Journal of Cleaner Production xxx (2013) 1–10

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Environmental impact assessment of tomato and cucumber cultivation in greenhouses using life cycle assessment and adaptive neuro-fuzzy inference system

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ARTICLE INFO

Article history:
Received 10 April 2013
Received in revised form
22 September 2013
Accepted 26 September 2013
Available online xxx

Keywords:
Greenhouse production
Life cycle assessment
Cucumber
Tomato
Artificial intelligence

ABSTRACT

This study was carried out in Isfahan province, Iran, to assess the environmental impact of greenhouse cucumber and tomato production using life-cycle assessment (LCA) methodology. In this study a cradle-to-farm-gate approach using data from greenhouse operators and two distinct functional units, one mass-based and the other land-based, were selected to analyze the impact categories. Data for production of inputs were taken from EcoInvent®2.0 database, and SimaPro software was employed for analysis. Ten impact categories including Abiotic Depletion potential, Acidification potential, Eutrophication potential, Global Warming potential for time horizon 100 years, Ozone Depletion potential, Human Toxicity potential, Freshwater and Marine Aquatic Ecotoxicity potential, Terrestrial Ecotoxicity potential, and Photochemical Oxidation potential were selected based on the CML 2 baseline 2000 V2/world, 1990/characterization method. In addition, adaptive neuro-fuzzy inference system (ANFIS) was employed to predict the environmental impact of both crops on the basis of input materials. The results indicated that greenhouse tomato production had a lower environmental impact than cucumber due to less total energy input and correspondingly lower environmental burdens in all impact categories. Almost all impact categories were dominated by natural gas, electricity and nylon (as cover of greenhouses). Furthermore, the results revealed that ANFIS was capable of forecasting the environmental indices of greenhouse production with a high degree of accuracy and minimal error.

1. Introduction

Growing demand for fresh, out-off-season agricultural produce has driven an increase in greenhouse-based production. While a wide variety of plants can be grown in greenhouses, including flowers, vegetables, fruits, and transplants, especially cultivars of tomatoes and cucumbers, are commonly produced commercially in Iran. Based on recent statistics, the area under greenhouses production increased from 3380 ha to 6630 ha between 2002 and 2007, with an expectation that it will reach 20,000 ha (Anonymous, 2007; Omid et al., 2011). Greenhouse production has an advantage in that environmental parameters affecting plant growth, such as sunlight, air composition and temperature, can be controlled, but material inputs, particularly the consumption of mineral nitrogen fertilizers, can result in significant environmental impacts (Brentrup et al., 2001).

The contribution of agricultural production, including greenhouse plant production, to atmospheric greenhouse gases (GHG) on a global scale is significant, accounting for 14% of global net CO_2 emissions (Cooper et al., 2011). Life-cycle assessment (LCA) is a method of evaluating the environmental effects associated with any given activity, beginning with the initial gathering of raw materials from the earth to the point at which all residuals are returned to the earth. Greater environmental awareness among

Abbreviations: AD, abiotic depletion; AC, acidification potential; EU, eutrophication potential; GW, global warming potential; OD, ozone layer depletion; HTP, human toxicity; FAET, freshwater aquatic ecotoxicity; MAET, marine aquatic ecotoxicity; TE, terrestrial ecotoxicity; PhO, photochemical oxidation; LCA, life cycle assessment; LCI, life cycle inventory; *R*, correlation coefficient; RMSE, root mean square error; MAPE, mean absolute percentage error; AI, artificial intelligence; ANFIS, adaptive neuro-fuzzy inference system; GHG, greenhouse gas emission; ANN, artificial neural network; FU, functional unit.

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http://dx.doi.org/10.1016/j.jclepro.2013.09.057

consumers over the past decade has sharply increased the number of organizations conducting LCA studies (Romero-Gámez et al., 2012). The results of these studies have been used to support public claims about various products or processes. Accordingly, many researchers have employed LCA to evaluate the environmental impact of different cropping systems (Antón et al., 2005; Martínez-Blanco et al., 2011; Mourad et al., 2007; Nemecek et al., 2012; Russo et al., 2008). For example, Abeliotis et al. (2013) conducted an LCA study of bean production in the Prespa National Park, Greece. In another study, carried out by Sahle and Potting (2013), LCA of Ethiopian rose cultivation was performed and concluded that nutrient and pesticide management were obvious starting points for improving environmental performance. Cellura et al. (2012) performed an LCA of protected crops in Italy and reported that for all the examined vegetables, including peppers, melons, tomatoes, cherry tomatoes, and zucchini, the packaging step and the greenhouse structures accounted for a substantial share in the environmental impact distribution.

