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Thinking beyond agronomic yield gap: Smallholder farm efficiency under contrasted livelihood strategies in Malawi

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A B S T R A C T

Analyses of yield gaps i.e. the difference between observed and attainable crop yields in a given location, have raised expectations of significant potential progress in crop productivity in sub-Saharan African countries. However, an important question remains unanswered: Are those biophysically-determined attainable yields possible given the socio-economic context of farming systems in sub-Saharan Africa? In this study, we explored the potential increase in efficiency of crop production given the diversity of farming systems and livelihood strategies for the case study of smallholder farmers in Malawi. We implemented a non-parametric frontier efficiency method, Data Envelopment Analysis (DEA), which allows for the assessment of technical efficiency with respect to a production frontier. The frontier efficiency is based on best-performing farms in terms of input minimization and output maximization. Based on survey data of 102 households, we first built a typology of farming systems and distinguished two types, i.e. “maize-based smallholders under land pressure” (type 1) and “diversified crop-livestock producers” (type 2). By comparing results from farming system type-specific frontiers with those from an enveloping meta-frontier, we showed that the efficiency yield gap was overestimated by 13% in the case of the meta-frontier approach. Moreover, based on observed farming system-specific livelihood strategies, we defined different directions for reaching the efficiency frontier. For type 1 farming system, we assumed efficiency increase through reduction of both labor and inputs. For type 2 farming system, as income was mainly derived from agricultural activities, we assumed that efficiency increase could be achieved through increase in outputs, i.e. total calorie production from all cultivated crops. We quantified efficiency scores and identified their determinants to provide more specific recommendations on the levers for action to increase efficiency of crop production. Common determinants for both farming system types were adult equivalents in the household and specific efficiency determinants were percentage of cultivated land and average walking time to fields for the type 1 farming system, and farmer’s age and percentage of cultivated land allocated to groundnuts for the type 2 farming system. It is clear that maize-based smallholder farmers under land pressure have little room for improvement of crop yields, and assessing potential gains through more efficient input use is more appropriate than increasing crop yields per se. In this context, a more rational strategy for improving livelihoods is to stimulate labor markets for off-farm income, rather than pursuing increased crop production by closing the yield gap.

1. Introduction

Yield gap is commonly defined as the difference between observed crop yields and those attainable in a given location (Lobell et al., 2009; Mueller et al., 2012; van Ittersum et al., 2013). The assessment of yield gaps requires skills from diverse disciplines such as agronomy, crop ecology, soil science, climatology and social sciences. However, in the last decade yield gap has been approached mainly from a pure agronomic point of view, where yield gap is defined as the difference between potential yield (for irrigated crops) or water-limited yield (for rain-fed crops) using optimal agronomic management, and actual observed yield (van Ittersum and Rabbinge, 1997). Studies on yield gap analysis have therefore focussed on identifying crop growth factors responsible for the yield gap and how yield gaps can be closed through

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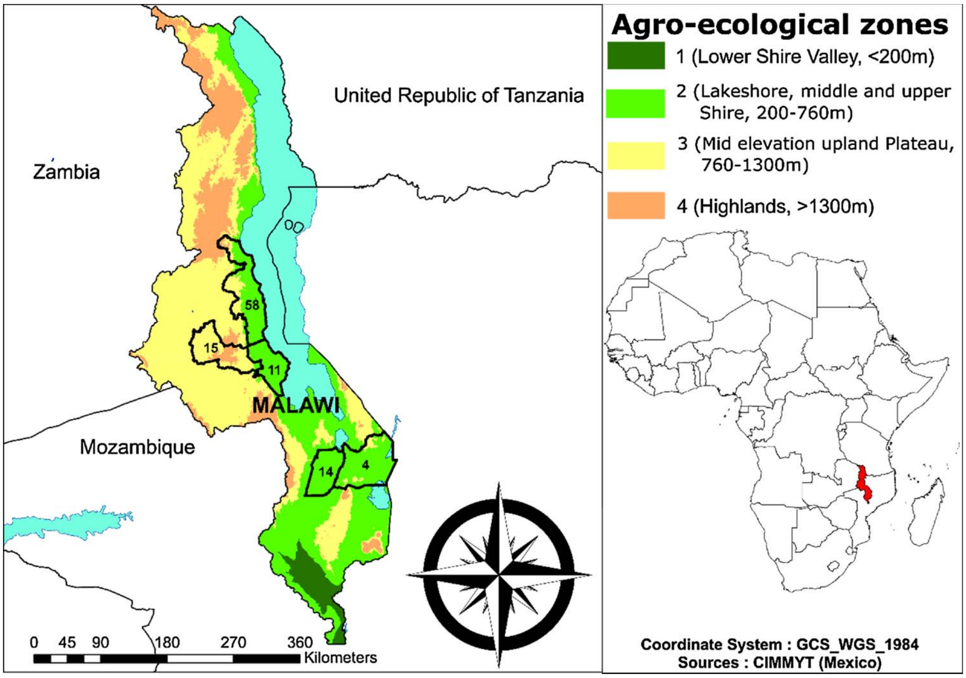

