G Model
EURAGR-25557; No. of Pages 19
ARTICLE IN PRESS
Europ. J. Agronomy xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
European Journal of Agronomy
journal homepage: www.elsevier.com/locate/eja

Explaining rice yields and yield gaps in Central Luzon, Philippines: An application of stochastic frontier analysis and crop modelling

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

[a] *Plant Production Systems, Wageningen UR, Wageningen, The Netherlands*
[b] *Social Sciences Division, IRRI, Los Baños, Laguna, Philippines*

ARTICLE INFO

Article history:
Received 6 October 2015
Received in revised form 25 April 2016
Accepted 30 June 2016
Available online xxx

Keywords:
Oryza sativa L.
Rice
Yield variability
Yield gap
Philippines
Stochastic frontier analysis
Crop modelling

ABSTRACT

Explaining yield gaps is crucial to understand the main technical constraints faced by farmers to increase land productivity. The objective of this study is to decompose the yield gap into efficiency, resource and technology yield gaps for irrigated lowland rice-based farming systems in Central Luzon, Philippines, and to explain those yield gaps using data related to crop management, biophysical constraints and available technologies.

Stochastic frontier analysis was used to quantify and explain the efficiency and resource yield gaps and a crop growth model (ORYZA v3) was used to compute the technology yield gap. We combined these two methodologies into a theoretical framework to explain rice yield gaps in farmers' fields included in the Central Luzon Loop Survey, an unbalanced panel dataset of about 100 households, collected every four to five years during the period 1966–2012.

The mean yield gap estimated for the period 1979–2012 was 3.2 ton ha^{-1} in the wet season (WS) and 4.8 ton ha^{-1} in the dry season (DS). An average efficiency yield gap of 1.3 ton ha^{-1} was estimated and partly explained by untimely application of mineral fertilizers and biotic control factors. The mean resource yield gap was small in both seasons but somewhat larger in the DS (1.3 ton ha^{-1}) than in the WS (1.0 ton ha^{-1}). This can be partly explained by the greater N, P and K use in the highest yielding fields than in lowest yielding fields which was observed in the DS but not in the WS. The technology yield gap was on average less than 1.0 ton ha^{-1} during the WS prior to 2003 and ca. 1.6 ton ha^{-1} from 2003 to 2012 while in the DS it has been consistently large with a mean of 2.2 ton ha^{-1}. Varietal shift and sub-optimal application of inputs (e.g. quantity of irrigation water and N) are the most plausible explanations for this yield gap during the WS and DS, respectively.

We conclude that the technology yield gap explains nearly half of the difference between potential and actual yields while the efficiency and resource yield gaps explain each a quarter of that difference in the DS. As for the WS, particular attention should be given to the efficiency yield gap which, although decreasing with time, still accounted for nearly 40% of the overall yield gap.

1. Introduction

Agronomists and agricultural economists have developed different concepts and quantitative methods to estimate and explain yield gaps, i.e. the difference between climatic potential and actual farmers' yields. Agronomic studies traditionally rely on field experiments (e.g. Affholder et al., 2012) and/or crop growth models (e.g. Angulo et al., 2012) to assess the contribution of different management practices to crop yield following the so-called theory of production ecology (van Ittersum and Rabbinge, 1997). The main limitation of these types of studies is that these do not explicitly take into account farmers objectives and constraints (and other socio-economic conditions) because they are usually performed at field and regional levels (Beza et al., 2016). On the other hand, production economics deals with the estimation and interpretation of technical and allocative efficiencies using farm level data. Technical efficiency can be defined as the maximum output that can be achieved given a specific level of inputs while allocative efficiency refers to the success of a farm in choosing the optimal proportion of inputs given a pre-defined objective and set of constraints (Farrell, 1957). Although this methodology is highly flexible and versatile (Thiam et al., 2001; Bravo-Ureta and Pinheiro, 1993), its outcomes are heavily dependent on the inputs used and

* Corresponding author at: Plant Production Systems, Wageningen UR, Wageningen, The Netherlands.
E-mail address: joao.silva@wur.nl (J.V. Silva).

http://dx.doi.org/10.1016/j.eja.2016.06.017
1161-0301/

Please cite this article in press as: Silva, J.V., et al., Explaining rice yields and yield gaps in Central Luzon, Philippines: An application of stochastic frontier analysis and crop modelling. Eur. J. Agron. (2016), http://dx.doi.org/10.1016/j.eja.2016.06.017

refer to current technologies and practices used by farmers which are often far below the agronomic optimum.

Different attempts have been made to reconcile agronomic and economic theories for integrated analysis at farm level (Hoang, 2013; de Koeijer et al., 1999; Herdt and Mandac, 1981). Most of these studies use concepts and definitions from both agronomy and agricultural economics, propose methodological modifications of existing methods to gain further insights on existing yield gaps and provide an empirical application of the concepts using farm survey data. To perform meaningful comparative analysis, it is important to estimate and explain yield gaps using a consistent protocol with local to global relevance (van Ittersum et al., 2013) and to acknowledge that yield gaps exist due to suboptimal crop management and/or resource allocation strategies adopted by farmers given their personal circumstances.

