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Identifying sustainable farms under diverse agro-ecological conditions and livelihood strategies in southern Africa: An interdisciplinary simulation-based approach

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1 Introduction

Agricultural systems face the challenge to feed a growing population while at the same time reducing their environmental impact in a changing world subjected to shocks, such as extreme weather and economic volatility (Godfray *et al.*, 2010). In this global context, southern Africa appears as a particularly sensible region due to the fact that more than 60 % of the livelihoods rely on rain-fed agriculture and have low adaptation capacity (Zinyengere *et al.*, 2014). The diversity of biophysical and socio-economic situations in this region requires prudence in the promotion of "good practices", and a good understanding of local farming systems complexity and their current level of inefficiency. In order to identify the most efficient farms (i.e. minimizing their inputs and simultaneously maximizing their outputs), we implemented the Data Envelopment Analysis (DEA, Charnes *et al.* (1978)) method, which is the most commonly used non-parametric frontier efficiency approach. Using results from farm household surveys conducted in Zambia and Malawi, we modelled the efficiency frontier based on observed best practices in 2012 and identified potential progress margin of efficiency. Even if those results are themselves significant outcomes as efficiency analysis in southern Africa are very rare (Chiona *et al.*, 2014), the originality of this research is the combination of DEA with APSIM (Agricultural Production Systems Simulator) crop model to assess the evolution of this multi-dimensional efficiency frontier. The crop growth model APSIM was used to simulate the performance of a wide range of maize-based cropping systems under different agro-ecological conditions and future climatic scenario, for several types of farming systems identified on structural data basis (cattle, adult equivalent, income, etc.). With this approach we aim to identify cropping systems and farms in southern Africa that are most efficient under future climate.

2 Materials and Methods

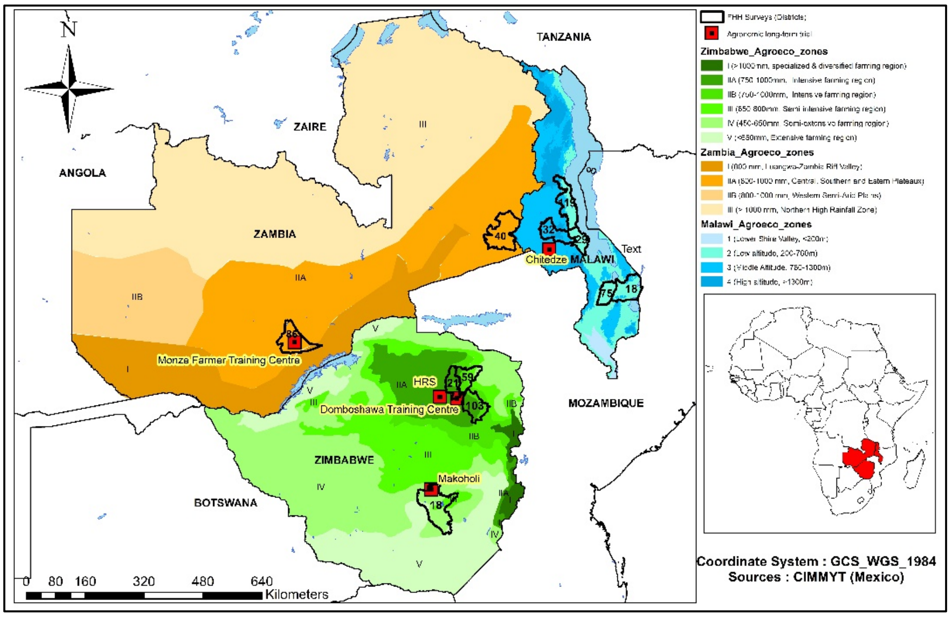

Fig.1. Data overview in the study region: From field scale (long-term agronomic trials) to farm scale (farm household surveys)

Figure 1 shows the location of the long-term agronomic trials used for APSIM calibration and the number of farm households investigated in each district where trial data were available. At the field scale, APSIM (v. 7.6) was calibrated using long-term trial data and future climate was generated with 17 General circulation models (GCM) for two extreme emission scenarios (RCP 2.6, RCP 8.5) (Rusinamhodzi *et al.*, 2015). At the farm scale, farming typology has been implemented with a classic Principal Component Analysis - Ascendant Hierarchical Classification in R 3.0.0. Compared to data displayed in Figure 1, the final typology includes only half of the data available as some survey was incomplete and/or data inconsistent. The efficiency frontier analysis was implemented in GAMS 23.4. The chosen model assumed variable return to scale, i.e. marginal cost differs for each level of inputs and outputs, which implies that each farm can only be compared with farms of similar size. Undesirable outputs are included in the model using the weak disposability assumption (Färe *et al.*, 1989), i.e. to connect undesirable production to the desirable output, while the first one is minimized and the later maximized.

3 Discussion

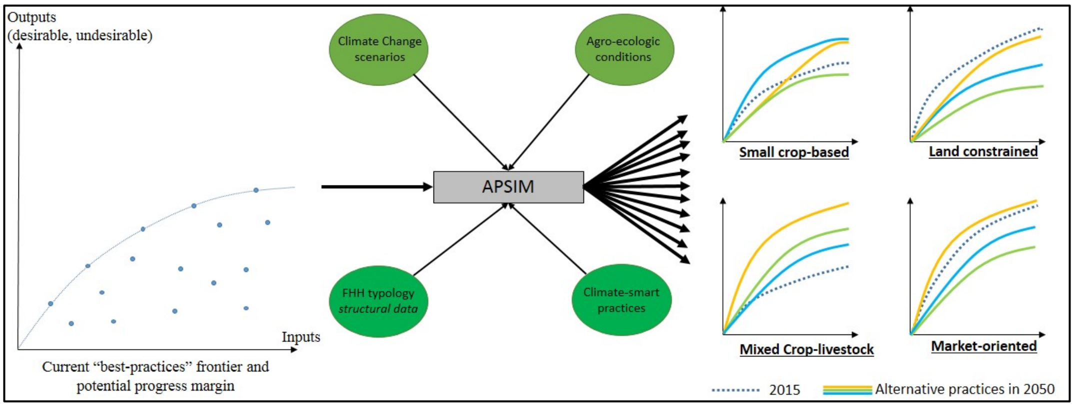

Fig.2. Combining efficiency frontier analysis with APSIM for ex-ante assessment of climate-smart practices

Figure 2 represents the modelling framework implemented to identify future climate smart practices in southern Africa. In this simulation-based optimization modelling approach, APSIM allows simulating the levels of inputs and outputs for several combinations of climate change scenarios, agronomic practices and agro-ecological conditions, for each types of farming system identified. DEA, represents the optimization model which allows assessing on a multidimensional plan the most appropriate climate-smart practices, for every level of inputs, outputs, and undesirable outputs. Compared to classical approach where farm and crop models are combined in a complex integrated framework, our model represents a "loose coupling approach" as promoted by Van Wijk *et al.* (2012) in their review of farm household modelling in climate change context.

4 Conclusions

The diversity of agro-ecologic and socio-economic situations in southern Africa must be tackled with a site and farm-specific calibration of crop models and ad-hoc farm models taking into account farm constraints and farmers' objectives. Frontier efficiency analysis appears as very promising approach compared to other optimization model (e.g. multi objective optimization, multicriteria decision making, etc.) as it allows identifying a whole set of efficient solutions (instead of few Pareto ones) and an interdisciplinary interpretation including microeconomic theory (marginal cost, allocative inefficiency).

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