

April 15, 2021

Understanding the Impacts of CGIAR Research on the Global Geographic Distribution of Land Use, Undernutrition and Biodiversity*

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INCOMPLETE PRELIMINARY DRAFT
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Abstract

This year (2021) marks the 50th Anniversary of the establishment of the Consultative Group on International Agricultural Research (CGIAR). This collection of international research institutes has had a profound impact on agriculture around the world – but particularly in the developing countries where they are physically located. The CGIAR played a central role in the ‘Green Revolution’ that took place across Asia, Latin America and parts of the Middle East and North Africa with the introduction of improved varieties of rice, wheat, maize and other crops. This paper is part of a set of papers designed to evaluate the impacts of the CGIAR’s research contributions to crop productivity since 1961. Towards this end, we employ the estimated productivity gains, attributed to these new crop varieties, by Fuglie and Echeverria. These are incorporated into the SIMPLE-G gridded model of global agricultural production in order to estimate the consequences for food production and prices, cropland extent and biodiversity at a fine scale (5-arc minutes), globally. To accomplish this, we first run the SIMPLE-G model backwards in time from its current benchmark in 2017 to 1961. We then adopt the 1961 benchmark as a starting point for our analysis in which we run the model forward in 5-year increments under two scenarios: baseline (historical) and counterfactual (absent the CGIAR crop productivity gains). The difference in key variables between these two paths (baseline - counterfactual) is attributable to the CGIAR system. We find that the innovations provided by this novel institution served to increase global crop yields and production, reduce cropland requirements, enhance biodiversity and lower food prices, thereby accelerating the reduction in undernutrition observed over the 1961-2017 period.

Keywords: technological progress, agricultural development, food security, biodiversity, undernutrition

JEL codes: Q16, Q17, Q56

*Paper prepared for the Annual Conference on Global Economic Analysis (Virtual Conference), June, 2021.

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1. Background and Motivation

This year (2021) marks the 50th Anniversary of the establishment of the Consultative Group on International Agricultural Research (CGIAR). This collection of international research institutes has had a profound impact on agriculture around the world – but particularly in the developing countries where they are physically located. The CGIAR played a central role in the ‘Green Revolution’ that took place across Asia, Latin America and parts of the Middle East and North Africa with the introduction of improved varieties of rice, wheat, maize and other crops. This paper is part of a set of papers designed to evaluate the impacts of the CGIAR’s research contributions to crop productivity since 1961. Towards this end, we employ the estimated productivity gains, attributed to these new crop varieties, by Fuglie and Echeverria. These are incorporated into the SIMPLE-G gridded model of global agricultural production in order to estimate the consequences for food production and prices, cropland extent and biodiversity at a fine scale (5-arc minutes), globally. To accomplish this, we first run the SIMPLE-G model backwards in time from its current benchmark in 2017 to 1961. We then adopt the 1961 benchmark as a starting point for our analysis in which we run the model forward in 5-year increments under two scenarios: baseline (historical) and counterfactual (absent the CGIAR crop productivity gains). The difference in key variables between these two paths (baseline - counterfactual) is attributable to the CGIAR system. We find that the innovations provided by this novel institution served to increase global crop yields and production, reduce cropland requirements, enhance biodiversity and lower food prices, thereby accelerating the reduction in undernutrition observed over the 1961-2017 period.

2. CGIAR Contributions to Agricultural Productivity

Figure 1 displays the countries that are the focus of our study (see the companion paper by Fuglie, 2021). In these countries, the extent of adoption of CGIAR crop varieties has been studied and estimates are summarized in Figure 2 (also from Fuglie, 2021). Here, it is clear that South Asia

was at the heart of the early Green Revolution, but more recently Sub Saharan Africa has benefited increasingly from CGIAR crop technology.