In a recent study, Laborte et al. (2012) estimated rice yield gaps in Central Luzon (Philippines), Suphan Buri (Thailand), Can Tho (Vietnam) and West Java (Indonesia). Rice yield gaps were highest in Central Luzon with a magnitude of about 5.0–5.5 ton ha^{-1} in both wet and dry seasons. An initial analysis further revealed that actual farmers' yields were positively associated with N fertilizer application and labour use. The authors acknowledged the need for a more thorough yield gap analysis and concluded that "a more in-depth farm survey could shed more light on the explanations of the yield gaps and the differences in performance between average and best-yielding farmers".

In this paper, we propose to combine production ecology with methods of frontier analysis in a theoretical framework and apply this to a longitudinal survey of rice farming households in Central Luzon, Philippines. The objective of this study is to decompose the rice yield gap into efficiency, resource and technology yield gaps and to explain those yield gaps using information related to crop management, farmers' objectives and constraints, and production technology employed. Specific research questions for this study were (1) what is the magnitude of the partial yield gaps (i.e. efficiency, resource and technology) in rice-based farming systems of Central Luzon; (2) how have those partial yield gaps changed over time and (3) what are the overriding factors referring to crop management explaining the aforementioned yield gaps?

2. Theoretical framework

Yield gap analysis can be used to investigate the relative contribution of different growth factors to actual yields (van Ittersum and Rabbinge, 1997). As schematically represented in Fig. 1, we propose

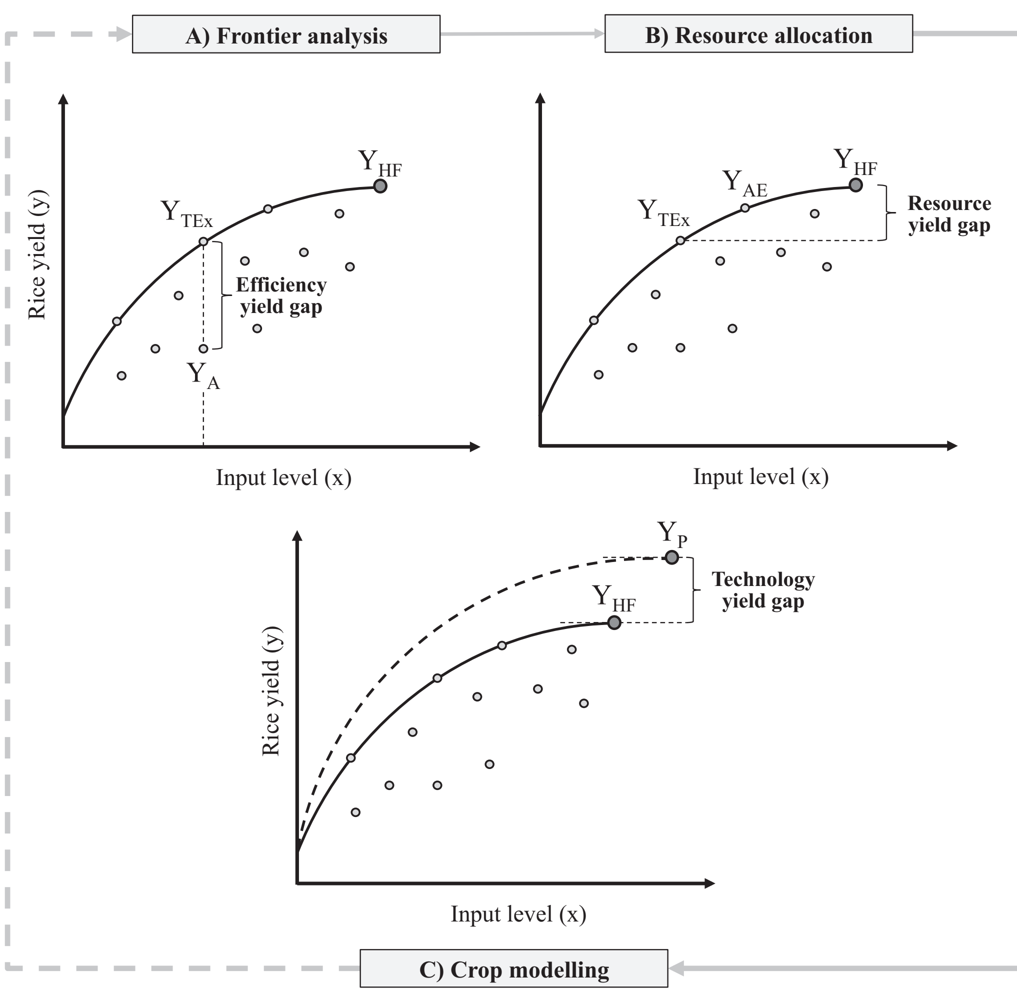

Fig. 1. General framework for explaining rice yield gaps in lowland irrigated rice-based farming systems. Rice yield (Y) is expressed in ton ha^{-1}. Input level (x) refers to a vector of input variables defined based on growth-defining, -limiting and -reducing factors which are expressed either as continuous (kg input ha^{-1}) or dummy variables. Single input–output relationships are shown for illustration purposes only. Y_p is the potential yield as defined by van Ittersum and Rabbinge (1997). Y_{HF}, Y_{TEx} and Y_a are abbreviations for highest farmer's yield, technical efficient yield at a specific input level and actual yield of each individual farm, respectively. Y_{AE} is the allocative efficient yield which can be obtained given farmers' objectives and constraints: it is equal to Y_{HF} from a production perspective. Each dot represents an individual field in a well-defined biophysical environment.