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Can yield gap analysis be used to inform R & D prioritisation?

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ABSTRACT

The phrase "biggest bang for a buck" is associated with the policy making question that governments and development agencies face: "Where and which crops should receive highest priority for improving local and global food supply?". A first step of prioritisation is to identify region x crop combinations for which high impact can be anticipated. We developed a new method for this prioritisation exercise and applied it to data from the Global Yield Gap and Water Productivity Atlas (GYGA). Our prioritisation distinguishes between two policy objectives (humanitarian and economic) and builds upon the relative yield gap and climate risk. Results of the prioritisation are presented and visualised in Google Earth.

1. Introduction

A number of recent studies have estimated the gap between potential yield and actual yield obtained in farmers' fields (e.g. Waddington et al., 2010; see van Ittersum et al., 2013 for a review of recent yield gap analyses). However, such studies have been criticised (Sumberg, 2012). Sumberg observed that in the yield gap analyses which he reviewed, "no indication is given how to move systematically from the identification of a gap to the development of specific policy prescriptions". Sumberg observed that where possible interventions to close the yield gap are mentioned, these are in most cases "a set of broad responses around which there is already general agreement and which do not follow directly from the yield gap analysis". According to Sumberg, yield gap analysis is used as "a simple and powerful policy framing device", and "It brings an aura of scientific analysis and quantification and appears to be technically rooted. A large gap focuses the mind: surely something must and can be done!".

Can yield gap analyses be more than just a framing device? We propose that the answer depends on the type of yield gap analysis. One type can be described as 'broad scope, low detail on causes', i.e. with a broad scope in terms of crops, large spatial coverage and less focus on identification of causes of yield gaps. A second type is 'narrow scope, more detail' with narrow focus (often just one crop), limited spatial coverage, and with much more detail on identification of causes for closing the yield gap. Examples of yield gap analyses in the 'narrow scope, more detail' category refer to specific crops, e.g. rice: Tanaka et al. (2015, 2013); wheat: Van Rees et al. (2014); maize: Tamene et al. (2015); and soybean: Grassini et al. (2015a). It is easier to derive more specific policy recommendations from such studies because they do provide information about the causes of yield gaps, which can include biophysical constraints such as abiotic/biotic stresses, poor land and crop management practices, socio-economic constraints such as limited access to financial services, and institutional or political constraints including market price. Once specific causes of yield gaps have been identified, the priorities follow directly from the analysis: priority must be given to addressing those factors contributing most to large yield gaps. Prioritisation can be further refined with information on which causes of yield gaps can more easily be resolved and which ones are very hard to resolve based upon available technologies and expected cost-benefit ratios.

Potentially the studies in the 'narrow scope, more detail' category can be useful for local action. However, such studies all use somewhat different methods and are restricted to a certain crop (or two) and one or a few regions making comparison among crops and regions difficult. The 'broad scope low detail on causes' category of yield gap analyses does not have these limitations, but one is left wondering if their role can be more than a framing device. The Global Yield Gap and Water Productivity Atlas (GYGA - www.yieldgap.org) explicitly mentions two policy questions that can be answered with yield gap analyses: (1) are production targets (for self-sufficiency or export) attainable on current land by increasing yields, or will additional area expansion be necessary? and (2) which parts in the world, which parts in a country and which crops should get priority for efforts to narrow the yield gap?

The first policy question has already been addressed in a number of

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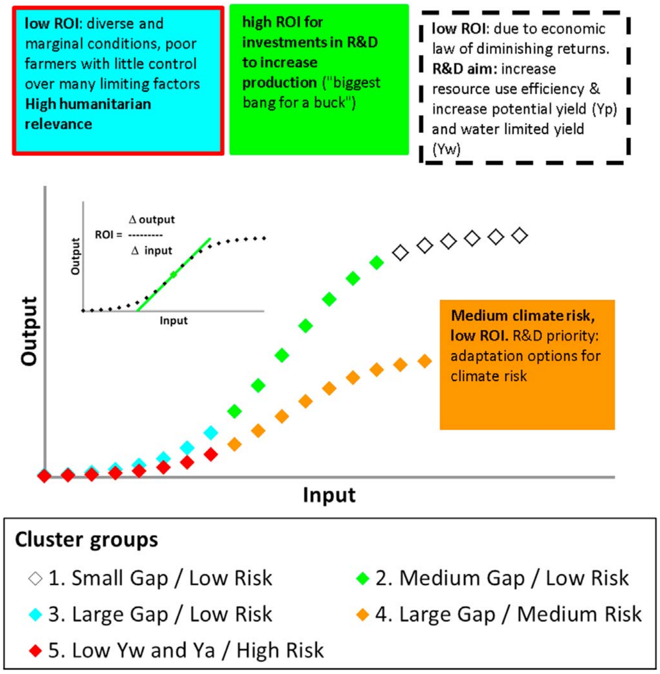

Fig. 1. Conceptual model for prioritisation. Top left inset shows how ROI is calculated, bottom legend shows the names of the 5 cluster groups. Coloured boxes briefly describe the five cluster groups; the description for groups 3 and 5 is merged in one box. Slope (=ROI) is low in the left and right, higher in the middle (orange) and highest in the green group. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 1
R & D recommendations for five groups identified by cluster analysis (Fig. 1).

