Decomposing economic and technology yield gaps in Nigeria

Michiel van Dijk, Tom Morley, Zuzana Smeets-Kristkova

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# Introduction

Yield gap is a powerful concept to illustrate the possibilities to increase future crop yield and the investigate why actual yield is lower than the biophysical potential. It is defined as the difference between potential yield and actual yield observed at the plot, farm or regional level. Despite its abundant use, the yield gap can be defined and measured in a number of ways, which has resulted in lack of consistency in yield gap analysis in the literature (Lobell, Cassman, and Field 2009). Furthermore, in a recent review of the use of yield gap analysis in key policy papers Sumberg (2012) noted that *"there is a tension between the notion of yield gap as developed in crop ecology (although even here there is no single or consistent usage) and micro-economic studies"* [p. 510].

The aim of this paper is to address some of these criticisms by integrating micro-economic and agronomic yield gap approaches into one single framework. The framework follows the reasoning of Tittonell and Giller (2013), who argue that the gap is caused by two main factors: (1) resource use intensity and (2) access and use of technology. It also extends the work of Fischer (2015), who recently reviewed definitions of crop yield and yield gaps and builds on the work of Van Dijk et al. (2016) and Silva et al. (2016), who combine agronomic and economic approaches to yield gap analysis and measurement.

We start by critically reviewing the most common crop yield and yield gap definitions and highlight a number of inconsistencies in their definition and use. We demonstrate that 'actual yield' can be measured in different ways, leading to different yield gaps. Similarly the use of 'attainable yield' is fraught with difficulties and in practice have been used to define conceptually different production levels. We continue by critically addressing the use of the term 'exploitable yield level (Cassman et al. 2003; Ittersum et al. 2013), sometimes referred to as 'economic yield level' (Fischer 2015). Exploitable yield is normally used to capture the part of the yield gap that will not be closed because of economic constraints and is normally set to 75-85% of potential yield (Cassman 1999; Cassman et al. 2003; Ittersum et al. 2013).

As pointed out by Fischer (2015), these numbers are based on "general experience" [p.11] and mainly represent to situations *"where there is no other competition for the farmers’ resources, and world prices and reasonable transport costs operate"* [p.11]. He also points out that in situations Where this does not occur, such as Sub-Saharan Africa, which is characterized by poor infrastructure and weak institutions, the exploitable yield gap is expected to be much higher. Despite its weak underpinnings the 75-80% 'rule of thumb' is applied frequently as a 'target' in studies to assess potential to increase future crop production. (Oort et al. 2015; Aramburu Merlos et al. 2015), which can be potential misleading, in particular when applied to developing countries. We argue that the definition of (true) economic yield should be rooted in neoclassical economic theory, the dominant paradigm in economics, and be estimated using information on the prices of inputs and outputs. Analogue to arguments in crop ecology, which stress the localized nature of agroclimatic conditions, we argue that economic yield levels are location specific. It is well-known that in many developing countries (sub-national) trade is limited due to poor infrastructure resulting in isolated markets and differentiated market prices (**???**).

To solve some of the inconsistencies with the existing yield and yield gap definitions our conceptual framework introduces three new yield levels that make it possible to decompose the conventional yield gap into a ' technical efficiency', 'economic', 'feasible' and 'technology'. We believe that our framework is able to capture all existing yield gap definitions and reveal the impact of resource intensity and technology on yield gaps.

To demonstrate our framework we present an application using a large nationally representative farm level survey on maize production in Nigeria. [ADD].

The structure of the paper is as follows. Section 2 provides a conceptual framework that integrates varies definitions of yield levels and yield gap. Section 3 briefly discusses the Nigerian farm level maize data set that is used to illustrate the conceptual model. Section 4 computes the yield levels and yield gaps followed by a discussion in Section 5. Finally, Section 6 concludes.

# Background

## Conventional yield levels

For the discussion it is relevant to briefly summarize the conventional yield levels that are used in the agronomic literature to estimate yield gaps.

* *Actual yield* also sometimes referred to as (average) farm yield (Fischer 2015; Ittersum et al. 2013), is the (average) yield obtained by farmers in a geographic area for a given crop with a given water regime (Grassini et al. 2015). It is defined as:

Actual yield is typically expressed in kilograms or tons per hectare and measured relative to harvested land area (Fischer 2015)

