Exploring Maize Intensification with the Global Yield Gap Atlas

By Patricio Grassini, Kenneth G. Cassman, and Martin van Ittersum

The Global Yield Gap Atlas (www.yieldgap.org) provides estimates of yield potential, yield gap, and water productivity for maize and eight other major food crops.

Maize yield gaps range from 80% in Sub-Saharan Africa and India to 15% in irrigated and favorable rain-fed environments in USA and Europe. The Atlas can help identify regions with greatest potential for sustainable maize intensification.

The global community must find a way to provide food and water security for a population expected to reach 9.7 billion by 2050. Global carrying capacity for food production and our ability to protect carbon-rich and biodiverse natural ecosystems from conversion to cropland ultimately depends on achieving maximum possible yields on every hectare of currently used arable land and achieving this goal with sustainable use of available water resources. **Yield potential** is the maximum attainable yield as determined by climate and soil in absence of nutrient deficiencies and biotic stresses. **Water productivity** is the efficiency with which water is converted to food. Yet for most major crop-producing regions of the world, including data-rich regions such as the U.S. Corn Belt and Europe, there were, until recently, no reliable data on yield potential and water productivity. These two parameters are critical benchmarks in agricultural areas where rain-fed and irrigated agriculture is under pressure. With good crop and water management practices, farmers should be able to attain about 80% of the site-specific yield potential and water productivity (**Figure 1**).

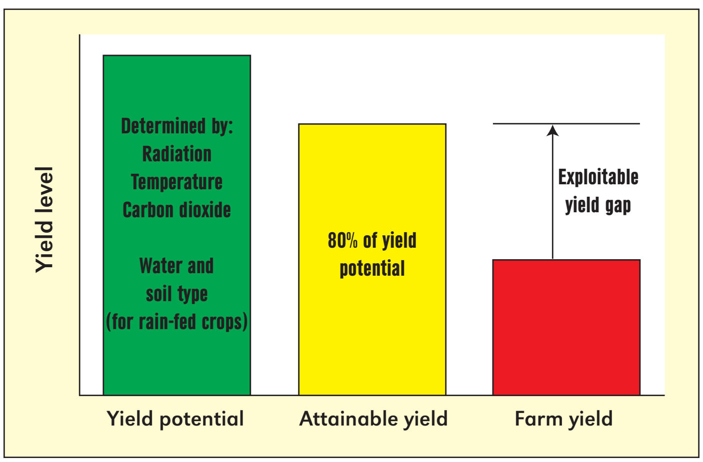

Figure 1. Crop yield potential (either irrigated or rain-fed), attainable yield, and on-farm yield. Adapted from van Ittersum et al. (2013).

In 2011, researchers from University of Nebraska-Lincoln (USA) and Wageningen University (The Netherlands) began the development of the Global Yield Gap Atlas (GYGA), with the goal of establishing improved methods for estimating the yield gap -- the difference between current average on-farm yield and yield potential -- and water productivity on every hectare of existing crop land worldwide. The first phase of the project (2012-2015) focused on cereal crops. Recently, the crop list has been extended to include soybean, sugarcane, and potatoes. The country-crop combinations included in the Atlas so far account for 60%, 58%, and 35% of the global rice, maize, and wheat production, respectively (**Figure 2**).

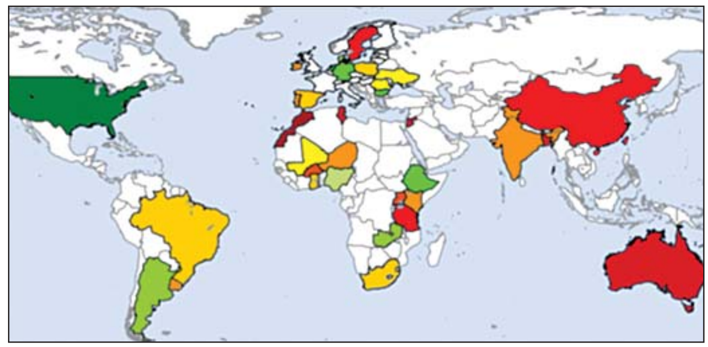

Figure 2. Current coverage of the Global Yield Gap Atlas (www.yieldgap.org). The Atlas currently covers nine crops (maize, rice, wheat, sorghum, millet, soybean, sugarcane, barley, and potatoes) and 42 countries.

