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Energy consumption and CO_2 emissions analysis of potato production based on different farm size levels in Iran

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ABSTRACT

The aim of this research was to examine the energy consumption and CO_2 emission of potato production in three different farm size sin Esfahan province of Iran. For this purpose, data were collected from 300 farmers by a face to face questionnaire. The results revealed total energy consumption and GHG emission of 47 GJ ha^{-1} and 992.88 kg CO_{2eq} ha^{-1}, respectively. The most significant energy consumer was chemical fertilizers (49%), especially nitrogen (40%) and followed by seed with share of 24%. The energy use efficiency, specific energy and energy productivity were determined to be 1.71, 2.12 MJ kg^{-1} and 0.47 kg MJ^{-1}. The different cultivated area levels analysis revealed that, large farms used the least amount of energy input significantly. It was found that the contribution of indirect energy was higher than that of direct energy and also the proportion of non-renewable energy was more than renewable resources. The results of econometric model estimation revealed that the impact of seed, water for irrigation, diesel fuel and chemical fertilizer energy inputs were significantly positive on potato yield. The sensitivity analysis illustrated that the marginal physical productivity (MPP) value of chemical fertilizer, diesel fuel and seed energy were −1.78 and −1.63 and 1.54, respectively.

1. Introduction

Potatoes (*Solanum tuberosum L.*) are grown worldwide under a wider range of altitude, latitude, and climatic conditions than any other major food crop from sea level to over 4000 m elevation. No other crop can match the potato in its production of food energy and food value per unit area (Mohammadi et al., 2008).

In 2008, the global ranking of potato was five among other crops with an overall annual production of nearly 325 million tons (FAO, 2007). China, India, Russian Federation, Ukraine, United States, Germany and Poland are the main potato producer countries. Iran with annual production of nearly 4.7 million tons is the fourteenth country in world potato production (FAO, 2007). Esfahan province with cultivated area of 17,581 ha was one of the most important potato producers in 2008 (Anonymous, 2009). The production of this province was 379,348 tons with average yield of 21 tons per hectare (Anonymous, 2009).

Energy, being the capacity to do work, is at the heart of all human activities, especially those concerning the production of goods and services (Canakci and Akinci, 2006). Energy in all its forms is essential to humanity and is central to the improvement in people's quality of life (Contreras et al., 2010). The continuous growth in energy demand, the inevitable decline in the availability of fossil fuels, and the growing concerns about climate change have resulted to a number of activities from governments around the world to increase the production of energy from renewable sources (Quintero et al., 2008). The relation between agriculture and energy is very close. Agriculture is one of the most important sectors, which consumes and supplies energy in the form of bio-energy (Ozkan et al., 2004a). The demand for energy in agriculture has increased considerably with the introduction of high yielding varieties, mechanized crop production practices, increasing populations, limited supply of arable land and desire for an increasing standard of living (Esengun et al., 2007b; Pannu et al., 1993). In all societies, these factors have encouraged an increase in energy use to maximize yields, minimize labor intensive practices or both. Therefore, it is necessary to analyze the energy input and output in crop production.

Several studies on energy input and output have been concentrated generally on worldwide production of field crops such as wheat (Singh et al., 1999), cotton (Singh et al., 2000, Singh, 2002), forage maize (Pishgar Komleh et al., 2011; Phipps et al., 1976), sugarcane (Karimi et al., 2008), apricot (Gezer et al., 2003), tomato (Hatirli et al., 2006; Esengun et al., 2007a), greenhouse cucumber (Mohammadi and Omid, 2010), kiwifruit (Mohammadi et al., 2010),

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Nomenclature

d	Precision
D^2	d^2/z^2
DE	direct energy
e_i	Error term
FYM	Farmyard manure
GHG	Greenhouse gases
$GM(X_j)$	geometric mean of j_{th} energy input (the 'j'$_{th}$ root product of 'j' energy inputs)
$GM(Y_i)$	geometric mean of yield (the 'i'$_{th}$ root product of 'i' yields)
IDE	indirect energy
LCA	Life-cycle analysis
MPP_{xj}	marginal physical productivity of j_{th} input
N	Required sample size; Number of holdings in target population
N_h	Number of the population in the h stratification
NRE	non-renewable energy
RE	renewable energy
s	Standard deviation
S_h^2	Variance of h stratification
UK	United Kingdom
USA	United States of America
X_1	Human labor energy
X_2	Diesel fuel energy
X_3	Biocide energy
X_4	Chemical fertilizer energy
X_5	Farmyard manure
X_6	Machinery energy
X_7	Seed energy
X_8	Water for irrigation energy
Y_i	Yield level of the ith farmer
z	Reliability coefficient(1.96 in the case of 95% reliability)
α_i	Coefficients of the exogenous variables
α_j	regression coefficient of j_{th} input
β_i	Coefficients of the exogenous variables
γ_i	Coefficients of the exogenous variables

citrus (Ozkan et al., 2004b), canola (Unakitan et al., 2010; Mousavi-Avval et al., 2011), soy bean (Mandal et al., 2002; Chamsing et al., 2006), pear (Liu et al., 2010) and etc.