* *Potential yield* is defined as *“the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting and with pests, diseases, weeds, lodging, and other stresses effectively controlled”* (L. Evans and Fischer 1999). It depends on local climate and weather factors, including atmospheric CO2 emissions, solar radiation, temperature as well as plant characteristics but is independent of soil, which is assumed to be physically and chemically favorable to crop growth (Van Ittersum and Rabbinge 1997; Sadras et al. 2015). Potential yield is the preferred benchmark for irrigated crops, where precipitation is not a constraining factor.
* *Water-limited potential yield* (or just water-limited yield) is similar to potential yield but takes into account that water supply is limited, which is particularly relevant for rain fed crops. It is therefore strongly influenced by the water holding capacity and rooting depth of the soil, which regulate the supply of water. Water-limited potential yield is the reference value to estimate yield gaps for rain fed crops.
* *Exploitable yield.* is defined as 70-85% of (water-limited) potential yield. The 70-85% is used as a 'rule of thumb' to capture the empirical finding that yield levels tend to stagnate at around 70-85 percent of potential yield (Cassman 1999; Cassman et al. 2003; Lobell, Cassman, and Field 2009, Ittersum et al. (2013), Fischer (2015)). The explanation for stagnating yield levels is mainly economic. For most farmers it will not be cost-effective to purchase the large amount of inputs (e.g. fertilizer) that are needed to produce at the potential yield level (Fischer, Byerlee, and Edmeades 2014) nor will farmers be willing to pay for the additional costs that are needed to 'fine-tune' crop and soil management (Cassman et al. 2003). Fischer (2015), uses exact the same definition but calls it\_economic yield\_.
* *Attainable yield* is used frequently in the yield gap literature but often in a rather ad hoc and inconsistent way, meaning a variety of things. Fischer and colleagues (Fischer, Byerlee, and Edmeades 2014; Fischer 2015) equate attainable yield with *economic yield* by defining it as *'the yield attained by a farmer from average natural resources when economically optimal practices and levels of inputs have been adopted while facing the vagaries of weather'* [p.32]. Sadras et al. (2015) use the following definition: *'the best yield achieved through skilful use of the best available technology'* [p. 6]. A similar definition is provided by (Tittonell and Giller 2013), who defined coin the term 'locally attainable yield', which is *the maximum yield achievable by resource endowed farmers in their most productive fields'* [p78]. Clearly, the definition of attainable yield by Sadras et al. (2015) and (**???**) differs from that of Fischer and colleagues (Fischer, Byerlee, and Edmeades 2014; Fischer 2015) because it reflects the highest possible yield that can be reached with best available technology and not economic constraints. Finally, several researchers take an empirical approach and refer to attainable yield as the average of the (90 or 95 percentile) highest yield in the sample of observations (A. J. Hall et al. 2013; Mann and Warner 2017). In many cases, the empirically observed attainable yield is used to approximate (water-limited) potential yield when results from crop simulation, the preferred measure (Ittersum et al. 2013), are not available.
* *Highest farmers' yield.* (or best farmers' yield) is average of the top 90 or 95 percentile actual yield observed in a sample of farmers or plots (Laborte et al. 2012; Silva et al. 2016). It is identical to the last definition of attainable yield mentioned above.

## Conceptual framework

We use the conceptual framework developed by (**???**) to decompose the conventional yield gap. Figure 1 shows the observed input and output combinations of a number of agricultural units (e.g. field, farm or region). For purpose of illustration, we assume that the observations are small-scale farms in Africa, who produce a single output (e.g. maize) using one input (e.g fertilizer), agroecological conditions are identical for all farms and water is not limited. The *theoretical yield response function* describes the relationship between yield and inputs under perfect crop management and most advanced technology. The maximum of the function is the potential yield level. The *frontier yield response function* is estimated using actual observations from a sample of farmers or plots in a specific country or region. It measures best-practice performance at all input levels and reflects the best management practices and technology that are available in the region. The diagonal line presents the relative input () and output () market price faced by the farmers.

Figure 1 depicts the two yield levels that determine the conventional yield gap, actual yield () for farm and potential yield () as well as the associated input levels. Similar to Tittonell and Giller (2013), we argue that the yield gap is caused by two main factors. The first is resource use intensity. The relationship between resource use and yield is given by the yield response curve. Intensification will results in higher yields, represented by a movement over the curve to the right. We argue that for the majority of farmers the decision on how much inputs to use depends on economic considerations (i.e. profit maximization behavior). Under the assumption of perfect functioning agricultural markets and full information, the demand for inputs will solely depend on relative market prices of inputs and output, and production technology (Sadoulet and Janvry 1995). In developing countries, the assumption of perfect markets is not realistic because of high transaction cost, missing credit and insurance markets and lack of information on input and output prices and available technologies (Stiglitz 1989; Dillon and Barrett 2014). Under these circumstances, the demand for inputs tends to be lower than the economic optimum resulting in lower output and yield (V. Kelly, Adesina, and Gordon 2003). In some cases, farmers the input decision of farmers can be guided by other non-economic objectives such as environmental awareness or output targets [Ref to RUE Rabbinge? - Example] resulting in sub optimal economic input use.

The second major cause of yield gaps is related to the efficient use and adoption of technology. Two different aspects are relevant. The first is technical efficiency, which is defined as the farm’s ability to produce maximum output given a set of inputs and technology (Farrell 1957; Coelli et al. 2005). Best-practice farmers, who are located on the yield response frontier, are considered technically efficient. Farmers below the frontier are considered inefficient because they have a lower yield despite using the same level of inputs and experience the same agroecological conditions. Technical inefficiency implies that crop management is sub optimal, referring to differences in planting dates, spacing, weeding and form of the inputs applied, which, in turn can be related differences in experience and practices, and access to extension services (see Bravo-Ureta et al. 2007; Ogundari 2014 for reviews).