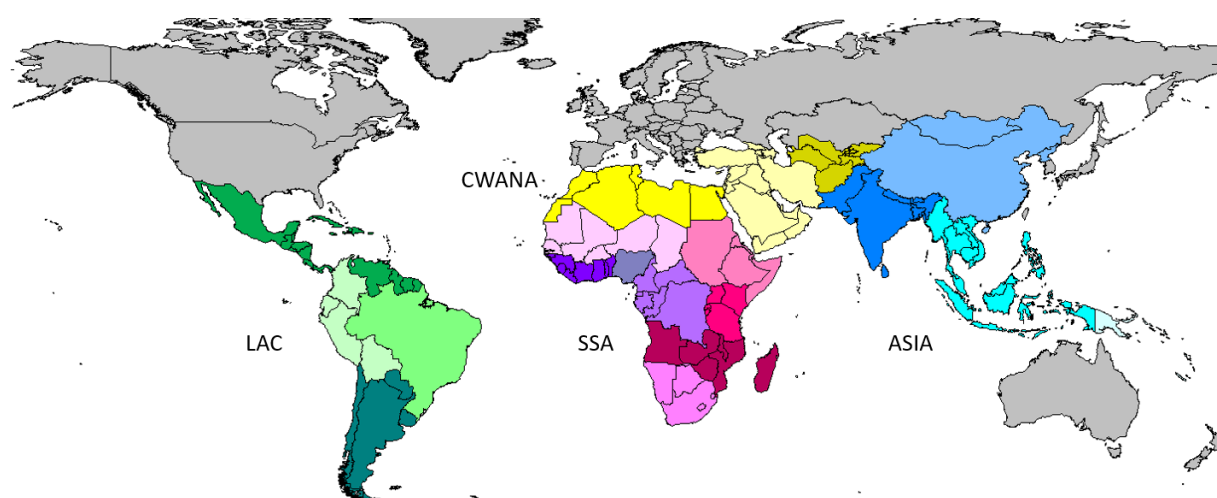


Figure 1. Countries included in the study. Source: Fuglie, 2021

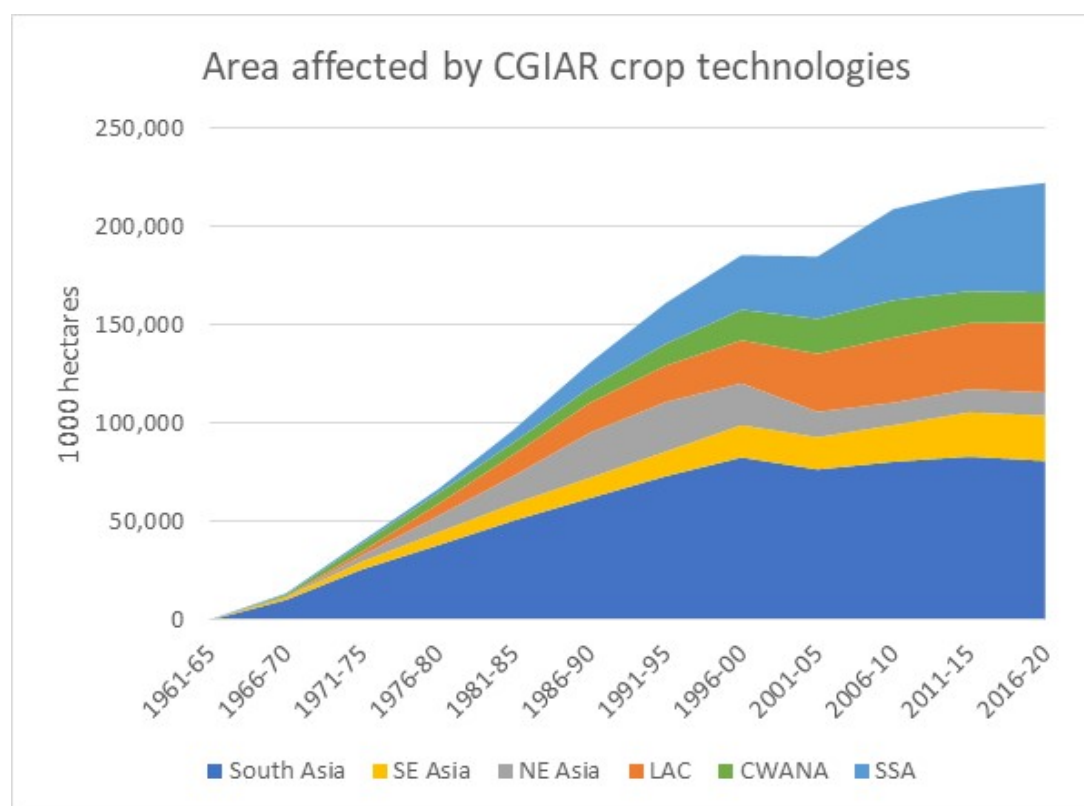


Figure 2. Cropland area dedicated to CGIAR crop technologies. Source: Fuglie, 2021

Estimation of the productivity gains from the CGIAR crop technologies is challenging due to a number of factors. First, we don't know what would have been grown on this land, absent the CGIAR varieties. This is assumed to be a traditional crop variety. The second complication is that some of these new varieties require significantly more variable inputs (e.g., fertilizer, irrigation, labor) and so the question arises: How much of the yield gain is a pure productivity improvement and how much is due to the additional inputs? This is a key theme of Fuglie's (2021) work. The resulting estimates of productivity gains from CGIAR crop technologies is given in Figure 3b, at global scale, broken out by crop. Figure 3a reports area affected, by crop.

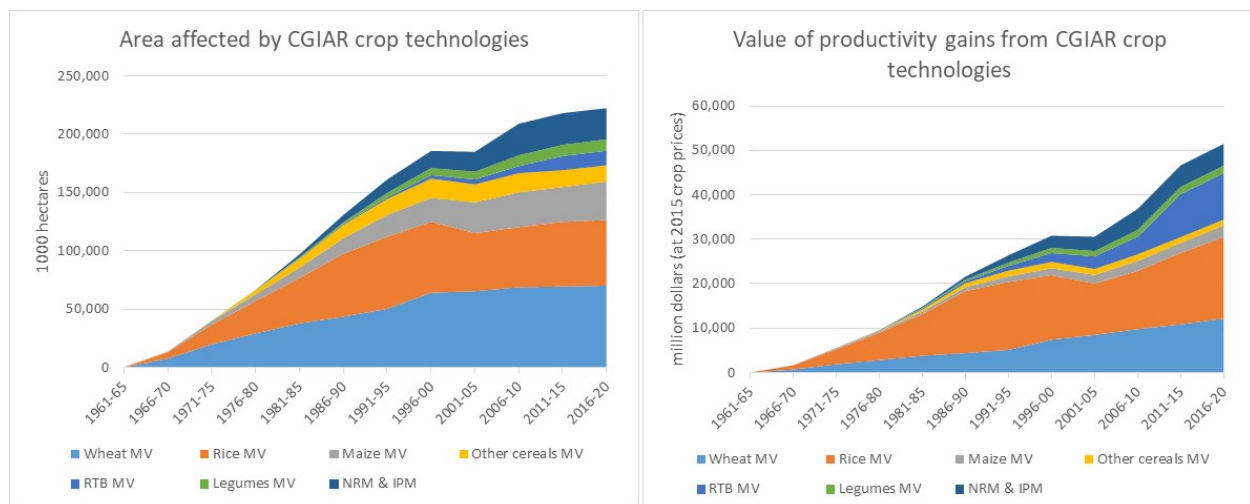


Figure 3. Area affected by CGIAR crop technologies and value of productivity gains. Source: Fuglie (2021).

3. Modeling Framework

3.1 *SIMPLE-G Structure*

In order to evaluate the impact of CGIAR technologies on food and environmental security, we employ the SIMPLE-G model. This builds on SIMPLE: a Simplified International Model of Prices Land use and the Environment, which has been used to analyze the long run drivers of future food production, prices and land use change (Baldos and Hertel 2013; Hertel, Baldos, and van der Mensbrugghe 2016), adaptation to climate change (Baldos and Hertel 2015; Lobell, Baldos, and Hertel 2013), the role of R&D and productivity growth in ensuring food security and environmental sustainability (Baldos and Hertel 2014; Hertel, Ramankutty, and Baldos 2014) and the market impacts of reducing food waste and post-harvest losses (Hertel and Baldos 2016). As its name suggests, this has been designed around the principle that a model should be no more complex than is absolutely necessary to understand the basic forces governing the global supply and demand for crops, cropland and food prices (Figure 4). The -G appended to SIMPLE denotes that we are using the gridded version of this model as documented in Baldos et al. (2020).