Hetz (1998) studied on the utilization of energy of the fruit production in Chile in order to improve the efficiency of its use. Mohammadi et al. (2008) calculated the energy input and output per hectare in order to increase the energy ratio by reducing the energy consumption for potato production. Zangeneh et al. (2010) studied the energy consumption of potato production in different levels of farming technology in Iran to reduce energy consumption of this crop. Rajabi Hamedani et al. (2011) determined the energy consumption and the relationship between energy input and yield of potato production in Hamadan province. The results indicated that nitrogen fertilizer had the highest consumption and followed by diesel fuel and seed with share of 39%, 21% and 14.9% of total energy input.

Global warming is one of the most important issues in recent century. Global warming is the continuing rise in the average temperature of Earth's atmosphere and oceans and is caused by increased concentrations of greenhouse gases in the atmosphere, resulting from human activities such as deforestation and burning of fossil fuels. There is scientific agreement that global warming poses one of the major environmental challenges in the future. While the bulk of the so called greenhouse gases (GHG) originate from fossil fuel consumption (Pathak and Wassmann, 2007). Agricultural greenhouse gas (GHG) emissions account 10–12% of all manmade GHG emissions (Brownea et al., 2011). Production, transportation, storage, distribution of the inputs and application with machinery lead to combustion of fossil fuel and use of energy from alternate sources, which also emits greenhouse gases in to the atmosphere. Thus, an understanding of the emissions expressed in kilograms of carbon equivalent (kg CE) for different tillage operations, fertilizers and pesticides use, supplemental irrigation practices and harvesting is essential to identifying C-efficient alternatives such as biofuel and renewable energy sources for seedbed preparation, soil fertility management, pest control and other farm operations (Lal, 2004). Life-cycle analysis (LCA) in potato production is a tool used to assess the amount of greenhouse gas throughout its whole life cycle (includes production, use of machinery and application of agricultural chemicals such as pesticides and fertilizers).

LCA methodology has been used for assessing a number of agricultural systems. In literature, Ferreira et al. (2011) analyzed the energy consumption and CO_2 emissions of biological hydrogen production from sugarcane and potato peels using life cycle assessment methodology for the Portuguese scenario. The results showed that sugarcane had the lowest values for energy consumption and CO_2 emissions with 0.30–0.34 MJ of consumed energy and 24–31 g of CO_2 emitted per 1 MJ of H_2 produced. On the other hand potato peels presented values of 0.49–0.61 MJ/MJ_{H2} and 60–77 g CO_2/MJ_{H2}. Kramer et al. (1999) calculated the total greenhouse gas emissions related to the Dutch crop production system (potato, grain, vegetable and…) and found that the agricultural products produce 1100 k ton CO_2, 3 k ton N_2O and 0.7 k ton CH_4. The results indicated the production of 0.147 kg CO_{2eq} per kg of potato production. Ho (2011) calculated the amount of GHG emissions in wheat production and found 2963 $MgCO_2$ ha^{-1} where, fertilizer production had the highest GHG emissions (with share of 89%). De Figueiredo et al. (2010) studied the association of greenhouse gas emission with sugar production in Brazil. According to their research, 241 kg of carbon dioxide equivalent were released to the atmosphere per a ton of sugar produced (2406 kg of carbon dioxide equivalent per a hectare of the cropped area). The major part of the total emission (44%) resulted from residues burning; about 20% resulted from the use of fertilizers, and about 18% from fossil fuel combustion.

There are several studies on energy consumption of potato production but no research has combined the energy analysis and GHG emission calculation. As specified formerly, energy usage and GHG emission are related to each other and consequently this paper aimed to put both analyses in one paper. The aims of this study were to calculate the input–output energy and greenhouse gas emission use in potato production, to investigate the efficiency of energy consumption, to find a relationship between input energies and yield and sensitivity analysis of the energy inputs on potato yield in Esfahan province of Iran.

2. Material and methods

The study was done in Esfahan province which covers an area of approximately 1 million hectare and is situated in the center of Iran within 30°43′ and 34°27′ north latitude and 49°36′ and 55°31′ east longitude (Asakereh et al., 2010). Data were collected from 300 farmers in 96 villages which growing potato by using a face to face questionnaire. The data culled from questionnaires were of the amount of consumed inputs in potato production (including the