Agricultural Systems 157 (2017) 1–10

Contents lists available at ScienceDirect

Agricultural Systems

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

Integrating economic and environmental impact analysis: The case of rice-based farming in northern Thailand

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ARTICLE INFO

Keywords:
Rice
Bio-economic model
Optimisation
Life Cycle Assessment (LCA)
Thailand

ABSTRACT

Crop production is associated with a range of potential environmental impacts, including field emissions of greenhouse gases, loss of nitrogen and phosphorous nutrients to water and toxicity effects on humans and natural ecosystems. Farmers can mitigate these environmental impacts by changing their farming systems; however these changes have implications for production and profitability. To address these trade-offs, a farm-level model was constructed to capture the elements of a rice-based production system in northern Thailand. Life Cycle Assessment (LCA) was used to generate environmental impacts, across a range of indicators, for all crops and associated production processes in the model. A baseline, profit maximising combination of crops and resource use was generated and compared with a greenhouse gas minimising scenario and an alternative inputs (fertilisers and insecticides) scenario. Greenhouse gas minimisation showed a reduction in global warming potential of 13%; other impact indicators also decreased. Associated profit foregone was 10% as measured by total gross margin. With the alternative farm inputs (ammonium sulphate, organic fertiliser and fipronil insecticide), results indicated that acidification, eutrophication, freshwater and terrestrial ecotoxicity impacts were reduced by 43, 37, 47 and 91% respectively with relatively small effects on profit.

1. Introduction

Farmers make decisions on what to produce, the timing and level of variable inputs used in production and over the longer term, the level of land, labour, machinery and other capital resources. Although they have multiple objectives, including management of risk, it is clear that farmer responses to changing output and input prices are guided by profit seeking behaviour. For example, recent global elasticity estimates indicate that production supply response to own crop price changes is positive and significant – through both area and variable input change – for soybeans, maize (corn), wheat and rice: four of the world's major food crops (Mekbib et al., 2016). If price changes fully capture all opportunity costs of production and if society is prepared to rely on new input and output technologies to meet a growing and changing demand for food, it could reasonably be concluded that the mainstream, commodity-based agricultural production on which the world relies is sustainable - and will continue to be so. However, it is clear, from theory and mounting evidence, that prices do not give a true indication of the full cost of agricultural production. Agriculture is subject to negative and positive environmental externalities: the prices of some of agriculture's major inputs - nitrogen and carbon in particular - are too low (or zero) when they leave the farm system in a form that has detrimental impacts beyond the farm. To take one major input, nitrogen fertiliser, as an example, Gruber and Galloway (2008) argue that "massive acceleration of the nitrogen cycle" is driving emissions of nitrous oxide and ammonia to the atmosphere and loss of nitrate to water; respectively contributing to global warming, acidification and eutrophication pollution problems. In contrast, biodiversity and other ecologically-based outputs and resources are undervalued and thus undersupplied or managed inappropriately. The profit-seeking behaviour of farmers will therefore tend not to be optimal from a wider societal viewpoint, particularly if a longer term view is taken. If the above framework of farmer response to costs and benefits is accepted; and if a better allocation of resources is desired, it is necessary to understand and measure the nature of agriculture's environmental effects. A further step would be to value these effects - and for these valuations to respond to changing scarcity. However, this is often not pragmatic, not least because valuation is difficult and tends to divide researchers from different disciplines. An alternative framework for analysis, employed in this paper, is to make greater use of the increasing amount of information available on the *physical* impact of agriculture on the natural environment through techniques such as Life Cycle Assessment (LCA, e.g. Blengini and Busto, 2009), the use of mechanistic models (e.g. Gibbons et al., 2005) and the development of environmental

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http://dx.doi.org/10.1016/j.agsy.2017.06.006
Received 31 October 2016; Received in revised form 27 April 2017; Accepted 12 June 2017

metrics and indicators (e.g., Moldan et al., 2012). When combined with bio-economic models that capture the elements of decision making described above (for example, as described in Janssen and Van Ittersum, 2007), this information can be used in three important ways. First, the cost of achieving some environmental outcome can be evaluated; a more subtle variant of this is to evaluate costs 'with' and 'without' *adaptation* – in the former, the system is allowed to change; in the latter the system retains some or all of the features of its original state. Second, new *interventions* designed to address sub-optimal environmental outcomes can be modelled. These can be introduced as different policy options – for example, to compare regulatory- or incentive-based approaches to achieving a desired outcome. Third, the effect of change on other aspects of the system can be assessed: land use, production, calorie and protein supply, susceptibility to risk, other environmental outcomes.

In this paper our objective is to apply the above framework to a rice production system typical of northern Thailand as an example. LCA was used to generate environmental indicators for all processes and inputs involved in the production of seven crops typically grown on farms in the region. A bio-economic optimisation model was constructed for the farm system, with all activity options and input requirements over the course of one production period calculated on a per hectare basis and linked to the per hectare LCA indicators. Baseline profit maximising production and environmental outcomes were generated and, following the above framework, compared with two alternative scenarios. The first represents farm-system *adaptation*, by farmers, to reduce detrimental environmental impact (reduced greenhouse gas emissions); the second represents external *intervention*, by enforcing an alternative, 'environmentally friendly' farm input (alternative fertilisers and insecticides) farm plan. In both cases, we estimate the impact on other environmental indicators, including an indicator of human health: the use of some agricultural pesticides has been linked to health problems among farmers in Thailand. The paper is organised as follows. Section 2 considers the wider environmental impacts of rice production; Section 3 describes the data and the two (LCA, bio-economic model) analysis tools. Results from the two scenarios are presented in Section 4 and in Section 5 we discuss the main findings and consider the extent to which the approach addresses current concerns about the sustainability of agriculture in Thailand. Section 6 concludes.