Cluster group	R & D recommendation
1. Small gap/Low risk (white ◊)	Focus on increasing resource use efficiency and increasing potential yield or water limited yield.
2. Medium gap/Low risk (light green ◊)	"Biggest bang for a buck". Most attractive from the economic perspective, as climate risk is small and expected return on investment (ROI) is largest. For governments/agencies seeking high impact in the short run, this is the group to focus on. Next step should be to identify where crops in this cluster group are located, conduct more detailed research on causes of yield gaps, promote good agricultural practices and improve institutions in the value chain.
3. Large gap/Low risk (light blue ◊)	High humanitarian relevance. This group has in the long run the highest potential for increasing crop yield. For governments/agencies seeking high impact in the long run, this is the group to focus on. The next step should be to investigate causes of yield gaps and possible solutions. No resources should be wasted on better understanding of the climate risk as climate risk is small.
4. Large gap/Medium risk (orange ◊)	High humanitarian relevance. Agricultural research and development (R & D) should focus on reducing climate risk. The next step could be to use crop growth models in a more diagnostic way to get a better understanding on the nature of the climate risk and options to reduce climate risk (such as shifting sowing dates, shorter duration varieties, water harvesting).
5. Low Yw and Ya/High risk (red ◊)	Same recommendation as group 4

studies (Tilman et al., 2011; Aramburu Merlos et al., 2015; Van Oort et al., 2015; Marin et al., 2016). The second policy question has to date not been addressed. But it seems very relevant for international agencies and national governments to know where and with which crop the highest impact can be achieved from their investments in research and development. Or in popular terms, where and with which crop they can achieve "the biggest bang for a buck". Here, we propose a method for deriving simple, first cut, prioritisation of R & D based on 'broad scope, low detail on causes' yield gap analyses from GYGA.

2. Conceptual framework

2.1. Prioritisation: economics, risk and humanitarian perspective

We present our conceptual model for prioritisation in Fig. 1, with 5 cluster groups, for which we expect different return on investment (ROI). As shown in the figure, ROI is the slope of the S-shaped input-output curves. Slope is highest in the middle part of the S-curves and lower in the left part and right part of the curves. We explain the causes and implications of these ROI differences in Section 2.1.1. In Fig. 1 we show two curves, one for lower climate risk and one for higher climate risk. We explain the causes and implications of climate risk for ROI and the research agenda in Section 2.1.2. Note that in Fig. 1 with inputs on the x-axis we refer not only to physical inputs such as water, labour and fertiliser, but also "institutional and information inputs" such as market access, well-functioning cooperatives and extension services. In Table 1 we present policy recommendations for the 5 cluster groups shown in figure 1.

2.1.1. Return on investment (ROI)

Return on investment ROI (=slope) in the left part of Fig. 1 is low. Here we find the farmers in marginal areas who face many constraints. As soon as input of one limiting resource is increased, leading to a small yield increase other resources become limiting, putting a low plateau to yield increase (Liebig's law of the minimum). In such cases one often finds that if multiple inputs are increased at the same time the yield increase is larger than when any one individual input is increased at a time (de Wit, 1992). But increasing multiple inputs at the same time often turns out to be difficult and this is why interventions are often less effective than aspired and more complex and costly to achieve (Fresco et al., 1994). Another issue for the marginal areas is that they often show large agro-ecological, social, infrastructural diversity and therefore require tailor made solutions for each particular area (Reece and Sumberg, 2003). The consequence of this is that science faces demand for a greater variety of technologies than it can feasibly develop (Settle and Garba, 2011; Sterk et al., 2013). Both the multitude of limiting resources and the large variability cause a low expected return on investment (ROI) for marginal areas. Slopes are steepest in the middle part of Fig. 1, indicating highest return on investment. These are the cases for which we may expect the "biggest bang for a buck". By definition slope is steepest in the middle part, but we can see it is still steeper in the low risk than in the high risk curve – we come back to this point in Section 2.1.2. Slope and therefore ROI is low again in the right part of Fig. 1. The slope flattens off because yields approach their biophysical maximum. As a result of the economic law of diminishing returns it is a well-known phenomenon that crop yields reach an economic plateau at around 80% of the potential (Cassman et al., 2003; Grassini et al., 2013). While ROI on further investments is low in these sites, their high productivity renders them important from a global food perspective. For sites in the right part, R & D could focus on increasing the yield potential, increasing resource use efficiency and reducing environmental impacts.

2.1.2. Climate risk and ROI

In Fig. 1 we show two response curves, reflecting different degrees of climatic risk. Cropping systems with high yield potential typically exhibit low year-to-year yield variability and vice versa (Grassini et al., 2014). Therefore, harsh and variable climate generally limits maximum productivity and makes investment in agricultural inputs more risky. Regions with a high climatic risk have a lower ROI (compare the slope for the light green and orange points). The distinction between high