Sustainable intensification of rice-based systems with potato in Eastern Indo-Gangetic Plains

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1. Abstract

In many parts of Asia food security and poverty remains an issue even though arable land is available to produce nutritious food. Sustainable intensification of agricultural systems has been proposed to produce more outputs on same land area whilst minimizing environmental degradation. Tradeoffs, however, are inevitable and evidence thereof is scant. In this study, we analyze effects of sustainable intensification of rice-based systems with potato and focus on the Eastern Indo-Gangetic Plains of India and Bangladesh. A literature review, expert consultation, and an economic surplus exercise are used to address our objective. We find that sustainable intensification has a huge potential and positive welfare effects. Socio-economic tradeoffs, especially for labor, need to be considered and balanced out. Input efficiency needs to increase for instance by improving farming practices to reduce negative environmental effects.

2. Context and challenge, including key interactions (range and nature) the case study addresses

Asia faces a tremendous food security challenge. Climate change, rapid population growth and the loss of arable land to urbanization exacerbate the problem (Knox et al., 2012; Masters et al., 2013; Wheeler and von Braun, 2013; Gerland et al., 2014). Meanwhile, existing arable land is intensified through monocropping and increasing use of pesticides and chemical fertilizers negatively affect the environment and its eco-system services (Liu et al., 2014). Globally, Asia also has the highest concentration of poverty. India and Bangladesh, for instance, jointly are still home to some 300 million poor people living on less than US$ 1,90/day in 2012 (World Bank, 2012). In addition, Asian economies, farming systems, and diets depend on a few commodities (Garnett et al., 2013) — mainly rice and wheat. This dependency alongside a lack of income to purchase sufficient and quality food contributes to high under- and malnutrition rates. Especially women and children under five are affected. India and Bangladesh report among the highest levels of infant and maternal morbidity and mortality (FAO, 2015).

Sustainable intensification (SI) has recently gained popularity and attention (Garnett et al., 2013). It acknowledges the importance of intensification and diversification of existing agricultural systems, but in a

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sustainable way. Although various definitions of the concept have been proposed (Godfray and Garnett, 2014), a consensus exists about its core: reducing pressure on the environment without compromising on securing future food production (Garnett et al., 2013).

The SI literature has pointed to three major elements: on productivity innovations (i.e. improved varieties, improved farming practices, such as integrated pest management), natural resource management innovations (i.e. erosion control), and institutional innovations (i.e. markets and inputs) which has received relatively little attention (Schut et al., 2016). Given the complexity of SI, the concept lacks clarity on the set of indicators used to assess the sustainability of the intensified system for specific contexts at household levels. Zurek et al. (2015) provide a SI framework with a focus on higher-level analyses and the intension to provide a tool for policy-makers. In contrast, Smith et. al (2017) provide a detailed framework of sustainability indicators in the context of livestock systems.

In this case study we contribute to the literature by adopting existing SI frameworks and adapt these to a specific context. Our context is the Indo-Gangetic Plains (IGP) of East India and Bangladesh where traditional rice-base cropping systems dominate the agricultural landscape. A fallow period in between the two rice cycles, however, allows farmers to intensify their cropping systems. Whereas various crops, such as pulses or mustard are suitable for intensification, our focus is on potato (*Solanum tuberosum*). Early maturing potato varieties which bulk within 75-90 days may be ideal for intensification without incurring major yield penalties, thus contributing to increasing rural incomes and improving diets. Potato is an important crop in our study region and production nearly doubled during the past decade (FAOSTAT, 2016).

Tradeoffs among SI indicators are inevitable. Increasing demand for food requires more inputs, such as water, chemical inputs and labor. Negative implications in the social, economic, and environmental realm may be the result. The most obvious one frequently addressed is between producing more food (on same area of land) and minimizing environmental degradation (Smith et al., 2017). Naturally, replacing fallow land with improved potato varieties will boost productivity of the entire agricultural system, as might the negative implications. Analyzing strategies to minimize environmental damages is an important of this paper. In contrast, household level social indicators such as labor and gender inclusiveness have received much less attention. Labor availability and farming households' choice to use hired or family labor has not been analyzed in the context of SI. In addition, gender disaggregated adoption decisions of SI practices have been analyzed (Ndiritu et al., 2014; Theriault et al., 2017), how additional labor requirements change gender dynamics and equity, is not well understood. In sum, literature on context-specific application of SI (i.e. rice-potato-rice cropping systems in Eastern IGP) that focus on the various household-level tradeoffs remains scant.

This case study addressed two research questions:

(1) What is the potential of sustainably intensifying rice-based systems with potato in Eastern IGP?
(2) What are the effects of sustainable intensification on farming outputs and inputs?