2. Environmental impacts of rice production

Although declining, rice continues to be an important source of energy for humans: in 2009, in Asia alone, 28% of calories in consumer diets derived from rice (Reardon and Timmer, 2014). Rice is also a major source of anthropogenic methane. Global emissions from the microbial decomposition of organic matter in anaerobic conditions in flooded lowland paddy fields account for circa 20% of total emissions from all anthropogenic sources (Neue, 1997; IPCC, 2006). Nitrate losses from rice paddy in Thailand across a four-month cropping season have been estimated at between 3.6 kg nitrate-N per ha (Pathak et al., 2004) and 8.0 kg nitrate-N per ha (Asadi et al., 2002). A range of pesticides used in Thai agriculture play a role in causing illnesses of farmers as well as environmental contamination. Thai farmers have shown acute symptoms related to organophosphate pesticide exposure such as muscle spasm and weakness, respiratory difficulty, nausea and chest pain (Norkaew et al., 2010; Taneepanichskul et al., 2010). There also appears to be a potential risk of long term pesticide exposure: Siriwong et al. (2008) found residual levels of organochlorine pesticide in freshwater, aquatic organisms and sediment collected in an agricultural area of central Thailand. The risk of cancer in fishermen in this region correlated positively with exposure to organochlorine pesticides in water bodies (Siriwong et al., 2009).

LCA assessments of rice production have been made in a number of geographical locations, including Italy, China and Japan (e.g. Blengini and Busto, 2009; Wang et al., 2010 and Hayashi, 2011). Most studies have focused on greenhouse gas (GHG) emissions and global warming potential, but without considering other potential impacts or the farm system more generally. Yossapol and Nadsataporn (2008) cite a figure of 2908 kg CO_2 equivalent per ha of GHGs emitted from rice production in the north-eastern region of Thailand; Pathak and Wassmann (2007) report a lower value of 2252 kg CO_2 equivalent per ha for a 'continuous flooding' rice farm using urea as fertiliser and removing straw from fields to feed animals. Thanawong et al. (2014), assessing the 'eco-efficiency' of three rice production systems in the north-eastern region of Thailand, found that rain-fed systems generally showed lower environmental impacts per ha and per kg of paddy rice produced.

In these previous studies, the focus is on one, albeit dominant, crop. While this allows the effect of some interventions that affect production to be evaluated (for example, by changing the type or amount of fertilisers used and re-running the LCA) it does not capture farm system adaptions, nor the factors that a farmer has to consider when making decisions about such adaptations – most particularly, the limits imposed by the farm system itself and availability of credit. We therefore develop an approach that allows these system level effects to be evaluated.

3. Materials and methods

3.1. Rice-based farming systems

Lowland rice production in northern Thailand requires a large amount of water and the season normally starts with the beginning of the rainy season, in June–July. Rice production in this period is known as 'in-season' or 'rain-fed' rice. Time to maturity depends on the cultivar; however, it generally takes up to 5–6 months before rice is ready to be harvested. After harvesting, at the end of the rainy season (October–November), farmers usually choose crops with lower water requirements, mainly soybean and shallot; these take around three months to grow before they are harvested. There is then a more diverse third three-month season of non-rice crops, normally drawn from maize, soybean, garlic, peanut, mungbean and shallot, before rice is re-established at the beginning of the next rainy season. Water is stored and available for irrigation through a network of irrigation ponds.

3.2. LCA framework

A standard LCA framework consists of four main stages: goal and scope definition, inventory analysis, impact assessment and interpretation. Here, the aim of the LCA was to quantify per hectare environmental impacts associated with each of the seven crops within the farm system described above; results were then incorporated into the bio-economic model, again on a per hectare basis. With the exception of buildings (sheds and storehouses), the system scope for the LCA includes all the associated processes and inputs from land preparation to harvesting ('cradle-to-the-farm-gate') for each crop. Buildings were excluded - their lifetime on farms in Thailand can be very long and adequate data were not available. Fig. 1 illustrates the system boundaries for the LCA.

An inventory analysis is essentially a collection of data on resource and input utilisation, energy consumption and environmental impacts that are directly related to each process within the boundaries of the farm system. Post-harvest processes (e.g. storing, drying, and husking) were excluded as being out of scope: these processes are usually located outside the farms and owned by different parties. All farm machinery associated with crop production and harvesting was included in the inventory, as were transportation of variable inputs (i.e. fertilisers and crop protection products, the latter subsequently termed 'pesticides') to the farm. Data were sourced from regional surveys and interviews conducted by government agencies and from relevant literature (Table 1). The amount of machinery used in terms of kg of machine required for a specific process was based on the weight, the operation