Journal of Environmental Management 166 (2016) 84–93

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Measuring environmental sustainability in agriculture: A composite environmental impact index approach

Noor-E. Sabiha [a], Ruhul Salim [b], Sanzidur Rahman [c, *], Maria Fay Rola-Rubzen [b]

[a] Department of Economics, Rajshahi University, Rajshahi 6205, Bangladesh
[b] Curtin Business School, Curtin University, Perth, WA 6845, Australia
[c] School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, UK

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form
1 October 2015
Accepted 4 October 2015
Available online xxx

Keywords:
Environmental impact assessment
Composite environmental impact index
Indicator
Agriculture
Bangladesh

ABSTRACT

The present study develops a composite environmental impact index (CEII) to evaluate the extent of environmental degradation in agriculture after successfully validating its flexibility, applicability and relevance as a tool. The CEII tool is then applied to empirically measure the extent of environmental impacts of High Yield Variety (HYV) rice cultivation in three districts of north-western Bangladesh for a single crop year (October, 2012–September, 2013). Results reveal that 27 to 69 per cent of the theoretical maximum level of environmental damage is created due to HYV rice cultivation with significant regional variations in the CEII scores, implying that policy interventions are required in environmentally critical areas in order to sustain agriculture in Bangladesh.

1. Introduction

Natural resource degradation in agriculture has always been a prime concern in agro-ecological research and sustainability analysis (Girardin et al., 2000; Alauddin and Hossain, 2001; Van der Werf and Petit, 2002; Rahman, 2005). Measuring the extent of environmental degradation in agriculture is therefore essential for countries dependent on agriculture (e.g., Bangladesh). However, developing a suitable measure of agricultural sustainability is challenging. Hypothetically, a good sustainability indicator should incorporate all of its operational dimensions and enable comprehensive formulation of its measurement method.

A variety of agri-environmental indicators and/or indicator-based methods have been developed for various sustainability dimensions to deal with such measurement challenges (Bockstaller et al., 1997; Halberg, 1999; Rigby et al., 2001; Bockstaller and Girardin, 2003; López-Ridaura et al., 2005; Bockstaller et al., 2009). For instance, some researchers focused on analysing spatial dimension e.g., regional, national and international level (OECD, 1999; FAO, 2000; Delbaere and Serradilla, 2004; Payraudeau and Van der Werf, 2005) while the others chose to explore the local level effects. The latter group of studies mostly investigated environmental phenomena related to farming systems and/or farming practices (Rasul and Thapa, 2003; Oliveira et al., 2013; Palm et al., 2014; Rigby et al., 2001; Zhen and Routray, 2003; Wezel et al., 2014). Evaluation studies using specific environmental variables, such as nutrient imbalance, farm chemical contamination (Lindahl and Bockstaller, 2012; Mukhopadhyay et al., 2013) or soil quality (Qi et al., 2009; Moeskops et al., 2012; Rahmanipour et al., 2014), have also been widely used in other agro-ecological research.

The indicator accounting methods in the literature have usually been proposed for: (a) specific farming sectors, such as arable farms, crops and livestock (Dalsgaard and Oficial, 1997), fishery, poultry, and fruit farms (Oliveira et al., 2013) and forestry; and (b) for specific target groups, such as farmers (Häni et al., 2003), farm advisers, policy makers, or researchers. Most importantly, methodological criteria used for investigating specific focus groups revolves around issues, such as incorporating environmental dimensions (Van Cauwenbergh et al., 2007), selection of different attributes (Girardin et al., 2000), aggregation techniques, validation and its potential for wider applicability (López-Ridaura et al., 2005). Riley (2001) noted that it is challenging to define an indicator which reveals important but inaccessible information about the

* Corresponding author.
E-mail addresses: nooresabiha@yahoo.com (N.-E. Sabiha), Ruhul.Salim@cbs.curtin.edu.au (R. Salim), srahman@plymouth.ac.uk (S. Rahman), F.Rola-Rubzen@curtin.edu.au (M.F. Rola-Rubzen).

http://dx.doi.org/10.1016/j.jenvman.2015.10.003
0301-4797/

selected environmental variables it intends to measure. Most of the earlier studies were rarely successful in dealing with all of these challenges. Moreover, these indicator-based methods of sustainability analysis are complex and subject to some constraints, such as time, costs and data availability when applied empirically. Incorporation of agricultural multi-functionality, utilization and implementation of knowledge assessment and identification of conflicting goals and trade-offs were noted as some of the challenges in examining sustainability issues in agriculture (Bindera and Feola, 2010). Therefore, there is a need to define environmental factors and design a comprehensive measurement method which is capable of accommodating different types of environmental impacts arising from various environmental sources. Such a method can then be used effectively as an operational tool for evaluating environmental sustainability in agriculture.

