Global drought-induced crop losses during 1983-2009

Introduction. Droughts are a major climate extreme to reduce crop production. Nonetheless, the historical analysis of global crop losses associated with droughts is poorly investigated so far. In the near future, more severe and more frequent droughts are anticipated under climate change, understanding the vulnerability of crop production to droughts is therefore a key research priority to secure global food security. Here, we investigate the global drought-induced crop losses of maize, rice, soy, and wheat during 1983-2009 using a relationship among crop yields, a drought index, and annual precipitation. We find that approximately three-fourths of the global harvested areas—454 million hectares: 161 Mha of wheat (75% of the world’s harvested area), 124 Mha of maize (62%), 102 Mha of rice (62%) and 67 Mha of soy (91%)—experienced drought-induced yield losses over this period, and the cumulative production losses correspond to 166 billion U.S. dollars—maize is associated with the largest economic loss ($58 B or 35% of the global total loss), followed by wheat ($47 B or 28%), rice ($37 B or 22%), and soy ($24 B or 14%). Our results also shown that crop production systems display increased vulnerability to drought according to decreases in per capita gross domestic production in the countries with extensive semiarid agricultural areas. This article is available (https://journals.ametsoc.org/doi/full/10.1175/JAMC-D-18-01174.1) as open access in Journal of Applied Meteorology and Climatology, American Meteorological Society.

Method. 1) The percentage yield anomaly at year $t$ is calculated from one grid cell (0.5° x 0.5°) to another using the spatially explicit global yield dataset (Iizumi et al. 2018) for the period from 1983 to 2009: $\Omega = 100(y_t - m_t)/m_t$. 2) The drought magnitude at year $t$, which is 3-month aggregation of the standardized precipitation index (SPI) before harvest, is calculated grid cell by grid cell: $Z_t = \sum_{i=1}^{m} y_{t-i+1}/m$. 3) A linear regression analysis between the annual time series of $\Omega$ and $Z_t$. 4) The percentage drought-induced yield loss at year $t$ is calculated on a per-gridcell basis using $Y_t = Y_{t-1} + \frac{1}{\beta}$. 5) The average yield loss per drought event from 1983 to 2009 (Fig. 1) is estimated on a per-gridcell basis using $T = \sum_{t=1}^{m} Y_t/n$. 6) The national-level drought-induced economic loss for four target crops from 1983 to 2009 is calculated using $E = \sum_{k=1}^{n} P \sum_{j=1}^{m} (A \sum_{i=1}^{m} \Omega_t/100)$. 7) The agricultural gross domestic production is estimated using AGDP=GDP x Value-Added agricultural percentage of GDP/100.

Results and Discussion. a. Sensitivity of yield anomaly to drought. Globally, the harvested areas of different crops with significant correlations between $\Omega$ and $Z$ from 1983 to 2009 account for 21–73 million hectares (Mha; Fig. 1 in Kim et al., 2019). Wheat displays the most extensive area of correlations (73 Mha, 34% of its global harvested area), followed by maize (41 Mha, 27%), rice (31 Mha, 19%), and soy (21 Mha or 28%). b. Global estimation of drought-induced yield loss. The harvested areas that experienced yield losses by droughts correspond to 161 Mha (75% of global harvested area) for wheat, 124 Mha (82%) for maize, 102 Mha (62%) for rice, and 67 Mha (91%) for soy (Fig. 1). The global averages of drought-induced yield losses per drought event $T$ are 3% for wheat, 7% for maize and soy, and 3% for rice; these losses correspond to 0.29, 0.24, 0.15, and 0.13 (Fig. 2) from 1983 to 2009, respectively. c. Global estimation of drought-induced economic loss. The worldwide aggregated national $E$ for the four crops from 1983 to 2009 corresponds to $166$ billion (B). Maize is associated with the largest economic loss ($58 B or 35% of the global total $E$), followed by wheat ($47 B or 28%$), rice ($37 B or 22%$), and soy ($24 B or 14%$). Approximately 93% of the aggregated loss is associated with the 25 most vulnerable countries, and 96% in China and the United States only because of the large areas of cropland in these countries (Fig. 5a in Kim et al., 2019). d. Economic damage caused by drought-induced crop losses. Drought damage measured as a percentage of agricultural gross domestic production (AGDP) may have relevance for international or national-level policy makers who allocate resources to the reduction and prevention of drought damage. The worldwide relative economic loss per drought corresponds to 0.8% of the national AGDP calculated as the average for 119 countries that experienced drought-related losses from 1983 to 2009. The crops with the largest impact on the global AGDP are wheat (39%), followed by maize (36%), rice (21%), and soy (4%). Only two crops—wheat and maize—account for three-fourths of the drought-induced economic damage to AGDP. Importantly, our analysis suggests that $T$ values in developed countries are lower than those in developing countries where semiarid agricultural areas ($k < 0.9 m yr^{-1}$; the circles colored with orange and yellow in Fig. 1) are extensive, and the AGDP makes up a relatively large proportion in developing countries. e. Limitations and uncertainty. 1) The estimated damages in western Africa and western Asia are more uncertain than those for other regions. 2) The uncertainties that originate in the limitations of the available data also propagate into our damage estimates because of the use of a fixed crop calendar year, harvested area, and producer prices for drought magnitudes and economic losses.

Fig. 1. Global patterns of average drought-induced yield loss per drought event $T$ from 1983 to 2009. The gray areas represent regions where the effects of droughts are not detected in harvested areas, and the white areas represent regions where either a crop is not harvested or yield data are not available. The pie chart represents the ratio of the harvested area to the total harvested area written in the center (Portmann et al. 2010) given the five ranges of yield losses indicated on the scale bar.

Fig. 2. Relationships between the per capita GDP (World Bank 2017) and the average drought-induced yield loss $T$ produced by individual drought events from 1983 to 2009 (Fig. 1). The colors of the circles denote the average annual precipitation $x$ given the five ranges of $x$ indicated on the scale bar, the sizes of the circles denote the percentages of agricultural GDP to GDP (World Bank 2017), and the two-character country codes are based on the ISO standard 3166. The blank country codes indicate that AGDP data are not available at World Bank (2017). The solid line presents the regression line among the orange and yellow circles for which $x$ values are less than 0.9 m yr$^{-1}$; which is the average $x$ where our target crops are harvested.