The SIMPLE-G model disaggregates the world economy into seventeen market regions. Within each region, an aggregate crop commodity is produced using technologies which vary by grid cell. (There are XXX grid cells in total in this model.) And within each grid cell, producers have a choice between allocating land to irrigated or rainfed crop production. Nitrogen fertilizer is treated as a distinct input, as are land, irrigation water (surface and groundwater are distinct in this model), and other non-land inputs. Land and water supply response are grid cell specific. Figure 5 provides more detail on this nested CES production structure.

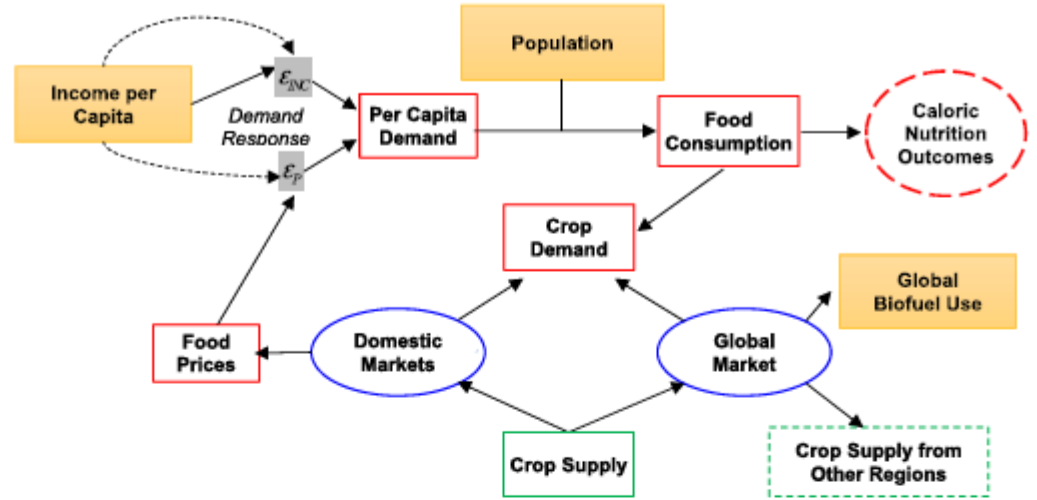


Fig. 1. Structure of regional food demand in SIMPLE-G model.