GYGA is an international project that requires "boots-on-the-ground effort" because it is based on local data from each of the world's major crop production countries. Essential data include soil properties that govern plant-available water holding capacity in the soil profile to maximum rooting depth, long-term weather records, and planting and harvest dates of major crops in existing cropping systems. A standard protocol for assessing yield potential, yield gaps, and water productivity based on a strong agronomic foundation was developed (**Figure 3**) and applied in a bottom-up process that uses local experts and networks to provide knowledge about crop management and productivity and existing soil and climate databases.

These data are used with the most appropriate crop simulation models and a geographic information system and scaling method to produce detailed maps with associated databases displayed. All maps and underlying data are accessible through an interactive web-based platform suitable for expert and non-expert users (www.yieldgap.org). To the extent that intellectual property restrictions allow, all data used in building the Atlas are made publicly available as a resource for scientists, policy makers, agri-business, and others. In other words, GYGA provides a web-based platform for estimating yield potential, yield gaps, and water productivity that is transparent, accessible, reproducible, geospatially explicit, agronomically robust, and applied in a consistent manner throughout the world.

Table 1 provides a summary of maize average yield potential, on-farm yield, and yield gaps estimated across the maize producing countries included in the Atlas. Yield potential was simulated for each cropping system based on long-term weather data and local soil and cropping system data. Estimates of yield potential shown here represent national averages, calculated

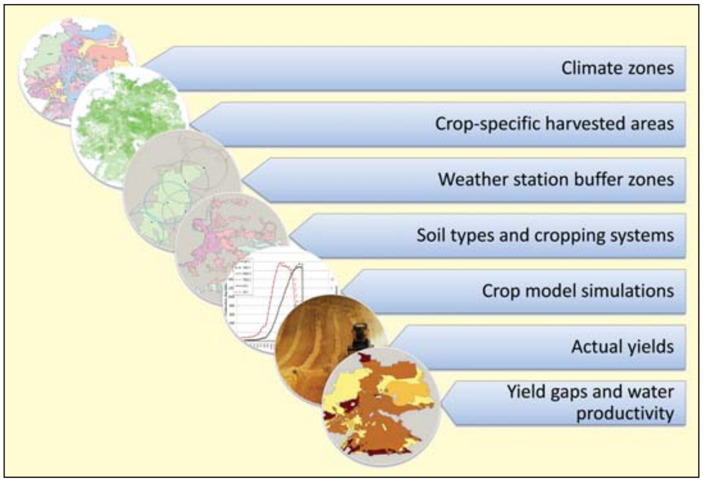

Figure 3. Protocol developed by the Global Yield Gap Atlas to estimate yield potential, yield gaps, and water productivity. Briefly, sites located within the major crop producing areas within a country are selected and local weather, soil, current yields, and cropping system data are used as basis to simulate yield potential and estimate yield gaps and water productivity. Figure developed by Dr. René Schils, regional coordinator for GYGA-Europe. Detailed description of the GYGA methodology can be found in Grassini et al. (2015) and van Bussel et al. (2015).

Table 1. Yield potential, on-farm yield, and yield gap (expressed as % of yield potential) for selected maize producing countries included in the Global Yield Gap Atlas. Source: www.yieldgap.org

Region/country	Water regime	On-farm yield, t/ha[5]	Yield potential, t/ha	Yield gap, %
West Africa[1]	Rain-fed	1.7	10.0	83
India	Rain-fed	1.6	9.3	83
East Africa[2]	Rain-fed	1.8	8.0	78
Brazil	Rain-fed	4.7	8.7	54
East Europe[3]	Rain-fed	4.5	8.7	48
Bangladesh	Irrigated	5.7	10.1	43
Argentina	Rain-fed	6.8	11.6	42
South Europe[4]	Irrigated	10.2	14.8	31
USA	Rain-fed	9.7	12.4	22
USA	Irrigated	11.8	14.0	16
Germany	Rain-fed	9.7	11.0	12

[1]Includes Ghana, Mali, Burkina Faso, and Nigeria.
[2]Includes Ethiopia, Uganda, Kenya, Tanzania and Zambia.
[3]Includes Bulgaria, Ukraine, Hungary, Poland, and Romania.
[4]Includes Spain and Portugal.
[5]Actual yields estimated based on most recent available statistics in the last 10 years.