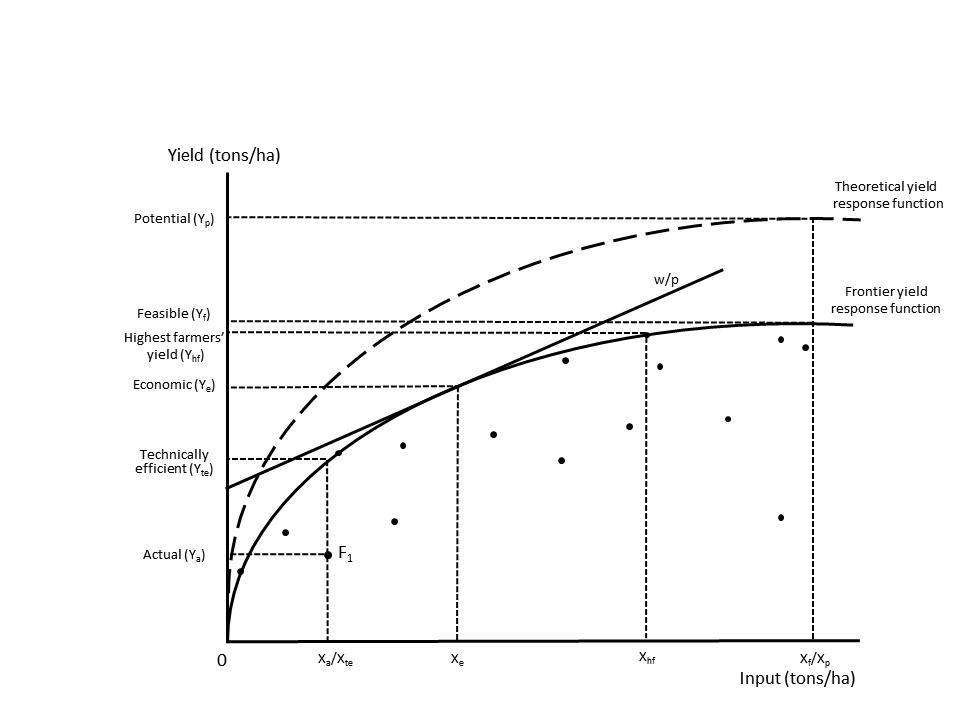
The second technology aspect is the adoption of advanced technologies. As has been pointed out by Tittonell and Giller (2013) most small-scale farmers are subsistence farmers with limited access to appropriate technologies. Even if resource availability would not be a problem and farmers would produce at best-practice level, there would still be a gap with the potential yield level. Closing this gap would require the use of advanced technologies such as precision agriculture, advanced crop management and the adoption of the latest varieties (hybrid seeds). The adoption of advanced technologies will help farmers to increase their yield to a level that previously not could be attained. The effect is an upward shift of the frontier yield response curve in the direction of the theoretical yield response curve and a reduction of the yield gap.

Figure 1 depicts the three yield levels that can be derived on the basis of the economic, technical efficiency and technology constraints discussed above:

* *Technical efficiency yield* measures best-practice performance for a field, farm or region at each input level and reflects the available technology and best management practices in the sample.
* *Economic yield.* is defined as the yield level where profits are maximized (Van Dijk et al. 2016). At this level, the marginal cost of acquiring an additional unit of input (e.g. fertilizer) is equal to the marginal revenue of producing an additional unit of output (e.g. tons of maize). This is a situation of allocative efficiency where Inputs and outputs are distributed in an economic optimal way. This definition of economic yield is consistent with neoclassical economic theory, the dominant paradigm in economics, which postulates that economic actors (e.g. farmers) maximize profits (not production), subject to given output prices, input costs and production technology (Sadoulet and Janvry 1995). *Economic yield* is identified by the point where the relative market price line () is tangent to the frontier yield response function. We prefer this definition over the use of *exploitable yield* and *economic yield* outlined above, which are based on a 'rule of thumb' rather than theoretical assumptions.
* *Feasible yield.* Feasible yield represents the maximum feasible yield that can be reached on a plot with the available technology and best-practice management but without any economic constraints (e.g. inputs are free). This yield level is also sometimes referred to as ‘potential farm yield’ (Datta 1981), ‘maximum attainable yield’ (FAO 2004) and ‘technical on-farm ceiling yield’ (De Bie 2000). It has the same meaning as the definition of *attainable yield* used by Sadras et al. (2015) and Tittonell and Giller (2013).

The figure also depicts the *highest farmers' yield* (for convenience measured as a single observation). In the present situation highest farmers' yield is much higher than economic yield. This implies that, given relative market prices () the farmer with the highest yield is not producing at the economic optimum level. Potential reasons for this behavior might be [ADD]. Another reason might be that the actual relative price of the farmer is lower than the market because of (fertilizer) subsidies, which are common practice in many sub-Saharan African countries. Hence, this particular situation demonstrates that the *highest farmers' yield* is not a good proximate for *economic yield*. On the other hand, although resource use differs considerably (the difference between and ) the *highest farmers' yield* is very close to the *feasible yield level*. A well-known observation in agronomy is that the response to inputs is decreasing (or even stagnates or becomes negative) [REF], at high levels of input use. Hence, despite constraints to resource use, the yield of farmers with the highest yield is likely to be close to the feasible yield level [WILL CHECK IF THIS IS THE CASE FOR NIGERIA]. For this reason, we argue that the \_highest farmers\_yield is an acceptable indicator if one is interested in having a benchmark for the maximum yield achievable on a field using the best-available technology. It is an empirical question whether actual yield, technical efficiency yield, economic yield and feasible yield are located at or close to the same point. This is further investigated below.

**Figure 1: Conceptual framework**



##### Source:

The total yield gap () can be decomposed in four parts: the technical efficiency yield gap (), the economic yield gap (), the feasible yield gap () and the technology yield gap () (Van Dijk et al. 2016). The sum of the economic yield gap and the feasible yield gap has been referred to as the resource yield gap () (Silva et al. 2016). Table 1 summarizes the definitions and potential causes for the the six yield gaps that can be derived from Figure 1.

Global studies of yield gaps clearly show that the (total) yield gap is highest in sub-Saharan countries like Nigeria (Mueller et al. 2012; Licker et al. 2010; Neumann et al. 2010). The decomposition of the yield gap provides a deeper understanding for this finding and its causes. Knowledge constraints (e.g. access to extension services) result in technical efficiency yield gaps while pervasive market failures that characterize (agricultural) input and output markets in many sub-Saharan countries will lead to economic yield gaps. Similarly , we expect a large feasible yield gap because of the unfavorable balance between input and output prices in sub-Saharan countries. This is underscored by the high fertilizer price in many sub-Saharan countries caused poor dealer networks, high transportation costs and small market size (Morris et al. 2007). Finally, the technology yield gap is also expected to be large. [ADD evidence technology use in Africa]. The existence of (agricultural) technology gaps between rich and poor countries has been studied widely (Fagerberg 1994, Mekonnen et al. (2015), Headey, Alauddin, and Rao (2010)) and can been related to the combination of broader institutional, technological, economic and social factors.

