Agricultural Systems 165 (2018) 55–70

Contents lists available at ScienceDirect

Agricultural Systems

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

Intensification of rice-based farming systems in Central Luzon, Philippines: Constraints at field, farm and regional levels

João Vasco Silva[a,*], Pytrik Reidsma[a], Ma. Lourdes Velasco[b], Alice G. Laborte[b], Martin K. van Ittersum[a]

[a] Plant Production Systems, Wageningen University & Research, Wageningen, The Netherlands
[b] Social Sciences Division, IRRI, Los Baños, Laguna, Philippines

ARTICLE INFO

Keywords:
Yield gap
Sustainable intensification
Crop management
Farmers' objectives
Integrated assessment
Farm structural change

ABSTRACT

Understanding the opportunities for sustainable intensification requires an integrated assessment at field, farm and regional levels of past developments. Two hypotheses regarding current rice production in Central Luzon (Philippines) were developed for this purpose. First, we hypothesize that there are trade-offs between rice yields, labour productivity, gross margin and N use efficiency and, second, that farm(er) characteristics and socio-economic conditions at farm and regional level affect the management practices used by farmers. These hypotheses were tested using two household surveys characterizing rice-based farming systems in Central Luzon in terms of changes over time (1966–2012) and spatial variability. Over the past half-century there was an increase in the proportion of irrigated fields and adoption of improved varieties, which allowed the cultivation of a dry season rice crop in Central Luzon. Moreover, transplanting has been replaced by direct-seeding and herbicides substituted hand-weeding. These resulted in greater rice yields and labour productivity, and contributed to gradual transition from subsistence to commercial farming systems, as observed in the increasing proportion of hired labour and rice sold. Our results indicate the existence of a trade-off between rice yields, labour productivity and N use efficiency as yield levels maximising labour productivity and N use efficiency were ca. 25% and 35% lower than climatic potential yield in the wet and dry season, respectively. At field level, this can be explained by 1) the use of transplanting as crop establishment method, which resulted into higher yields but lower labour productivity as compared to direct-seeding, and 2) the high N application levels, which led to higher yields but lower N use efficiency. In contrast, yield levels which maximised gross margin were ca. 80% of the climatic potential in both wet and dry seasons, so there was little trade-off between rice yields and economic performance. Regarding the second hypothesis results were not always conclusive. As an example, N application per ha was negatively associated with farm size and the timing of the first fertiliser application positively associated with household size and with the number of parcels. More intensive practices, and better farm performance, were recorded in the province at the heart of the irrigation system. We thus conclude that closing rice yield gaps in the production systems of Central Luzon incurs trade-offs with environmental and social objectives at field and farm levels but less with economic objectives. However, we could not clearly show whether, and to what extent, management practices used by farmers are influenced by farm or regional level constraints.

1. Introduction

Sustainable intensification has been proposed as a strategy to raise productivity and resource use efficiency, through its focus on yield potential, soil quality and precision agriculture (Tilman et al., 2011; Cassman, 1999). This is particularly relevant in developing countries where large yield gaps persist (Beza et al., 2017; Tittonell & Giller, 2013; Laborte et al., 2012). Understanding the opportunities for sustainable intensification requires analysis of possible constraints at field, farm and regional levels. At field level, crop management packages need to fit farmers' needs not only in terms of high yields and resource use efficiencies, but also labour productivity and profitability. At farm and regional levels, structural changes may be needed to alleviate farmers' resource constraints (in terms of land, labour and capital), to ensure equitable natural resource management and to reduce the bio-physical and economic risk of farming.

Yield gap analysis of rice-based farming systems in Central Luzon, Philippines, revealed that crop establishment method (transplanting

* Corresponding author.
E-mail address: joao.silva@wur.nl (J.V. Silva).

https://doi.org/10.1016/j.agsy.2018.05.008
Received 23 June 2017; Received in revised form 11 May 2018; Accepted 15 May 2018

and direct-seeding), nitrogen (N), potassium (K) and seed use were significantly related with rice yields (Silva et al., 2017a). Moreover, the timing of the first and second applications of fertiliser and pesticides explained part of the variation in the efficiency yield gap, i.e. the difference between technical efficient and actual yields. Technology yield gaps, defined as the difference between climatic potential and highest farmers' yields, were mostly attributed to sub-optimal water and nutrient use as compared to input requirements to achieve the climatic potential yield. From an agronomic perspective, overcoming these limiting factors requires the use of 'management packages', which can achieve yield levels close to the climatic potential yield while ensuring high resource use efficiency (Savary et al., 2012; Dobermann et al., 2002; Bouman & Tuong, 2001). Moreover, these management packages need to suit the livelihoods of smallholder farmers.

An integrated assessment of agricultural systems considering drivers at different scales can be used as a framework to identify constraints to sustainable intensification. This requires developing indicators, which capture different dimensions of smallholder farming systems and exploring possible synergies, and trade-offs, among those indicators (Klapwijk et al., 2014). In this way, it is possible to assess whether technically feasible management packages for yield gap closure fit the needs and characteristics of smallholder farmers, the farm level consequences of using a particular management package, and the ideal management package to narrow the yield gap considering multiple objectives and resource constraints. In addition, it is necessary to understand how factors at farm and regional levels interact with crop management practices (e.g. resource availability, farm(er) characteristics and socio-economic conditions), as these define the 'operating space' for agricultural production (for Asian agriculture see e.g. Studwell, 2013; Takahashi & Otsuka, 2009; Estudillo & Otsuka, 1999; Ledesma, 1980).

