Journal of Environmental Management 197 (2017) 70–79

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Performance analysis of different rice-based cropping systems in tropical region of Nepal

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ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form
24 January 2017
Accepted 13 March 2017
Available online 19 March 2017

Keywords:
Cropping systems
Energy input-output analysis
Technical efficiency
Data envelopment analysis
Greenhouse gas emissions
Financial analysis

ABSTRACT

Energy inputs, environmental impacts and economic outputs are the main concerns in today's agricultural production systems. The current study investigated the energy, environmental and financial performances of different rice-based cropping systems (CSs). The CSs studied were: Rice-Wheat-Fallow (R-W-F), Rice-Wheat-Maize (R-W-M), Rice-Wheat-Mungbean (R-W-Mu), Rice-Lentil-Maize (R-L-M), Rice-Lentil-Mungbean (R-L-Mu), Rice-Garlic (R-G) and Rice-Onion (R-O). Primary data were collected from 210 randomly selected farms by using structured questionnaire. In this study, Data Envelopment Analysis (DEA) was used to analyze the technical efficiencies of the farms in order to estimate their energy inputs saving potential, under different CSs. Among the studied systems, R-W-M, R-L-M and R-W-Mu were found energy efficient, R-L-Mu, R-W-F and R-W-Mu were efficient considering their greenhouse gas emissions, and R-G, R-O and R-L-M were more profitable systems. Based on the combined energy, environmental and economic criteria, we conclude that R-L-M, R-L-Mu and R-W-M are the most energy, environmentally and economically efficient CSs as compared to other systems in the study. The mean technical efficiency scores of farms indicated a considerable potential of reducing energy inputs (18–34%), without compromising the economic return of the majority farms under different CSs. The results of this study support eco-efficient CSs with modern production technologies.

1. Introduction

Energy use, environmental impacts and economic outputs in agricultural production systems are closely related (Mushtaq et al., 2009; Soni et al., 2013). The energy consumption in agriculture has increased over the year in response to feed the growing population with limited arable land (Nawi et al., 2012; Rahman and Hasan, 2014). The increasing use of energy intensive farm machinery and farm inputs in agricultural production systems, and increased greenhouse gas (GHG) emissions from agriculture have led to environmental problems (Maraseni et al., 2010; Mushtaq et al., 2013). Increased use of agricultural inputs affects financial returns to the farmers and also adversely affects the environment by deteriorating natural resources and substantially contributing to global warming (IPCC, 2006; Kuswardhani et al., 2013; Maraseni et al., 2015). According to Maraseni and Qu (2016), agriculture is a major source of GHG emissions, accounting for about 14–17% of global anthropogenic emissions. FAO (2014) reported that 44% of global GHG emissions from agriculture occurred in Asia, followed by the Americas (25%), Africa (15%), Europe (12%) and Oceania (4%) in 2011, while in 1990, the contribution to the global GHG emissions from agriculture was lower (38%) in Asia and much higher (21%) in Europe than at present.

The proportion contribution of agriculture emissions for developing countries has been increasing in the recent years. About 60% of the total emissions are comes from developing countries, mainly due to consumption of energy intensive farms inputs (Maraseni et al., 2009). In developing country like Nepal, the CO_2e (carbon dioxide equivalent) emissions from agriculture has increased by 40% in 2014 as compared to 1990, whereas the energy consumption in agriculture was more than double in 2012 as compared to 2007 (FAOSTAT, 2016). Driven by high population growth and limited arable land, today's agriculture is becoming energy intensive sector with much of its attributes to the inputs. With a predicted population of 40.6 million by 2030, the country needs to produce about 47% more cereals (rice, wheat and maize) as compared to 2010 in order to meet its domestic demand (Prasad

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http://dx.doi.org/10.1016/j.jenvman.2017.03.035
0301-4797/

et al., 2011). Although, FAO (2002) projected the 13% increased of arable land area in developing countries by 2030 as compared to 1999, in contrast the arable land area in Nepal has decreased by 2% in 2013 as compared to 2001, due to the human settlements and industrializations (World Bank, 2016).

In order to meet the basic food requirement of the nation and to improve the livelihood of the farmers, the government has focused on increasing cropping intensity, where the increase in yield and cropping intensity could feed the growing population (World Bank, 2016). Agricultural production through intensive cropping systems (CSs) depends on a large amount of energy inputs i.e. fertilizers, pesticides, farm machinery, diesel fuel, seeds and labor. Rice (*Oryza sativa*) in rainy season, wheat (*Triticum aestivum*), lentil (*Lens culinaris*), onion (*Allium cepa*) and garlic (*Allium sativum*) in winter season and maize (*Zea mays*) and mungbean (*Vigna radiata*) in spring season are the main crops, primarily grown in rice-based CSs in lowland ecological domain in all the geographic regions of the country. Cereal-cereal-fallow, cereal-cereal-cereal, cereal-cereal-legume, cereal-legume-cereal and cereal-vegetable are the most common CSs practiced by the Nepalese farmers because of increasing facilities of irrigation, agricultural inputs like high yielding and short duration crop varieties, farm mechanization, fertilizers and production technology (Shrestha et al., 2011).

