, fungicides, herbicides, insecticides [24], canola seed [25], canola grain [26], and canola residue [27] were used to calculate energy consumption associated with different inputs and outputs.

For economic analysis of canola production, the costs of inputs used in the production process were specified in order to calculate the total production costs in the study area for the production of one hectare of canola grain. Total costs included variable costs and fixed costs; the variable costs were those for human labor, machinery rental, repair, maintenance and services, chemical fertilizers and farmyard manure, chemicals, seed and other inputs used in canola production; while the fixed costs included depreciation of machinery, land rental and interest. The output was revenue from canola grain and a part of residue removed from farm for other applications. For analysis of economic aspects of production, benefit to cost (B-C) ratio was considered and was calculated by dividing the total income to the total costs of production.

LCA methodology follows the guidelines and procedures of ISO14040:2006 [28], and ISO 14044:2006 [29]. Using LCA, all energy requirements, material demand and environmental emissions associated with the manufacture, transportation, application and disposal phases of a product, throughout its life cycle, are identified [30,31]. LCA methodology typically includes four phases consisting of goal and scope definition, inventory analysis, life cycle impact assessment, and interpretation of the results.

By goal definition, the beneficiary and purpose of the study are explained. Likewise, by scope definition the product system and its boundaries, data collection and processing methods, functional unit, and environmental impact categories for the product under study are defined. The goal of the LCA part of this study is to analyze environmental emissions of canola production. The functional unit is the central reference unit to which all the other data are normalized [32]. Definition of functional unit depends on the environmental impact category and the aim of the investigation. The functional unit for this study was land-based which is defined as the production of 1 ha of canola during one production period. In doing LCA, the focus of our study was to apply multi-level ANFIS for modeling emissions of canola production rather than analyses of processing, distribution or consumption emissions. So, the system boundaries in this study were considered to be the cradle-to-farm gate for the production of all operational inputs used by the farmers in their production chain (i.e. from the production of fertilizer and pesticides from raw materials, as well as manufacture of farm machineries at the factory, to the harvesting, transportation of canola grain to the market and treatment of by-products) (Fig. 1).

Inventory analysis quantifies the natural resources and other inputs in one side, and environmental emissions and other outputs in the other side. Data used in this study can be classified as data for the production of used inputs from raw materials, resulting in off-farm emissions, and data for the application of inputs causing on-farm emissions.

In case of environmental impacts of agricultural inputs, nitrogen emissions often contribute considerably to the final results of the LCA studies. Although solar radiation is important for agricultural production, as it is a renewable resource, it is not considered as being an environmental problem or energy and economic input [2,33]. Inventory data for the production of inputs came from the process data of EcoInvent®3.0 database included in SimaPro 8.0.3.

Coefficients for calculating the inventory data for emissions related to the application of inputs presented in Table 1. Application of fertilizers results in a number of important emissions that affect global warming, acidification, eutrophication and other impact categories. The direct field emissions of ammonia (NH_3), nitrous oxide (N_2O), and NO_x emissions due to nitrogen containing fertilizers application emitted into air, carbon dioxide (CO_2) from urea emitted into air, nitrate (NO_3^-) due to nitrogen containing fertilizers application emitted into groundwater, phosphorus emissions from application of P containing fertilizers emitted into surface water, and indirect N_2O from atmospheric deposition of chemical fertilizers and farmyard manure have been calculated using emission models (Table 1). Using the IPCC guidelines, Eq. (1) was applied to calculate the direct N_2O