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**Table 1: Yield gaps**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Yield gap | Estimation | Definition | Measures | Causes |
| Total yield gap (Yg) | Yp - Ya | The gap between (water-limited) potential yield and actual yield | The biophysical potential for farmers to increase actual yield in a specific agroeconomic environment | The combination of all causes below |
| Technical efficiency yield gap (TEYg) | Yte - Ya | The gap between technical efficiency yield and actual yield measured as the distance to the frontier yield response function | The potential for farmers to increase actual yield in comparison with best-practice farmers that use the same level of inputs and operate under the same agroecological conditions. | Suboptimal crop management caused by knowlegde constraints (e.g. differences in experience, practice, management skills and access to extension services) |
| Economic yield gap (EYg) | Ye - Yte | The gap between economic yield and technical efficiency yield | The extent to which farmers can improve allocative efficiency and increase profits, given input and output prices and available technology. | Market failures caused by missing credit and insurance markets and information assymetries on input and output prices. Production objectives other than profit maximization. |
| Feasible yield gap (FYg) | Yf - Ye | The gap between feasible yield and economic yield | The extent to which economic constraints prevent farmers from producing maximum feasible yield with the available technology and best-practice management | Unfavourbale balance between input and output prices farm-gate (including transport costs, taxes, subsidies and other costs associated with the purchase of inputs and sale of outputs). |
| Technology yield gap (TYg) | Yp - Yf | The distance between the frontier and theoretical yield response curve measured by the gap between (water-limited) potential yield and feasible yield | The extent to which the lack of advanced technologies prevent (best-practice) farmers from reaching potential yield. | Various national-level institutional, technological, economic and social factors that prevent the diffusion and adoption of advanced and appropriate technologies to farmers. |
| Resource yield gap (RYg) | Yf - yte | The gap between feasible yield and technical efficiency yield | The extent to which allocative efficiency and economic constraints prevent farmers from producing at maximum feasible yield with the available technology and best-practice management | Market failures, production objectives otherr than profit maximization, and economic constraints. |

##### Source:

CHECK We also estimate highest farmers' yield to assess if it is close to any of the theoretical yield levels. A major problem with using highest farmers' yield in ##is dealing with the variation in agroecological conditions across the sample. In large samples such as the LSMS-ISA for Nigeria that cover plots in all #parts of the country, potential yield in the XXX zones much lower than that of farmers in XX zones [Figure X]. Simply taking the average yield of the top 95 #percentile of the complete sample will results in a highly biased benchmark. To only way to overcome this issue would be to take averages per agroecological #zone (**???**). However, it seems that this is not done in most studies [CHECK].