An LCA follows a standard procedure, requiring time and expertise. Since most farmers and greenhouse operators are not LCA experts they are likely not capable of reliably assessing the environmental burdens of their production systems. But predictive models can help give them production guidance and decision making tools to improve environmental performance. Energy modeling is used by engineers and scientists interested in energy use and its associated environmental impacts (Khoshnevisan et al., 2013). For many years regression analysis was widely employed as an ordinary modeling technique until artificial neural networks (ANNs), a branch of artificial intelligence (AI), were developed (Safa and Samarasinghe, 2011). Among the multitude of benefits provided by ANNs are the simplicity of application, robustness of the results, capacity for training with experimental data, lack of required assumptions about the fitting function, and the ability to model complex non-linear systems in a flexible and adaptive manner (Kalogirou, 2001; Khoshnevisan et al., 2013; Pahlavan et al., 2012a; Safa and Samarasinghe, 2011). Adaptive neuro-fuzzy inference systems (ANFIS), a branch of AI, are a blend of ANN and fuzzy systems and therefore, offer the advantages of both (Naderloo et al., 2012). Due to the difficulty in collecting precise data in agricultural production systems, employing fuzzy logic permits us to solve problems that are not well defined and for which it can be troublesome or even impossible, to find a solution.

The main objectives of this study were to evaluate the environmental impacts of greenhouse cucumber and tomato production and to develop ANFIS models to predict values for environmental-impact indices based on the inputs used during production season.

2. Materials and methods

2.1. Study area and farming system description

Isfahan Province is located about 340 km to the south of Tehran and is known as a major agricultural region with more than 5000 vegetable-production greenhouses throughout the province. The majority of these greenhouses are devoted to cucumber and tomato cultivation because of the great demand for fresh, out-off-season produce. The rural areas of Fereydonshahr – a small town in the west of Isfahan located within 30–42° and 34–30° north latitude and 49–36° and 55–32° east longitude – were used for the study during the 2011/12 production period. The total number of greenhouse operators participating in the study was 130 including 52 cucumber growers and 78 tomato growers. Initial data, including agricultural practices, machinery operations, infrastructures, input materials, and energy carriers, were obtained using questionnaires.

Cucumber and tomato are widely cultivated in the region using multi-tunnel, curved-roof plastic greenhouses covered with polyethylene film and multiwall sheets of polycarbonate material. Each tunnel is about 8 m wide and 60 m long with a central height of 5 m. The minimum area of a commercial production greenhouse in the region is about 2880 m^2, which is composed of six tunnels. All plants are cultivated directly in the soil.

The production life-cycle for cucumber in the region is 4–6 months while that of tomato is a full year. However, the crops have common and comparable agricultural practices, including field preparation, seeding, post-seeding, fertilization, irrigation, plant protection and harvesting. Crop seeds are sown in small plastic pots before being transplanted into the soil within the greenhouses. Soil texture in the region is typically 48% clay, 40% silt and 11% sand. Field preparation involves plowing and disk-harrowing, which usually takes place two weeks before transplanting. Fungicides and herbicides are often used after plowing – incorporated into the soil by disk-harrowing. Then the soil is covered with plastic for two weeks before transplanting takes place. The water requirements of the plants are met with drip irrigation, the frequency of which depends on soil characteristics, season, and ambient temperatures. Chemical fertilizers are applied through the irrigation system as needed during the production cycle based on plant needs. Most greenhouse operators, however, do not conduct any soil analysis – instead they base fertilization on personal experience. Crop nutrient requirements are also commonly met by farmyard manure (FYM) applications. Fruit harvesting is non-mechanized, instead relying completely on human labor.

2.2. Life cycle assessment

Life-cycle assessment (LCA) is a tool that can be used to evaluate the environmental effects of a product, process, or activity. Goal definition and scoping, life-cycle inventory (LCI), impact assessment, and improvement assessment are regarded as the four basic constituents of a full LCA (Boguski et al., 1996).

2.2.1. Goal definition and scoping

Goal definition and scoping are the first stage of an LCA study. Here, the intention of the research, anticipated product of the study, system boundaries, and suppositions are all clarified. Setting boundaries and defining the specific life-cycle systems being studied are essential for any LCI or LCA study (Boguski et al., 1996). The purpose of this study was to appraise the environmental performance of two major greenhouse crops (cucumber and tomato) and the indirect environmental impacts related to the use of energy sources, water and raw materials.

2.2.2. System boundary and functional unit

Defining the product system and its boundaries as well as assessing the functional unit (FU) are part of the scoping definition stage and are two key factors that can affect the results of LCA studies. To achieve a sharper understanding of the aims of LCI and LCA studies, the boundaries of the system must clearly be defined. Therefore all operations which contribute to the life cycle of the product, process, or activity of interest fall within the system boundaries. In this study a cradle-to-farm-gate approach was adopted and the focus was only on greenhouse crop production rather than storage, distribution or consumption (Fig. 1). The system boundary included all inputs from the cradle (e.g. fertilizer and pesticide production from raw materials) to the farm gate (harvested crops) as well as operational inputs including greenhouse plastic, planting material, fertilizer, acids, pesticide, water, agricultural machinery, diesel fuel, natural gas and electricity. It should