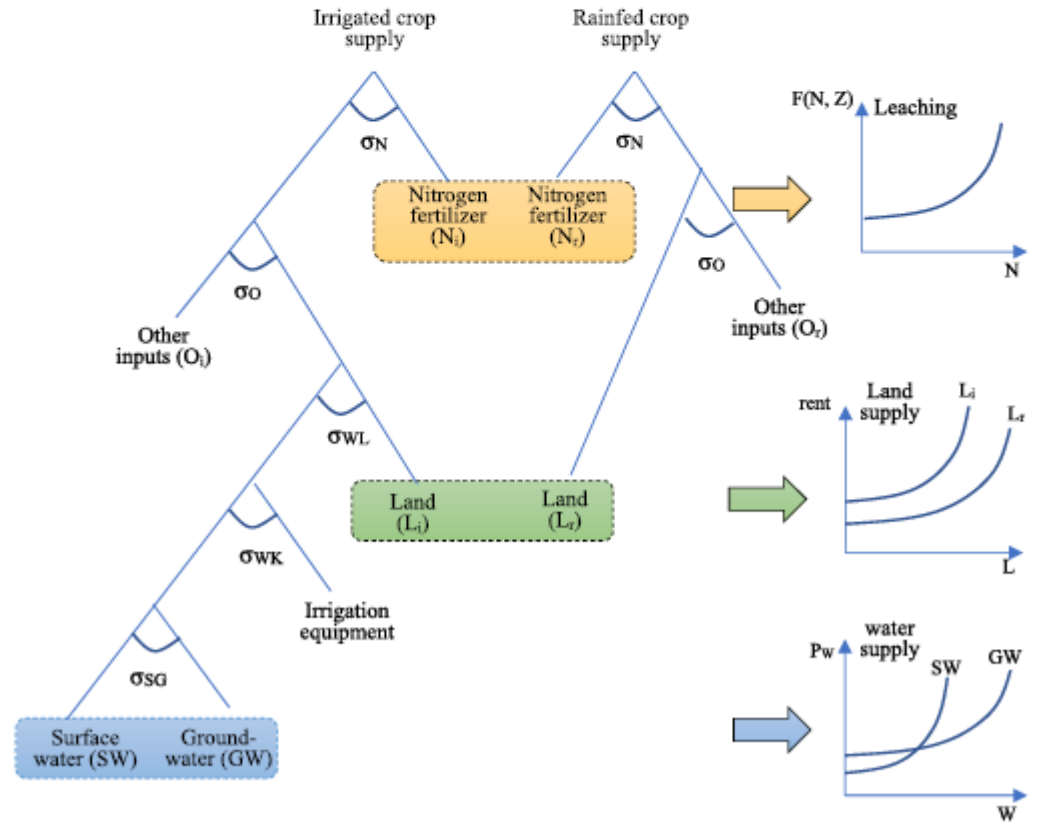


Fig. 2. Structure of crop production at each grid cell. Shocks and policy variables are defined for surface water, groundwater, irrigation equipment, land, nitrogen fertilizer, and overall crop production. Elasticity of substitution is shown by σ . The equilibrium quantity and price of land and water are determined at local level. Irrigated and rainfed practices compete for land. Land supply depends on total cropland supply and the elasticity of transformation between irrigated and rainfed. The leaching function is different for irrigated and rainfed crop production.

3.2 Historical Baseline and Calibration: Regional Data

SIMPLE has been tested over historical periods via backcasting, focusing on global changes in food production, prices and cropland (Baldos and Hertel 2013), regional output changes (Hertel, Ramankutty, and Baldos 2014; Hertel and Baldos 2016), as well as changes in undernutrition (Baldos and Hertel 2014). However, for purposes of this study, it is important that we match 1961 levels of production and land use as closely as possible, since this is the starting point for our technology evaluation. For this reason, in addition to shocking population, income and technology, as in the earlier validation work, we also allow for endogenous shifts in land and nonland supplies, thereby allowing use to exactly reproduce the global agricultural economy in 1961 as described by FAO data. This means that, when we run the model forward from 1961 to 2017, our baseline reproduces the changes in cropland area and production as reported by FAO.

More specifically, we calibrated SIMPLE for the historical validation over 1961-2017 by specifying exogenous changes in population, real GDP, historic trends in total factor productivity growths in the crop, livestock and processed foods sectors. Population and real GDP were taken from World Bank's World Development Indicators (2021). We use historical TFP growth from USDA (2019), Ludena et al (2007) and Redding et al (2004) for the crops, livestock and processed food sectors, respectively. We also eliminate crop use in the biofuels sector. Note that historical changes in these drivers of agriculture are not enough to fully capture the actual changes in crop production and land use over this period especially at the regional level. In the historical calibration, we impose observed changes in the global crop price, regional land use as well as crop export volumes. Figure 6 shows the actual changes computed from FAOSTAT (2021) and simulated regional changes from SIMPLE for crop production and cropland use over the period 1961-2017. Note from these historical data that Brazil and China show the strongest increases in

crop production (600%+) and Brazil, SSA and S.E. Asia show the largest increases in cropland area (around 80%).