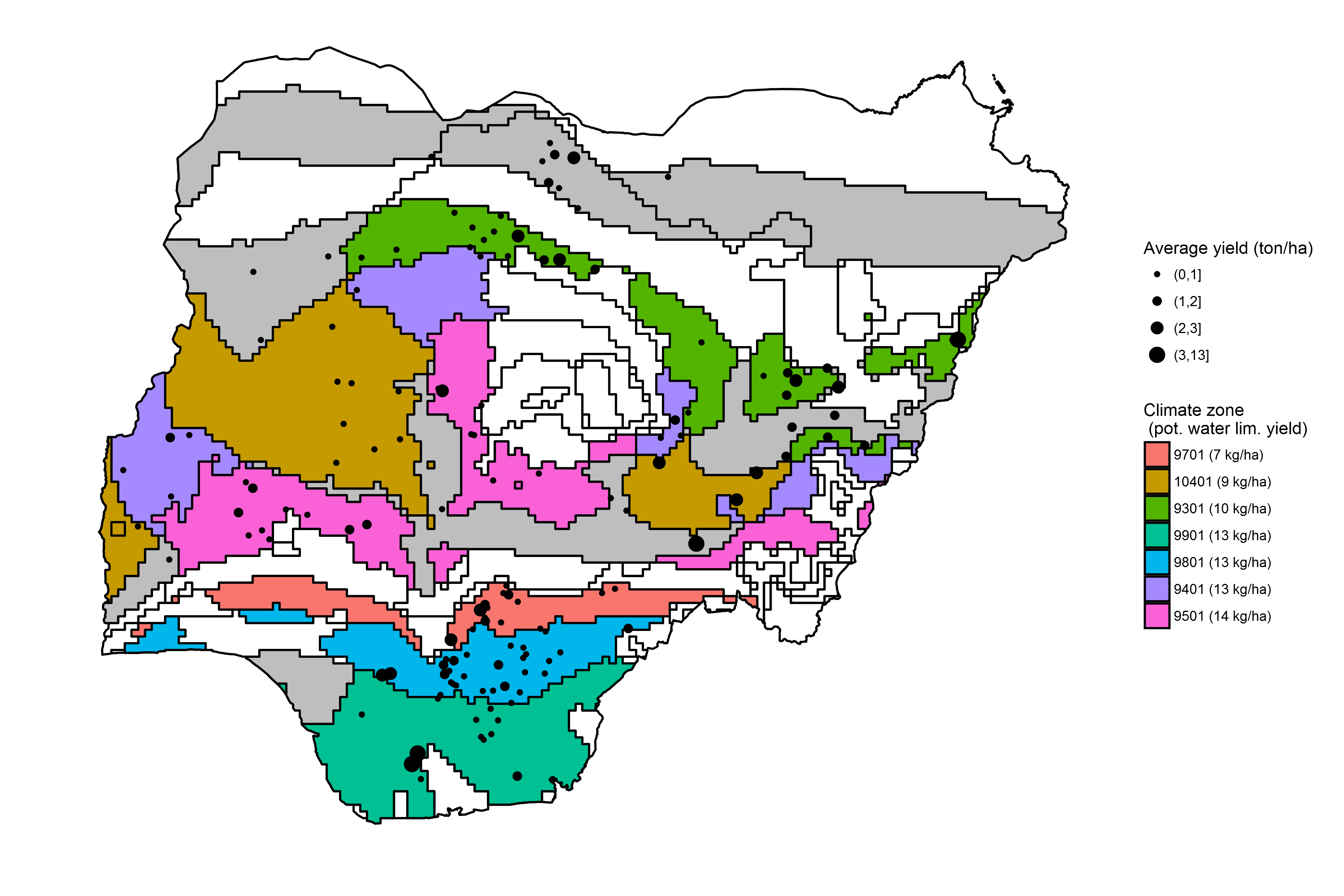
# Data

For the integrated analysis in this study we combine agronomic and economic information from several sources. The following section describes the various data sources and presents summary statistics for relevant variables.

## Potential yield estimations

We take

**Figure 2: Yield gap and LSMS**



##### Source: LMSS

## Farm and plot level data

The plot and farm level data for this study come from the nationally representative 2010-11 and 2012-13 waves of the Nigeria General Household Survey (GHS). In total the GHS is a cross section of 22,000 households, 5,000 of which were included as panel households forming the GHS-panel. The focus of the GHS is to improve the quality of data on the agricultural sector and was conducted by the National Bureau of Statistics in partnership with the Federal Ministry of Agriculture and Rural Development (FMA&RD), the National Food Reserve Agency (NFRA), the Bill and Melinda Gates Foundation (BMGF) and the World Bank (WB). In each wave, households were visited twice reflecting the post planting and post harvest visits. The data was collected at several levels, including at the plot, household and enumeration area level, and the location of each household was GPS recorded with an offset to preserve household anonymity.

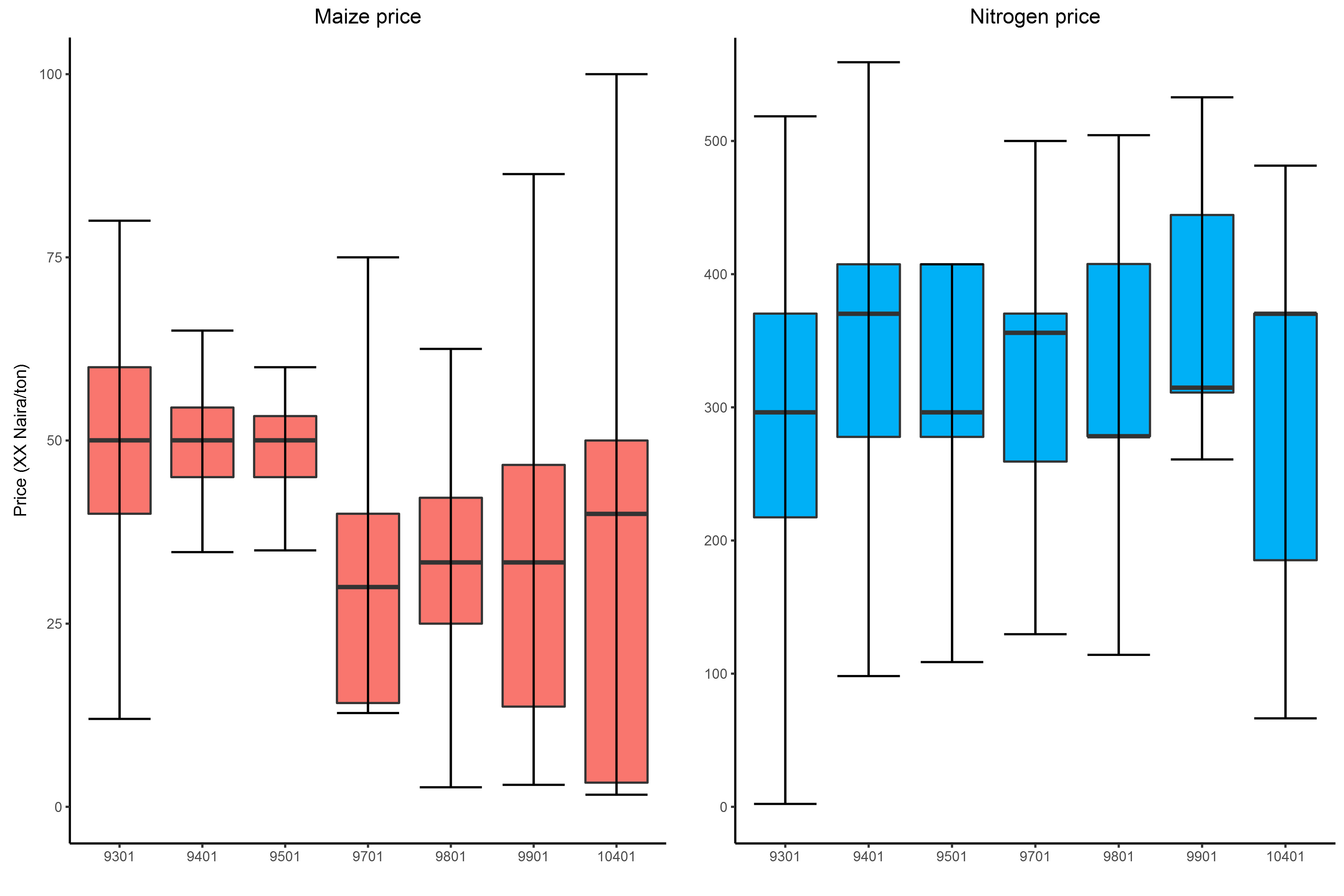
The agricultural questionnaire of the GHS records key information at the plot level including the quantity of crop harvested, the quantity of fertilizer and seeds applied and the area of the plot. Plot area measurements were recorded by GPS in each wave, and where it was not possible to record the GPS area, for example due to cloudy weather, the World Bank provides a complete set of plot areas with imputed missing values. (**???** on GPS vs harvested area). From this information maize yield, and nitrogen application rates can be calculated. As some yield and nitrogen measurements clearly fell outside a plausible range, we followed the approach of other studies that use similar plot and farm level surves (**???**) and restricted the size of the plot to XX and XX hectares, and the use of Nitrogen to 700 kg per hectare, the maximum use in the United States (**???**). Maize yields may also depend on factors including the amount of labour on a plot, the use of farm machinery (**???** antrac def) and other farm capital, which is also provided by the GHS.