Given the limited experimental evidence on the actual agronomic and economic benefits of SI on existing cropping systems, we apply a multimethod approach to address the formulated research questions. Therefore, instead of presenting new research results, this paper synthesizes available information from various sources including expert opinions, existing literature, and also performs a simple modeling exercise to simulate potential welfare impacts of SI on rice-based systems in Eastern IGP. This synthesis attempts to identify knowledge gaps and to inform future research regarding the data requirements for the integrated impact assessment of SI, thus laying the basis for more detailed analysis of its potential benefits and trade-offs at the agronomic, societal and environmental level.

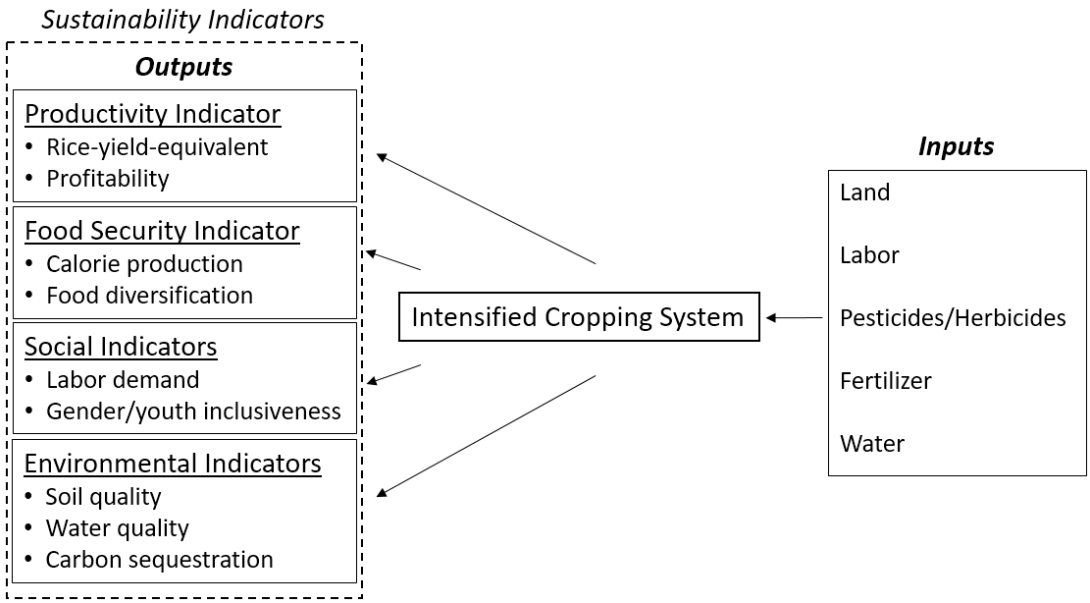
3. How did research efforts deal with the synergies and trade-offs?

Despite the overwhelming debate on the usefulness and definition of SI (Godfray and Garnett, 2014), in practice the concept lacks clarity on the set of indicators to be used to assess the sustainability of the intensified system. The main objective of intensification is (i) to produce more outputs – in an efficient way (i.e. less inputs) – while (ii) minimizing environmental damages. In a perfect world, SI achieves both objectives, however, this will not always be possible. Competition between different priorities of SI are inevitable and thus decision makers have to consider tradeoffs (Garnett et al., 2013). To do so, it is crucial to gain an understanding of various sustainability indicators and tradeoffs of rice-potato-rice systems. Zurek et al. (2015) and Smith et al. (2017) both provide a list of various sustainable indicators and their respective metrics. The main ones relevant for this research are summarized in Figure 1.

A priority of SI is to increase farming outputs in terms of productivity and thus incomes. Unless proper economic incentives are achieved/sustained through the improved system, farmers will likely hesitate to intensify their rice-systems with potato. A commonly used productivity measure is the 'Rice-Yield-Equivalent' (RYE). It compares yields across different cropping systems by converting yield of different crops in the system into rice yield equivalents (Biswas et al., 2006).

Profitability is another productivity indicator. The intensified system intends to generate additional incomes for farming households in rural areas. Farm profitability is usually measured in terms of revenues minus costs. To compare profitability across cropping systems, we apply the Benefit-Cost-Ratio (BCR) which is calculated as production costs over gross returns (Bardhan Roy et al., 2007).

***Figure 1**: Sustainability indicators framework for intensified cropping systems*



Source: adapted from Zurek et al. (2015) and Smith et al. (2017)

Increases in calorie production to feed a growing population is another priority of SI (Garnett et al., 2013). Although the focus is on producing calories per se, intensification and diversification are also important in terms

of combating hidden hunger (i.e. absence of micronutrients in diets). Potatoes are a good source for an improved diet. Compared with rice, potatoes have less calories but are richer in micronutrients such as Vitamin C, iron, or Vitamin B-6.