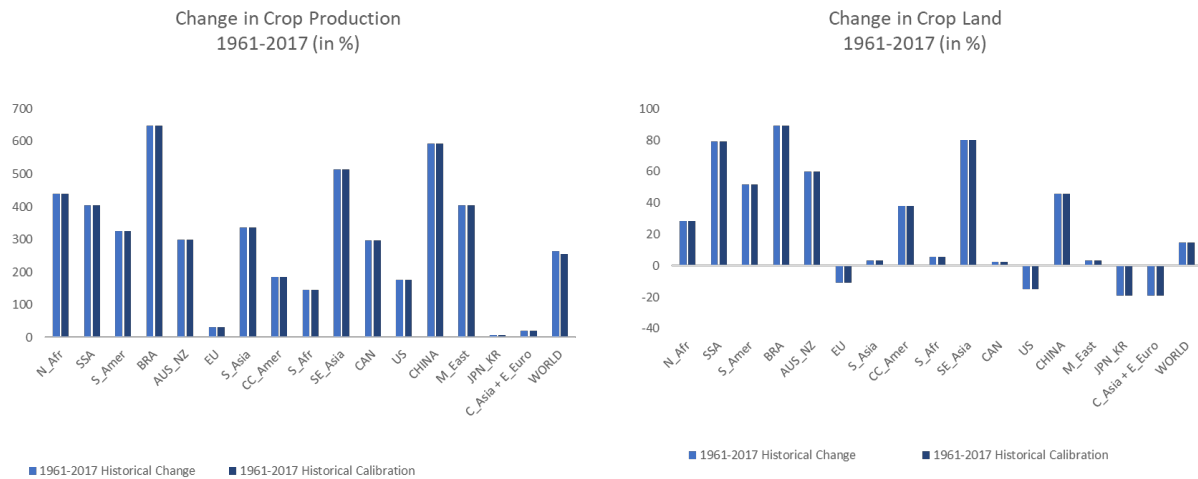


Figure 6. Growth in regional crop production and crop land cover: 1961-2017

3.3 Historical Baseline and Calibration: Gridded Data on Land Use and Biodiversity

Under the historical baseline, cropland conversion was highly concentrated in the tropics. As shown in Figure 6 above, Brazil, SSA and Southeast Asia were hotspots of cropland expansion. We use the Land Use Harmonization model (Hurt et al., 2020) to track land-use changes during this period ($0.25^\circ \times 0.25^\circ$ resolution), assuming that only crop expansion (increase of land use dedicated to crops: C3 annual, perennial, and nitrogen-fixing crops and C4 annual and perennial crops) have an impact on biodiversity.¹ Figure 7 maps these changes at the level of individual grid cells based on the data of Hurtt et al. (2020). This is important information for SIMPLE-G, which is calibrated to reproduce this historical pattern of cropland conversion using grid-cell-specific rates of technological progress.

¹ The proportion of land dedicated to crops contracted for some regions, such as in the United States of America and Europe, but any potential positive impact on biodiversity was ignored in this calculation.