based on the area where maize is currently grown in each country and using many years of weather data to account for weather variability. Likewise, the yield potential estimate here is based on current crop sequences and dominant management practices such as planting date, plant density, and cultivar maturity. For the purpose of this summary, some countries were aggregated into regions given the similarity of their yield gaps and yield potential. Average yield potential ranges from 14.8 to 8 t/ha across countries/regions, reflecting differences in water supply (irrigated *versus* rain-fed), length of crop growing season as determined by annual patterns of temperature and rainfall, and crop intensity (one *versus* multiple crops planted in the same piece of land in a 12-month period). However, a common feature is the existence of a yield gap, though the size of this gap is highly variable across countries (from 15 to 80%).

Figure 4 illustrates the range of yield gaps by looking at three maize producing regions with contrasting level of intensification: irrigated maize in the United States, rain-fed maize in Argentina, and rain-fed maize in Sub-Saharan Africa. Variation

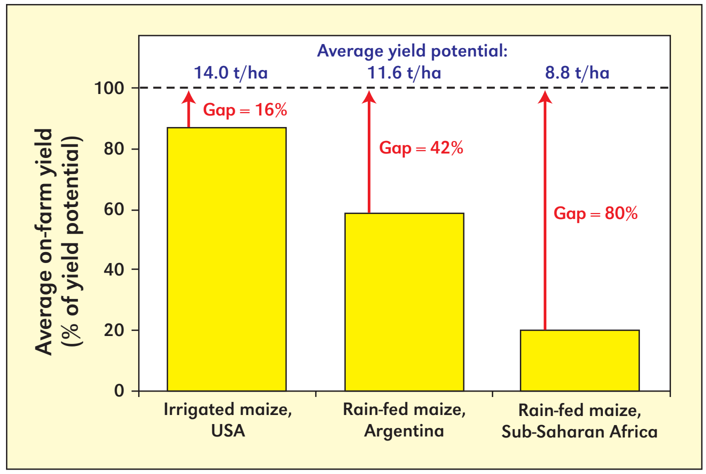

Figure 4. Average on-farm yield, expressed as a percentage of the yield potential, for three cropping systems with different level of intensification: irrigated maize in USA and rain-fed maize in Argentina and Sub-Saharan Africa. Values above bars indicate average yield potential, which was calculated using crop simulation models based on long-term weather data (solar radiation, temperature, and precipitation) and local soil and management data. Size of the yield gaps is shown with the red upward arrows. Sources: Global Yield Gap Atlas (www.yieldgap.org) and Aramburu et al. (2015).

in the size of yield gap reflects not only differences in access to information and inputs, but also differences in risk level in relation to weather variability. In the case of irrigated maize in U.S., access to irrigation water compensates for weather variability and associated risk, allowing crop producers to optimize farm management and achieve a small yield gap. Rain-fed producers in Argentina face large uncertainty about weather conditions in the season ahead, which in turn creates uncertainty about the appropriate level of inputs. If they apply input levels in excess of the amount needed for maximum profit in a year when yield potential is below average due to unfavorable weather, they will likely achieve a small yield gap but with smaller profit. On the other hand, if farmers are too conservative and under-invest in inputs in a year with high yield potential due to favorable weather, they will miss the possibility of achieving a large profit and will have a large yield gap. As a result, the yield gap for rain-fed maize in Argentina is larger than for irrigated maize in USA. Still, the maize yield gap in Argentina is relatively small compared to rain-fed maize in Sub-Saharan Africa. A key difference is that Argentine farmers have better access to inputs and information than Sub-Saharan African farmers.

The Atlas enables farmers, governments, policy makers, foundations, NGOs, the private sector, and others to identify regions with greatest potential for investment in agricultural development and technology transfer and to monitor impact over time. And the Atlas can be used to assess the feasibility of a country or region to achieve food self-sufficiency through crop intensification and, if this cannot be achieved, for assessing how much extra land clearing or food import will be needed to meet future demand for food. A number of studies have been published on these topics using the GYGA approach (Aramburu et al., 2015; van Oort et al., 2015; Espe et al., 2016, Marin et al., 2016, van Ittersum et al., 2016; Timsina et al., 2016).