## Input and output price information

A key aspect of this study is to investigate the economic constraints to closing the yield gap, which is influenced by the relative price of maize and inputs (in this case nitrogen). The GHS presents detailed information on the value and quantity of maize sold and fertilizer purchased at the plot level. We use this information to calculate plot level prices. We winsored the prices of both maize and nitrogen to remove values that were more than three standard deviations from the median per climate zone.

Figure X shows the distribution of maize and nitrogen prices per zone in Nigeria. It demonstrates that prices vary considerably within and between geographical locations. In the Northern zones, the **interquartile?** range lies between X and X Niara, while in the Southern zones prices are on average lower. Nitrogen prices also vary across Nigeria but exhibit a similar average that around XX Naira. It

**Figure 3: Maize and Nitrogen prices**



##### Source: LSMS-ISA and GYGA

(**???** Transport costs)

**Table 2: Descriptive statistics per climate zone**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| variable | 10401 | 9301 | 9401 | 9501 | 9701 | 9801 | 9901 | Minor zones | Total |
| area\_harv | 0.78 | 0.69 | 0.67 | 0.43 | 0.13 | 0.13 | 0.066 | 0.67 | 0.45 |
| mean\_N\_harv | 47.58 | 114.11 | 39.01 | 31.93 | 38.73 | 22.45 | 105.358 | 81.24 | 58.88 |
| Ncon | 117.86 | 169.22 | 142.53 | 96.47 | 239.19 | 133.61 | 343.801 | 150.57 | NA |
| NumberHH | 59.00 | 135.00 | 55.00 | 61.00 | 59.00 | 121.00 | 37.000 | 94.00 | 621.00 |
| Numberplot | 109.00 | 218.00 | 95.00 | 145.00 | 105.00 | 244.00 | 62.000 | 139.00 | 1,117.00 |
| sharePlots | 9.76 | 19.52 | 8.50 | 12.98 | 9.40 | 21.84 | 5.551 | 12.44 | 100.00 |
| yesN | 40.40 | 67.40 | 27.40 | 33.10 | 16.20 | 16.80 | 30.600 | 54.00 | 37.30 |
| Yield | 1,143.97 | 758.08 | 477.18 | 858.96 | 810.44 | 631.85 | 2,652.377 | 724.37 | 802.49 |

##### Source: LSMS-ISA and GYGA

## Climate and soil variables

In addition the biophysical role of nitrogen on maize can also depend on soil, seed type and climate conditions, for example the carbon content of the soil (Barrett). To some extent this information is included in the GHS and the spatial and climate data that accompanies the main survey. In this report we go further by using the GPS recorded household locations to combine the GHS with external data with a finer resolution than currently provided with the GHS survey. We therefore have more accurate information on key variables to improve the analysis of the maize yield gap and the role of nitrogen application.

# Estimation of yield levels

## Technical efficiency yield

Boundary lines are often used to estimate yield gaps [REFS]. In this study we use stochastic frontier analysis (Meeusen and van Den Broeck 1977; Aigner, Lovell, and Schmidt 1977) to estimate the yield levels in Figure 1. This approach is somewhat comparable to boundary analysis as it also estimates an envelope curve that represents best-practice yield at each level of input. The advantage of stochastic frontier analysis over boundary analysis is that it simultaneously takes into account multiple inputs instead of only addressing one input as is the case in boundary analysis. Depending on the functional form of the yield response curve, inputs can be complementary or substitutes. Stochastic frontier analysis is increasingly used to estimate yield gaps (Henderson et al. 2016, Hoang (2013), Silva et al. (2016), Van Dijk et al. (2016))

We estimate a frontier yield response curve that accounts for the impact of growth defining, growth limiting and growth reducing factors on crop growth [VanIttersum1997[ as well as economic production factors (**???**, (**???**)), which all will have impact on actual yield (**???**). It is defined as follows:

where are growth defining factors, including. are growth limiting factors, are growth reducing factors and $X $ are economic production factors.