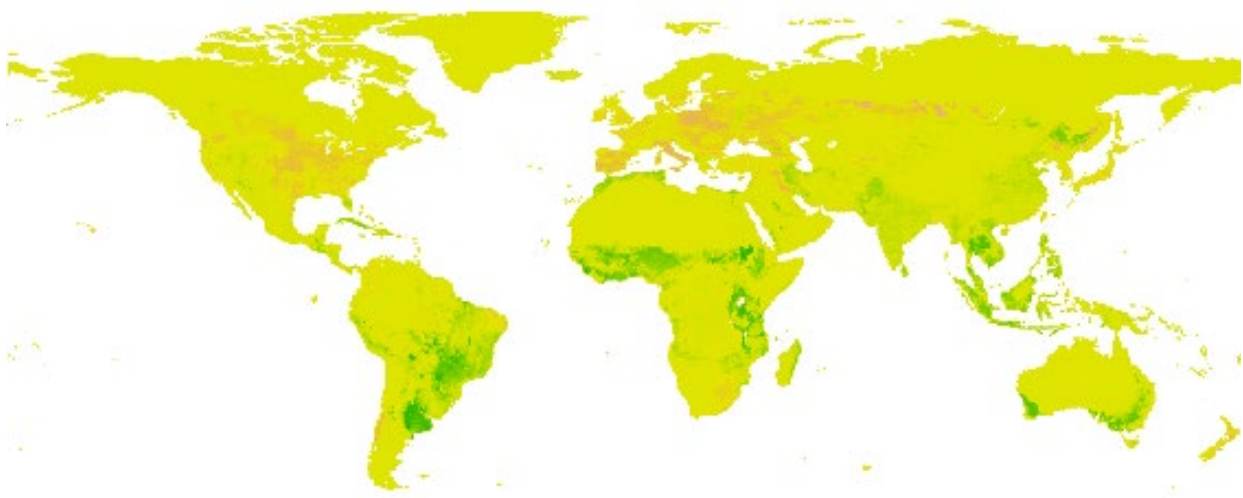


Figure 7. Cropland area expansion and contraction: 1961-2017. Source: Hurtt et al. (2020)

Associated with this cropland conversion are biodiversity losses. While we don't have observational data at this same resolution over this historical period, we can estimate these impacts. The additional number of species committed to extinction, or expected to be lost, due to crop expansion between 1961 and 2015 are 21,976 individual species. We use the projections of vertebrate species (mammals, birds, reptiles, and amphibians) likely committed to extinction associated to land-use change in 804 terrestrial ecoregions, using the mean values of the characterization factors of transformation (Chaudhary and Brooks, 2018). The characterization factors measure potential species loss per m^2 and were recently parameterized using the countryside species-area relationship model. The following figure shows the number of species projected to be driven to extinction due to an expansion of cropland in each ecoregion:

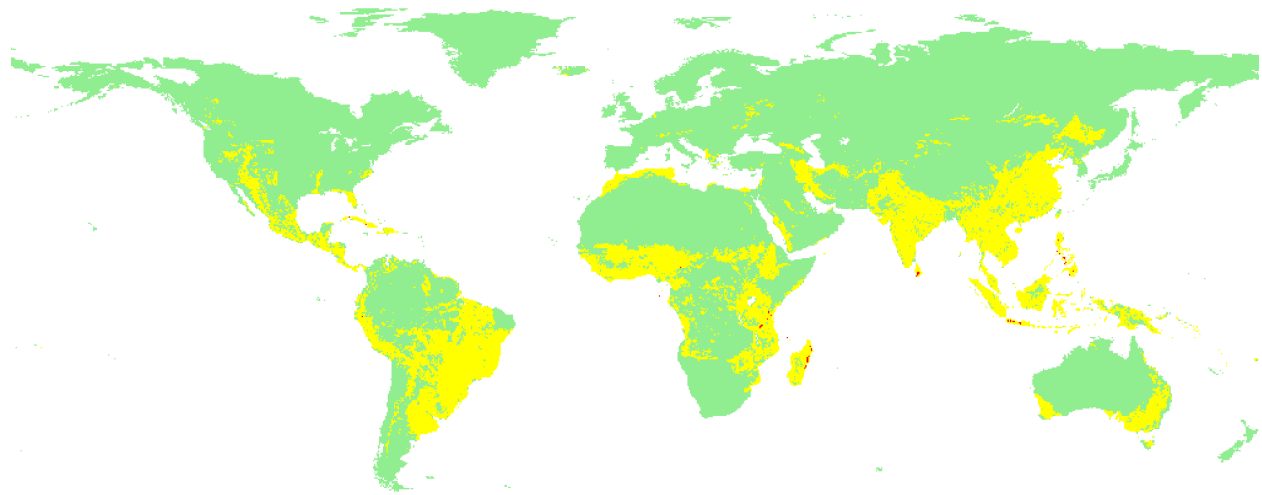


Figure 8. Loss in Biodiversity due to Cropland Expansion: 1961-2017. Source: Authors estimates

4. Consequences of CGIAR Technology for Food Security

7. Consequences of CGIAR Technology for Land Use and Biodiversity

8. Summary and Conclusions

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