Fig. 1. Case study districts with number of households surveyed per study area and the main agro-ecological zones in Malawi.

more efficient crop management and input use. Yield gap studies are mainly done at field scale, and have increasingly been applied at regional and even global scale in an attempt to estimate global food security and identify potential areas and crops where yield gaps can be closed more easily (e.g. the Global Yield Gap Atlas, www.yieldgap.org, Mueller et al., 2012; van Bussel et al., 2015; van Ittersum et al., 2016).

However, assessing and understanding yield gaps require a broader understanding of the farming systems in which the crops are grown recognizing that decisions on crops and crop management are made at farm level. Therefore, an analysis at farm scale taking into account socio-economic constraints, such as market conditions, labour availability and farmers' aspirations and strategies, is necessary to assess the causes of the yield gap and, more importantly, to identify whether closing the yield gap is the most suitable way to improve farmer livelihoods.

As pointed out by van Noordwijk and Brussaard (2014), a sole focus on the crop yield gap can have negative consequences on other components of the farming system, such as livestock production or off-farm income. This implies that the required level of inputs for closing the yield gap in a specific farm context does not necessarily represent the most cost-effective solution for the farmer. In the same way, Henderson et al. (2016) suggested a "system-wide" yield gap analysis by estimating yield gaps for both crops and livestock on farms and by taking into account all production inputs and outputs at farm level.

Recent publications (Silva et al., 2017; Van Dijk et al., 2017) have combined agronomic and economic approaches to unravel the causes of yield gaps in farming systems. Their framework combines the theoretical yield response function (potential yields calculated with crop models or from experiments under optimal conditions) with the frontier yield response function as used in production economics. The distance between these two functions is attributed to lack of access to and availability of appropriate technologies, and is labelled a technology yield gap. The yield gap is further split into a resource and an efficiency yield gap due to the differences in the level of inputs used and the efficiency with which they are used, respectively. This framework allows for the assessment of the relative importance of biophysical, technological and socio-economic factors in the overall yield gap analyses for a given region. However, it does not give insights on the importance of farmers' objectives and farm resources for closing yield gaps.

In our study, we aimed to identify and analyze prime factors that explain the technical efficiency yield gap in farming systems in Malawi, taking into account livelihood strategies and constraints of smallholder farmers. Using farm household survey data, we combined farm typology with methods of frontier efficiency analysis to determine technical efficiency yield gaps for farms belonging to two farming system types in Malawi. The technical efficiency of farmers is quantified as the distance to the production frontier, which depicts best-practice performance at different input levels (Van Dijk et al., 2017). In economic terms, the efficiency measure considered in this study is technical efficiency, i.e. without consideration of cost of inputs and price of outputs (allocative efficiency, revenue efficiency). We defined a set of distance functions to compute technical efficiency scores for each farm in the sample, both with regard to a meta-frontier that considers all farms of the sample and to the farming system type-specific frontiers that depict best-practice performance for a given group or type of farms. Finally, efficiency scores were regressed on a set of selected agronomic and socio-economic variables to explain the variability in computed efficiency scores and to gain insights on the determinants of the efficiency yield gap for farms and farming systems in Malawi.

A better understanding of the importance of farmers' objectives and farm resources can explain why crop yield gaps exist. We argue that livelihood strategies of smallholders are diverse and closing the yield gap is not always the most efficient strategy. The assumption is that considering distinct farming systems allows for a more accurate identification of determinants of efficiency, giving way to more specific recommendations on the levers for action to increase farm efficiency.

Our study was conducted for a case study of smallholder farmers in Malawi, where maize is the main staple food crop. Malawi is a perfect case study to explore farming system diversity and efficiency due to its diverse biophysical environments (see Fig. 1), crop production systems (Jones et al., 2014), and livelihood strategies (Simtowe, 2010). As illustrated by the outcomes of the Malawian food security strategy that was implemented following the 2005 famine, maize yields can be largely increased in Malawi: from 0.76 $t\,ha^{-1}$ in 2004–2005 to 2.04 $t\,ha^{-1}$ in 2006–2007 (Deening et al., 2009). With yield gaps estimated between 34 and 61% of attainable crop yields (Tittonell and Giller, 2013), sub-Saharan African smallholder farming systems are a high priority for which approaches should be developed to understand the drivers behind the yield gaps and assess whether closing these yield