The selection of CSs is an important determinant for increasing desirable outputs like yield and reducing undesirable outputs like GHG emissions. But, the selection of CSs depends on several factors (but not limited to) such as availability of suitable crop variety, soil conditions, temperature, rainfall, irrigation facility and availability of labors (Singh, 2012). Variation of CSs contributes variation in productivity, profitability, energy consumption and GHG emissions from various agricultural production activities at farm level (Biswas et al., 2006; Soni et al., 2013). Consumption of agricultural inputs by agriculture sector in Nepal is increasing, but there is no significant change in agricultural production (FAOSTAT, 2016). Fertilizer consumption in Nepal has been increasing over the years with annual demand growth rate of 18.5% (Shrestha, 2010). It is reported that the nutrients consumption from different chemical fertilizers has increased over 50% in the year 2014 as compared to 2012 (FAOSTAT, 2016). Similarly, electricity consumption in agriculture sector is increasing by nearly 8% annually, whereas diesel oil input is increasing by about 11% annually (WECS, 2010). The agricultural irrigated area as the percentage of total agricultural land has also increased from 24% in 2006 to 30% in 2010 (World Bank, 2016).

Improving energy use efficiency in agriculture has become increasingly important for the sustainable agriculture, where the maximization of land productivity and minimization of energy inputs and GHG emissions are the main aims for cultivation systems (Erdal et al., 2007). An input-output energy analysis is used to determine the effects of crop production systems on environment and efficient use of energy (Soni et al., 2013). In the study of energy efficiency, Data Envelopment Analysis (DEA) has been used to determine the technical and scale efficiencies (Nassiri and Singh, 2009; Khoshnevisan et al., 2013). The energy analysis of different CSs has also been used as an approach to assess environmental problems and sustainability issues.

Meeting the goals of sustainable growth in food production and reducing rural poverty, it is required to develop and identify more productive, profitable, resource efficient and environmentally friendly CSs in perspectives of ecological soundness, social acceptability and economic viability. This study investigates the performance of different rice-based CSs through energy input-output flux, CO_2e emission and economy of production under lowland ecological domain at farm level in Nepal, which would help the farmers to choose a better CS among the different rice-based CSs currently practiced.

2. Methodology

2.1. Study area and data collection

Primary data required for this study were collected from Baijapur village development committee of Banke district, Nepal. Acidic (6.3 pH), low level of nitrogen (0.07%), medium level of phosphorus (43 kg ha^{-1}), high level of potassium (310 kg ha^{-1}) and low level of organic matter (1.53%) were the main characteristics of soil in the study area. Data were collected from a total of 210 farms through household survey by using structured questionnaire through stratified random sampling method under this study, including 30 farms for each rice-based CS such as: Rice-Wheat-Fallow (R-W-F), Rice-Wheat-Maize (R-W-M), Rice-Wheat-Mungbean (R-W-Mu), Rice-Lentil-maize (R-L-M), Rice-Lentil-Mungbean (R-L-Mu), Rice-Garlic (R-G) and Rice-Onion (R-O).

2.2. Energy analysis

The sum of both direct energy inputs such as labor, draft animal and diesel fuel, and indirect energy inputs such as seeds, chemical fertilizers, farmyard manure, farm machinery and farm tools were used for the calculation of total energy inputs used in crop production systems; whereas, main product as economic yield of the crops were used for total energy output calculation. The energy input types were also classified as renewable such as labor, draft animal, seeds and farmyard manure and non-renewable such as diesel fuel, chemical fertilizers, farm machinery and farm tools (Pishgar-Komleh et al., 2011). Farmers did not apply any plant protection chemical for pest management in all the crops included in the study. The energy used and produced by the CS were calculated by multiplying the actual values with their corresponding coefficient of energy equivalent of their types and actual quantity of inputs used and output produced from the systems (Table 1). Total energy input and output were derived in the study as:

$$EI_{cs} = \left(\sum_{n=1}^{N} \sum_{i=1}^{I} e_i^{En} \times E_{c1,n,i}^{En} + \sum_{n=1}^{N} \sum_{i=1}^{I} e_i^{En} \times E_{c2,n,i}^{En} + \sum_{n=1}^{N} \sum_{i=1}^{I} e_i^{En} \times E_{c3,n,i}^{En} \right) \Big/ A_{cs} \quad (1)$$

where, EI_{cs} is the total energy input of the *CS* type (GJ ha^{-1}). e_i^{En} is coefficient of energy equivalent of energy input type *i*. $E_{c1,n,i}^{En}$, $E_{c2,n,i}^{En}$, $E_{c3,n,i}^{En}$ are energy recourse input type *i* for unit farm operation *n* for crop type *c1*, *c2* and *c3*, respectively.

$$EO_{cs} = \left(Y_{c1}^{M} \times e_{c1}^{En} + Y_{c2}^{M} \times e_{c2}^{En} + Y_{c3}^{M} \times e_{c3}^{En} \right) \Big/ A_{cs} \quad (2)$$

where, EO_{cs} is the total energy output of *CS* type (GJ ha^{-1}). Y_{c1}^{M}, Y_{c2}^{M} *and* Y_{c3}^{M} are the main product as economic yield and e_{c1}^{En}, e_{c2}^{En} *and* e_{c3}^{En} are the energy equivalent coefficients of their economic yields of crop types *c1*, *c2* and *c3*, respectively. A_{cs} is the cultivated area in hectare of *CS* type.

In order to study the system output of the selected CSs, economic yield of all crops were converted into rice equivalent yield (*REY*) as the main system's outputs based on prevailed market price by using following relation (Biswas et al., 2006):