Sustainability can also be measured in terms of social indicators. For example, the intensification of rice systems requires additional labor days to manage the introduced potato on land which would have been left fallow otherwise. Thus, demand for labor increases which, in principle, leads to more rural employment opportunities and thus higher incomes. In addition, apart from increasing demand for labor, intensification offers opportunities to boost involvement of women and youth in agriculture.

Intensification will only be sustainable if the increase in outputs is realized by making more efficient use of the inputs and by *minimizing* negative environmental effects. These can be manifold including effects on soil and water quality, and carbon sequestration. The next section briefly discusses some key potential tradeoffs.

Tradeoffs of sustainable intensification

Tradeoffs between outputs and sustainability indicators are inherent to the concept of SI. The extent, however, to which the negative effects on the environment are minimized and the output maximized depends on the efficiency in using the given inputs.

In both traditional and intensified rice-based systems with potato, the input *land* is held constant. In the first case, the fallow period allows nutrients in the soil and water levels to replenish. In the intensified case, fallow land is transformed into agricultural production. Despite the fallow period holds important ecological and agricultural functions, from an SI perspective intensification utilizes land in a more efficient way. In doing so, negative (unintended) environmental implications are inevitable.

For example, more of each of the inputs like *pesticides* and *fertilizers* will be required in case of intensification. Although generally increasing input level results in negative implications for soil and water due to runoffs, the intensified system may benefit from fertilizer residues from the additional fertilizer application. *Water* requirements, on the other hand, will naturally increase in the intensified system. In irrigated systems, this main strain or even deplete groundwater levels.

The intensified cropping system will require more *labor*. The farmer can decide to hire labor or use family labor. In the latter case, family members may be readily available which means that the household can make more efficient use of this input. However, the initial fallow period may also be used by family members to engage in other off-farm income-generating activities. Depending on the opportunity costs of these activities, family members will continue doing so or hire wage labor.

4. What kinds of partnerships were critical?

This research was made possible thanks to the great support of many experts from NARS and along the potato value chain in Bangladesh and India. The case study was undertaken as part of the CGIAR Research Program on Roots Tubers and Bananas (RTB) and the CGIAR Research Program on Policies, Institutions and Markets (PIM).

5. Lessons learnt, including knowledge gaps and good practices in employing these approaches at scale

Sustainable intensification has recently been promoted as a strategy to produce more food for a growing population, whilst reducing inputs used and minimize negative environmental effects. Tradeoffs, however, are inevitable and context-specific evidences which integrate socio-economic, food security, and environmental factors are scant. In this research we developed and applied a sustainability indicators framework for intensified rice-fallow-rice cropping systems with potatoes. We use the example of the Eastern Indo-Gangetic Plains where an estimated 6.2 million hectares of land suitable for intensification with potatoes and other crops are left fallow.

We conclude that sustainable intensification holds potential in our study area, while at the same time, farming households are required to make tradeoffs and are affected by exogenous factors. An important sustainability factor is that the improved system is economically viable creating incentives for farmers to intensify existing cropping systems. Despite the demonstrated higher profitability of SI with potatoes and the higher expected yields and food produced compared to traditional rice-based systems, it seems to be an insufficient requirement for its adoption. For instance, farming households must trade off other (income-generating) activities or lower productivity activities. Demands for other inputs, such as fertilizer, pesticides and (most important) water will increase and availability and prices are outside the control of farming households. As a result, production costs will increase but farmers may have financial constraints and limited access to credit. In addition, non-traditional crops such as potatoes are subject to higher price volatility and more unstable demand which increases the risk for farmers. A lacking cold store infrastructure may only partly reduce the risks. Furthermore, the increased demand and use for inputs will inevitably affect the environment, mostly negative. Various strategies and techniques exist to increase input efficiency, as proposed in this study, farmers rarely apply those due either to lack of knowledge or the associated intensity.

These factors will largely determine the success of SI; the estimated national economic welfare benefits and the large potential (fallow) area to be sustainably intensified are, however, relevant prerequisites. Therefore, providing opportunities to farming households to produce more with the same area of land needs to go hand-in-hand with a range of institutional innovations (Schut et al., 2016), creation of demand and the development of a potato value chain potentially in combination with the private sector.

We conclude that more empirical research on tradeoffs of sustainable intensification for rice-based systems with potatoes is needed. This research intends to lay the groundwork for structural future empirical research and, at the same time, points to the necessity to analyze complex phenomena, such as sustainable intensification, in a more integrated fashion. For this study in particular, empirical context-specific evidence is required on the various tradeoffs and constraints end- or exogenous of nature, which farming household are facing, while considering the entire cropping systems rather than single crops. And in doing so, the proposed framework may be applied to various other cropping systems and contexts.

Finally, food productivity on existing land will need to increase in a sustainable way to guarantee a food secure world for generations to come. Sustainable intensification is thus no silver bullet to achieve global food security (Fen and Brezeska, 2016), it is a necessity.

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