Given this backdrop, the principal aim of this study is to develop and formulate an indicator based approach that can effectively capture multi-dimensional aspects of agriculture in the measurement of its various environmental impacts at the farm level. The study also aims to evaluate the proposed method in terms of its validity with respect to its design and output as well as flexibility in analysing environmental impacts of any production activity in general and agriculture in particular. The effectiveness of the proposed approach is tested by empirically measuring the environmental impacts arising from high yielding variety (HYV) rice production at the farm level in three districts of north-western Bangladesh.

The rest of this paper is structured as follows. Section 2 presents a review of the literature of indicator-based methods to evaluate environmental degradation in agriculture from the environmental sustainability perspective. Section 3 describes the study area and explores the risks of experiencing various environmental impacts arising from practicing intensive HYV rice agriculture. The development of the proposed evaluation method is presented in Section 4. Section 5 presents the validation of the design of the proposed approach with respect to its conceptual validity. Section 6 describes the empirical data used for the study and discusses the results. Finally, Section 7 provides conclusions and draws policy implications.

2. Indicator based methods of agro-ecological sustainability: A critical review

A number of indicator-based approaches have been used in assessing agro-ecological sustainability. The importance of analysing environmental impacts as a fundamental aspect of measuring environmental sustainability in agriculture has been widely recognized in agro-ecological studies (Dalsgaard and Oficial, 1997; Girardin et al., 2000; Sands and Podmore, 2000; López-Ridaura et al., 2005; Van Cauwenbergh et al., 2007). Table 1 presents some of those approaches applied in agro-ecological research and sustainability analysis including their key features. Different environmental objective groups (or attributes) were assessed in these studies. Notably the Agro-Ecological System Attributes (AESA) and the Statistical Simulation Modelling (SSM) approaches covered three environmental objective groups (i.e., input-related, system-related and emission-related). The Response Inducing Sustainability Evaluation (RISE) and Scenario Based Approach (SBA) each incorporated only two environmental objective groups. Some agro-ecological sustainability indicators have been formulated considering any one environmental objective group (either input-related or system-related). For instance, Farmer Sustainability Index (FSI), Sustainable Agricultural Practice (SAP), Sustainability Assessment of the Farming and the Environment (SAFE), Environmental Sustainability Index (ESI) and Multi-scale Methodological Framework (MMF) methods. Most of the studies mentioned in Table 1 emphasised farm-level application of their proposed agri-environmental sustainability measurement approaches (e.g., Taylor et al., 1993; Sands and Podmore, 2000; Rigby et al., 2001; Häni et al., 2003; Basset-Mens and Van der Werf, 2005). However, farm-level studies of environmental sustainability in agriculture require incorporation of farmers' perceptions and awareness of the environmental impacts (Rahman, 2003, 2005; Rokonuzzaman, 2012; Rakib et al., 2014). This is because farmers' perceptions vary depending on the environmental impacts they experience, the agro-ecological conditions they face and the farm size they operate among others (Thomas et al., 1996; Wachenheim and Rathge, 2000). With a few exceptions, most previous studies qualitatively analysed farmers' environmental perception. Among the

Table 1
Review of methods used to asses environmental impact of agriculture.

Method	Reference	Object focused	Scale	Environmental objective groups	Target groups/users	Country focused
Farmer Sustainability Index (FSI)	Taylor et al. (1993)	Cabbage farm	Local	Input related	Farmers, Policy makers	Malaysia
Agro-ecological System Attributes (AESA)	Dalsgaard and Oficial (1997)	Integrated farm	Local	Input related, Emission related, System related	Researchers	Philippine
Sustainability Assessment of the Farming and the Environment (SAFE)	Van Cauwenbergh et al. (2007)	Farms in general	Local, regional, global	System related	Researchers, Policy makers	Belgium
Multi-scale Methodological Framework (MMF)	López-Ridaura et al. (2005)	Farms in general	Regional, global	System related	Researchers, policy makers	Mexico
Response Inducing Sustainability Evaluation (RISE)	Häni et al. (2003)	Crop, livestock, poultry, dairy farm	Local	Emission related, System related	Farmers	Brazil, Canada, China and Switzerland
Sustainable Agricultural Practice (SAP)	Rigby et al. (2001)	Crop farm	Local	Input related	Researchers, Policy makers	England
Statistical Simulation Modelling (SSM)	Stockle et al. (1994)	Crop farm	Local, Temporal	Input related, Emission related, system related,	Researchers	United States of America
Endogenous development scheme (EDS)	Oliveira et al. (2013)	Fruit farm	Local	Input related, system related	Farmers	Brazil
Scenario-based approach (SBA)	Basset-Mens and Van der Werf (2005)	Pig farm	Local	Input related, emission related	Researchers, policy makers	France
Enhanced Driving force-Pressure state impact-Response (EDPSIR)	Niemeijer and de Groot (2008)	Agriculture in general	Regional, Global	Emission related, system related	Researchers, policy makers	No specific country focused
Environmental Sustainability Index (ESI)	Sands and Podmore (2000)	Crop farms	Local, temporal	system related	Researchers, policy makers	Colorado (USA)