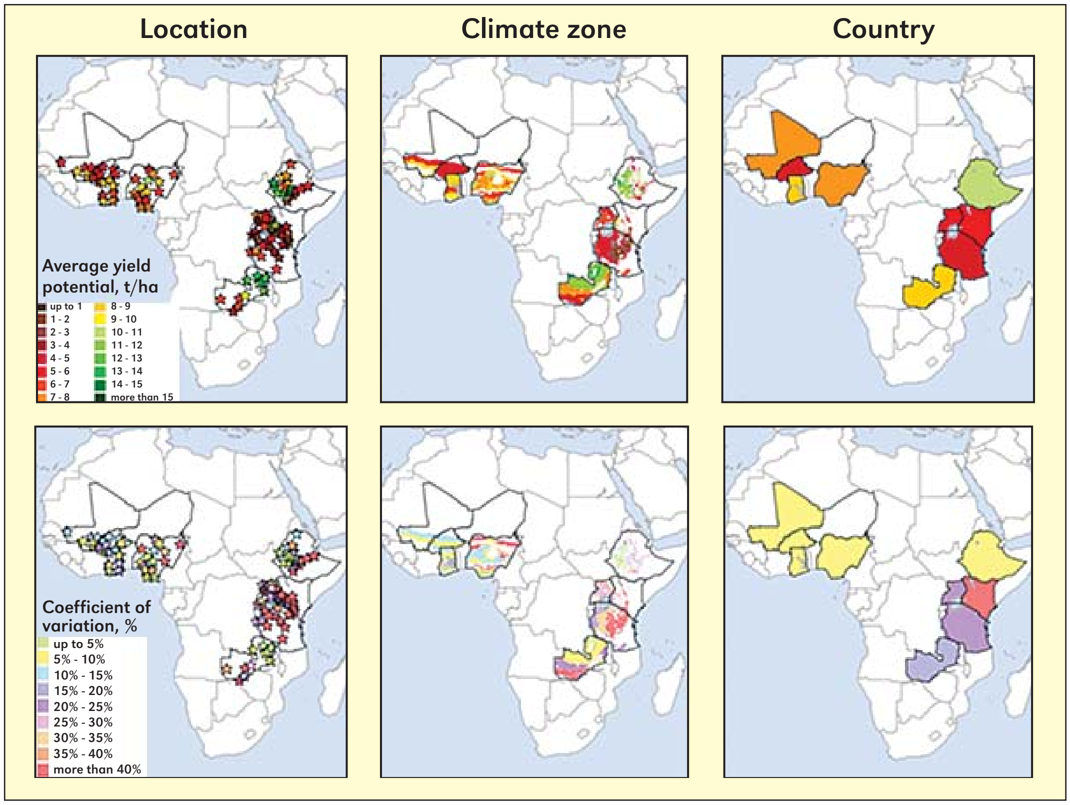

Figure 5. Estimates of yield potential (top) and its year-to-year variability (bottom) for rain-fed maize in nine countries in Sub-Saharan Africa at three spatial scales: location (left), climate zone (middle), and country (right). Source: Global Yield Gap Atlas (www.yieldgap.org).

Accurate estimates of yield potential (and its year-to-year variability) are also critical at the field level to improve current crop and input management (e.g., estimation of fertilizer nutrient requirements and probability of obtaining a profitable response) and also at larger (region and country) scales to inform investments and policy in agriculture. An example of yield potential and its variability is shown for rain-fed maize at three different spatial scales across nine countries in Sub-Saharan Africa (**Figure 5**).

Future developments of the Atlas include estimation of nutrient gaps and delineation of extrapolation domains for technology transfer and ex-post and ex-ante impact analysis. We believe that the spatial framework developed by the Atlas can be used to make agronomic research more efficient by providing an objective way to design field trials to maximize area coverage in relation to number of experimental sites and monitor the impact of policy and technologies over time and space. The Atlas can also be used as a foundation for studies aiming to explain and mitigate yield gaps and investigate impact of climate change, land use, and environmental footprint of agriculture, and as a platform for in-season yield forecasting.

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*Note that all articles related with the Global Yield Gap Atlas can be freely accessed and downloaded from: www.yieldgap.org/web/guest/gyga-publications.