## Economic yield

## Feasible yield

## Potential yield

# Results

## Frontier yield response estimation

**Table 3: Frontier yield response curve estimation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| variable | Coef. | Std. Error | Coef. | Std. Error |
| (Intercept) | -9.240 | 1.570 \*\*\* | -9.600 | 1.640 \*\*\* |
| noN | 0.600 | 0.370 | 0.870 | 0.380 \* |
| logN | 0.220 | 0.080 \*\* | 0.250 | 0.080 \*\* |
| logasset | 0.050 | 0.030 | 0.030 | 0.030 |
| logae | 0.150 | 0.120 | 0.410 | 0.080 \*\*\* |
| logseedq | 0.080 | 0.030 \*\* | 0.090 | 0.030 \*\* |
| logarea | -0.300 | 0.120 \* | -0.030 | 0.090 |
| pestherb | -0.110 | 0.150 | -0.200 | 0.140 |
| irrig | 0.280 | 0.660 | 0.460 | 0.660 |
| antrac | 0.590 | 0.170 \*\*\* | 0.570 | 0.170 \*\*\* |
| slope | 0.010 | 0.030 | 0.000 | 0.030 |
| elevation | -0.000 | 0.000 | -0.000 | 0.000 |
| SOC2 | 0.050 | 0.020 \* | 0.060 | 0.020 \*\* |
| phdum22 | 0.900 | 0.230 \*\*\* | 0.720 | 0.230 \*\* |
| phdum23 | 0.850 | 1.970 | 0.860 | 1.980 |
| rain\_wq | 0.030 | 0.000 \*\*\* | 0.030 | 0.000 \*\*\* |
| rain\_wq2 | -0.000 | 0.000 \*\*\* | -0.000 | 0.000 \*\*\* |
| crop\_count2 | 1.280 | 0.180 \*\*\* | 1.200 | 0.180 \*\*\* |
| surveyyear2 | 1.370 | 0.150 \*\*\* | 1.440 | 0.150 \*\*\* |
| sigmaSq | 5.450 | 1.370 \*\*\* | 4.750 | 1.310 \*\*\* |
| gamma | 0.490 | 0.260 | 0.320 | 0.340 |

##### Note:

# CLIMATE ZONES

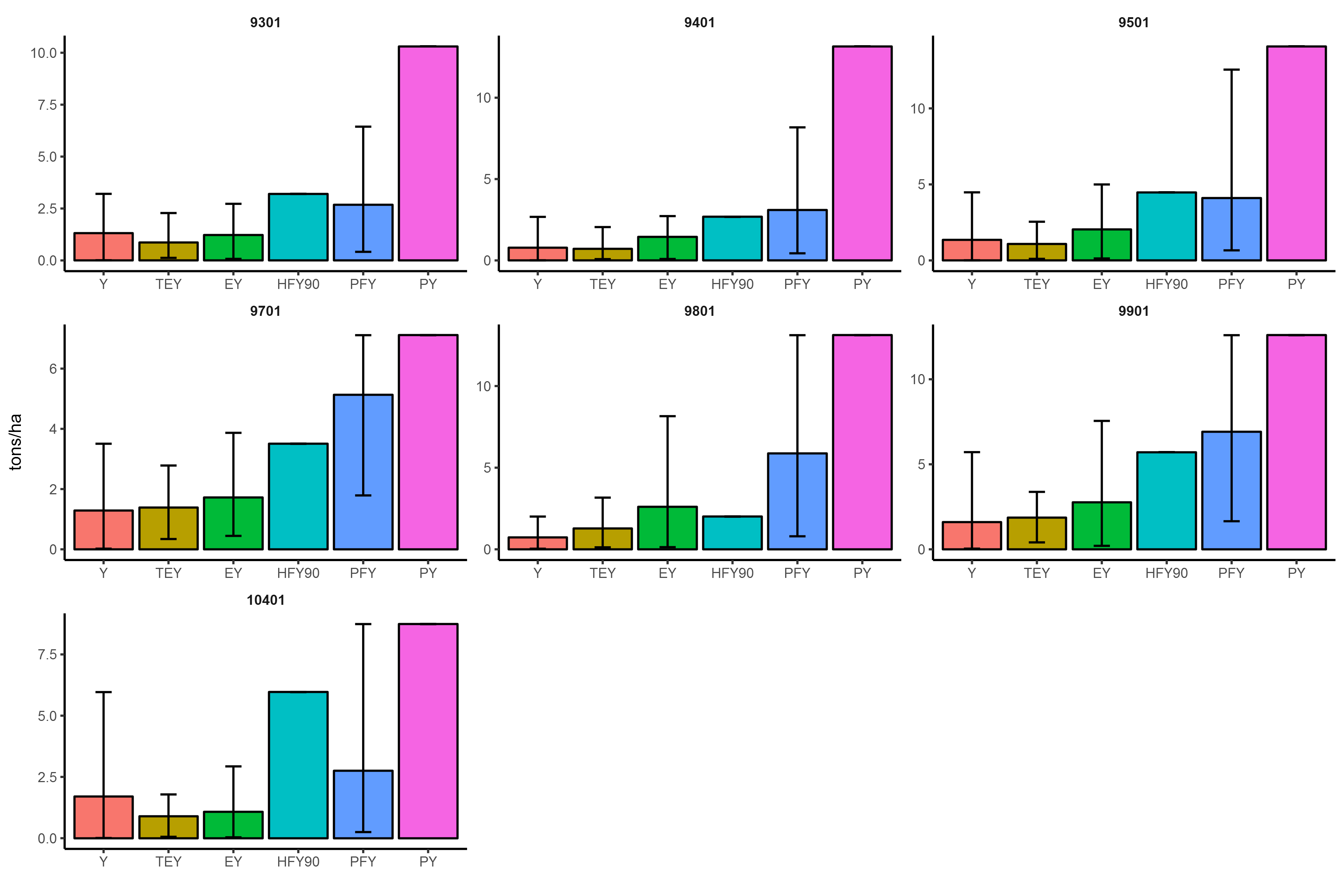
To calculate potential yield, the GYGA identifies climate zones, which have similar biophysical conditions (**???**). There are in total XX Climate zones in Nigeria. Climate zones are defined by their XX number.