The objective of this paper is to identify constraints and stimuli to intensification of rice-based farming systems in Central Luzon, Philippines at field, farm and regional levels. The two research questions we aim to answer are: 1) are there trade-offs between rice yields, labour productivity, gross margin and N use efficiency for the management packages used by farmers, and if so, what are their magnitudes, and 2) how do farm(er) characteristics and socio-economic conditions at farm and regional levels affect farmers' management practices and the aforementioned indicators? For these purposes, we analysed a panel household survey of about 100 rice farmers during 1966–2012 (Central Luzon Loop Survey, Moya et al., 2015) and an unpublished cross-sectional household survey of 1800 rice farmers conducted in 2013–2014 (Metrics and Indicators for Tracking in GRiSP) in Central Luzon, Philippines.

2. Conceptual framework

For irrigated conditions, the yield gap can be defined as the difference between climatic potential yield (Yp) and actual yields (Ya). Farmers can reduce yield gaps through improved crop management but this may not be their only objective. Moreover, yield gaps and associated management packages need to be evaluated in terms of different indicators and explained by farm and regional conditions (Fig. 1). We formulated two hypotheses for this purpose, which are explained below.

The first hypothesis is that management practices associated with small yield gaps perform sub-optimally in terms of labour productivity, gross margin and N use efficiency (cf. van Ittersum et al., 2013; Lobell et al., 2009; Cassman et al., 2003). Trade-offs between indicators are partially the result of the management packages used (step 1 in Fig. 1). In case of rice, modern varieties can achieve higher Ya (and Yp) than traditional varieties but these also have more labour requirements for crop management, harvesting and threshing (Estudillo & Otsuka, 1999). Herbicide use can result in greater Ya and labour productivity, as compared to hand-weeding, as it allows for more timely control of weeds due to lower labour requirements. As for crop establishment, Silva et al. (2017a) observed significantly higher Ya for transplanted compared to direct-seeded rice, while direct-seeding requires less labour for crop establishment but more labour for weed control (Pandey & Velasco, 2002). These examples illustrate how interactions between management practices at field level can affect performance at farm level.

We expect that closing yield gaps is associated with higher revenues, costs, labour requirements and fertiliser application levels (step 2 in Fig. 1). Trade-offs between maximising gross margin and minimising yield gaps are likely to occur when output prices are low and input prices are high. In addition, closing yield gaps requires greater amount of labour for crop management activities such as fertilisation, weeding, pest control and harvesting but adoption of capital intensive, labour-saving, technologies (e.g. tractors, herbicides and mechanical threshers) can mitigate potential trade-offs between high Ya and high labour productivity. Finally, closing yield gaps in lowland irrigated rice systems requires relatively high amounts of N (150–200 $kg\,N\,ha^{-1}$, Dobermann et al., 2000), which, following the law of diminishing returns, results in sub-optimal N use efficiency (Cassman et al., 1998; Kropff et al., 1993) and increases the risk of crop failure due to lodging (Lampayan et al., 2010).

The second hypothesis is that management practices used by farmers, and hence the variability observed in farm level indicators, can be explained by the availability of farm resources (land, labour and capital), farm(er) characteristics and regional conditions (Villano et al., 2015; Takahashi & Otsuka, 2009; Estudillo & Otsuka, 1999; Kerkvliet, 1990). This is depicted in steps 3 and 4 in Fig. 1. For instance, according to Erguiza et al. (1990) supervision of hired labour, cost of transplanting labour and use of credit were among the most important determinants of the crop establishment method used by rice farmers in Nueva Ecija. In Central Luzon, farmers adopted direct-seeding and increased mechanisation (Moya et al., 2004) perhaps due to the increasing importance of capital and non-rice income in the region (Takahashi & Otsuka, 2009). We expect non-rice income to be positively associated with fertiliser use because farmers are more likely to purchase fertilisers if more capital is available. Moreover, we anticipate that smaller farm size and greater labour availability lead to more timely crop establishment and fertiliser application dates. Finally, regional conditions can affect the land preparation and crop establishment dates because they determine the pattern of water release and availability (Tabbal et al., 2002; Loevinsohn et al., 1993). They may also affect the farm level indicators due to differences in water accessibility (Barker & Levine, 2012) and implementation of land reform programs (Ledesma, 1980).

Understanding the constraints to intensification of crop management requires an integrated assessment considering drivers at different scales because farm and regional level conditions are likely to influence the management practices adopted by farmers, and their performance. As constraints are not static, temporal trends should also be considered (Falconnier et al., 2015; Valbuena et al., 2015; Takahashi & Otsuka, 2009; Iraizoz et al., 2003).

3. Material and methods

3.1. Household surveys

Data from two different household surveys conducted by the International Rice Research Institute (IRRI) in Central Luzon were used in this study (Fig. 2). Double rice cropping is common in the region with a wet season (WS) crop cultivated between June - July and September - October and a dry season (DS) crop cultivated between December - January and March - April. The WS crop is cultivated with or without irrigation while the DS crop is only possible with irrigation.

The Central Luzon Loop Survey (CLLS) was collected at farm level every 4 to 5 years during 1966–2012 with the objective of monitoring