In this study we focus on the main maize producing area in Nigeria for which we have sufficient number of observations over space and time. Most maize is produced in seven out of the XX climate zones that are defined by the GYGA. In order to have sufficient units for our analysis we set the minimum number of observations to 50 per climate zone. Our final sample accounts for X percent of the total maize plots in Nigeria for which information is presented in the LSMS-ISA (Annex A). Most maize is produced in the cereal root crop mixed farming systems zone that forms a belt over Nigeria that expands from East till West (**???**). This zone is characterised by by XX and XX. [compare with other CZs and refer to table in Annex] (**???**). Hence, although our findings are not representative for total maize production in Nigeria, they can be considered for the main maize regions in the country.

Table x presents summary statistics for the climate zones that are located in the maize producing regions and Figure combines information from the LSMS-ISA and the GYGA (see annex X for the locations of the CZs).

## Yield levels

**Figure 4: Yield levels**



##### Source:

**Table 4: Frontier yield response curve estimation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Climate zone | TEYg | EYg | FYg | TYg | Yg |
| 9301 | 3 | 2 | 9 | 86 | 100 |
| 9401 | 2 | 4 | 8 | 86 | 100 |
| 9501 | 2 | 5 | 10 | 83 | 100 |
| 9701 | 6 | 8 | 31 | 56 | 100 |
| 9801 | 4 | 3 | 19 | 74 | 100 |
| 9901 | 5 | 5 | 31 | 60 | 100 |
| 10401 | 4 | 2 | 17 | 77 | 100 |
| Total | 3 | 3 | 12 | 82 | 100 |

##### Note:

* calculate different yield gaps, also attainable yield gap and show differences
* Compare distributions of yield gap per zone.

Comparison with literature

Compare highest farmer yield with economic and feasible and show difference!!

# Sensitivity analysis

Most attention in the literature on yield gaps has been devoted to the definition and measurement of potential yield, while that of actual yield has received relative limited attention (e.g. in recent reviews on yield gap approaches and data requirements for yield gap analysis (Ittersum et al. 2013, Grassini et al. (2015)), the definition of area is not addressed at all). It is evident that the measurement of the two components of actual yield - quantity harvested and area - have significant impact on estimations of actual yield and the yield gap. Although, the measurement of both components is fraught with difficulties (Fermont and Benson 2011; Reynolds et al. 2015), we fill focus here only on the measurement of area for which we have the data to compare a variety of definitions.

Two potential problems are relevant. The first is a question about which definition to use for area. It is common practice in the yield gap literature to follow the FAO definition and use harvested area to calculate actual yield (Fischer 2015). Nonetheless, in a recent study Reynolds et al. (2015) argue that this definition leads to serious overestimation of actual yield because it ignores crop losses that might occur between planting and harvesting and a definition of actual yield relative to planted area is recommended.

Causes for the difference in area planted and area harvested include crop management factors (e.g. poor germination, damage from pests and diseases) and economic constraints (e.g. labor and capital constraints and shortage of market opportunities). These are exactly the same factors that one tries to grasp when doing yield gap analysis. Crop management and resource use decisions by farmers will be based on total plot area that is considered for agricultural production, not only the harvested area. Yield gap assessments using a definition based on harvested areas therefore will only capture a part of the yield gap.

The second is a measurement problem and deals with how to measure area (planted and harvested) in the best way. It has been shown that farmer self-assessed area is characterized by systematic errors and therefore GPS measurements are recommended (Carletto, Gourlay, and Winters 2015). This is also underscored by the latest generation of (large-scale) household surveys, such as the LSMS-ISA that is used in this paper and the DHS, in which GPS measures are part of the standard protocol. Similarly, there are several initiatives that support the crowd-sourcing of plot size area using GPS to strenghten the property rights of farmers. Exact (GPS) measures of harvest area are often not available because this will tend to change every year. A potential disadvantage of using GPS measures is that they often measure the total size of the plot or field, which may contain more than one crop because of multi-cropping or inter-cropping. This will likely result in an underestimation when compared to plots where all planted area is used for a single crop only.

# Conclusions/Discussion

Main findings

* Reviewed conventional yield levels used in agronomic literature and revealed some inconsistencies in the use and definition of certain yield levels. In particular the use of attainable yield and exploitable yield.
* We present a consistent framework that decomposes the conventional yield gap into four parts that are firmly rooted in neoclassical economics and therefore provide a theoretical framework on explaining why yield falls below potential.
* We also demonstrated how the impact of actual yield definitions on yield gap.

Recommendations:

* We recommend that attainable yield gap is not used as it is a highly confusing term as it can mean: economic yield, technical efficiency yield or . We propose to use the definitions that actually. We have similar objections to the term exploitable yield, which is based on a rule of thumb. Better to use..
* We recommend that researchers are clear about their definition of actual yield. There is no perfect solution for the definition of area when measuring actual yield. Plot size is probably the best measure if one wants to capture all factors that cause the yield gap (including for example the economic or biophysical reasons, why a farmer did not harvest the full plot) but raises difficulties in situations where multiple crops are grown on one plat. On the other hand, harvest yield [ADD]. In any case researchers should properly explain which definition they used to measure actual yield.

Limitations

* study only covers two years. Recommended number of years is 5(?). Actual yield might be biased because of outliers. Better to use more years, possible in the future when LSMS is repeated.

A subsidy program did exist in Nigeria over the course of this survey. However, farmers were not asked whether they received these subsidies for the fertilizer they purchased which may also have consequences for the analysis ... # References

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