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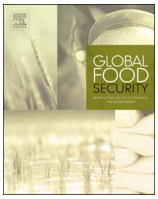

Drying tendency dominating the global grain production area

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ABSTRACT

Drought is considered an environmental disaster with a direct and devastating impact on agriculture. However, little research focuses on climate change related drought variations across the global grain production area (GGPA). Thus, the variation of crop yield across different grain production regions that experience severe drought remains inadequately studied. We analyzed drought variations across the GGPA to study the impacts of severe droughts on the yields of four major crops (maize, rice, wheat, and soybean). This analysis was based on the Standardized Precipitation Evapotranspiration Index (SPEI) and the crop yield dataset from 1951 to 2011. The results indicated that the entire GGPA experienced a significant increase in drought duration, impacted area, and severity of hazards. There was an average of 2.2 dry months and the dry area increased by 1.109% per decade. Regional variations existed across the GGPA, although the majority presented a tendency to increasing drought. Southern and Northern America tended to become wetter, while Eastern Asia, Southern Europe, and Africa (except for Eastern Africa) tended to become dryer. Developing countries and regions are generally more susceptible to extreme droughts and suffer more losses than developed countries and regions.

1. Introduction

Drought is one of the primary environmental disasters and imposes significant effects on global agriculture, global economy, water supplies, and environmental ecosystems (Piao et al., 2010). Droughts with high frequencies, long durations, and large ranges occur almost yearly across the globe, even in wet and humid regions (Mishra and Singh, 2010; Chen and Sun, 2015). According to incomplete statistics, the global percentage of dry area has increased by about 1.74% per decade from 1950 to 2008 and the number of drought events and corresponding economic losses have increased rapidly since 1960 (Fig. 1, EM-DAT, 2016). Worse still, droughts are expected to increase due to global warming (Cook et al., 2014) and therefore, drought has become a looming threat to human survival and global development (Dai et al., 2011; Trenberth et al., 2013). Focusing on drought variations will provide an epistemological foundation to prepare and understand drought events and their consequences. Increasing attention has recently been directed toward global drought variations, due to the threats posed by drought to global grain security (Hoerling et al., 2010; Sheffield et al., 2012; Dai, 2013; Beguería et al., 2014; Trenberth et al., 2014; Deo et al., 2017). Two current mainstream viewpoints have been presented on global drought changes that occurred over the past few decades, resulting from differences in the length of time series of climatic datasets and drought metrics (Trenberth et al., 2014). This has led to a debate over the severity of global droughts, and some researchers have suggested that global droughts are following an increasing trend (including occurrence, duration, intensity, and affected areas) due to global climate change (Dai, 2013). Other researchers have suggested that global droughts have seen little change over the past 60 years (Sheffield et al., 2012). Both viewpoints have been supported by a large number of studies, although the contradictory arguments can confuse policy-makers and practitioners of the food sector as both groups strive to be proactive and adaptive to current drought hazards.

The 4th and 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) have predicted that grain yield in middle to high latitude areas will see some increase if the temperature increase by 1–3 °C while it will decrease if this increase in temperature exceeds a certain threshold. Food crops are particularly susceptible to climatic changes; therefore, the impact of such changes on grain production may be quite severe. Recent research typically focuses on the response of crop yields on either a regional or global scale and in response to climate change (e.g., precipitation, temperature, and evapotranspiration) (Lobell et al., 2011; Asseng et al., 2013; Wheeler and Von Braun, 2013; Ray et al., 2015). These studies could reveal how crop yield has been

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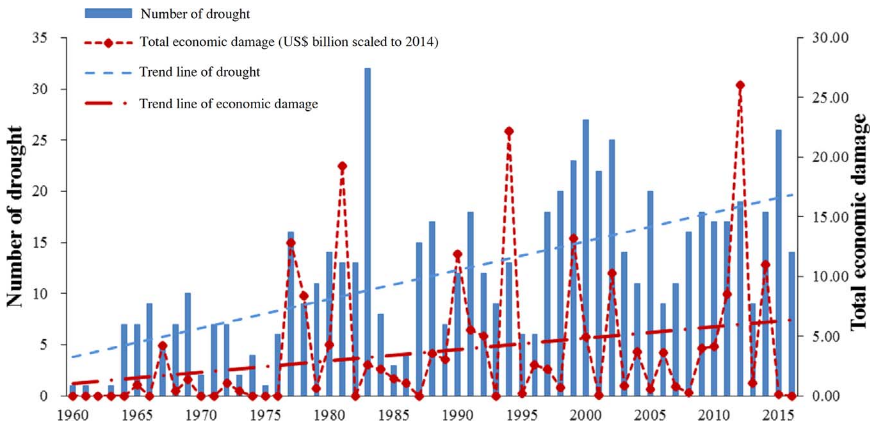

Fig. 1. Number of droughts and total economic damage since 1960 from around the world. The data was available from the Emergency Events Database (EM-DAT).

affected historically by climatic anomalies and would furthermore allow the prediction of crop yield changes over time with regard to global climate change. Among meteorological disasters, there is no doubt that drought disasters have become the focus of recent research because it could result in severe damage due to high temperature, low soil moisture, and high evapotranspiration, originating from the reduction of agricultural water. Therefore, drought could potentially damage water resource systems, which has the potential to destabilize entire food systems, thus threatening local or global food security (Dai, 2011; Lesk et al., 2016). Furthermore, the majority of evidence indicates that droughts are expected to increase in frequency and as well as in severity in the future (Sheffield et al., 2012; Lesk et al., 2016). To develop effective countermeasures, an evaluation of the effects of droughts on crop yields is both necessary and significant, while still ensuring stable crop production.

The global grain production area (GGPA) is directly connected to food security and is important when ensuring adequate crop production that meets the requirements of the growing population as well as the socio-economic development of entire regions. Intensive, large-scale droughts have recently occurred in the GGPA, which could threaten agricultural production and global food security, particularly for the four major crops (i.e. maize, rice, wheat, and soybean) (Mishra and Singh, 2010; Geng et al., 2016). Few studies to date have quantitatively examined the impacts of drought on the GGPA in response to global climate change. Controversy exists about the severity of the drought in GGPA. The variations of crop yields caused by different droughts across different sub-areas of the GGPA require investigation, and these are the main focus of the current study.

This study aims to specifically examine the characteristics of drought over the GGPA. It will also discuss the impact of severe droughts on the yield of four major crops (i.e. maize, rice, wheat, and soybean). The study is geared toward agricultural production and management, prevention and reduction of droughts, and the safeguarding of the global food security.

2. Data and methods

2.1. *Standardized Precipitation Evapotranspiration Index*

Drought variations were quantitatively evaluated using the Standardized Precipitation Evapotranspiration Index (SPEI) based on the Penman–Monteith equation (Beguería et al., 2014). The time series of the SPEI encompass 1951–2011 and the data is available from http://sac.csic.es/spei/. Among the SPEI data, the Penman-Monteith (PM) method was used to calculate the potential evapotranspiration; furthermore, the water balance of climate that would be suitable to study the effect of global warming on drought severity was considered within the dataset. Shorter accumulation periods (e.g. SPEI-3 and SPEI-6) were rated as sensitive to extreme, although longer periods (e.g. SPEI-24 and SPEI-48) typically missed relevant drought events. After considering SPEI-1 to SPEI-48, a medium-term accumulation period was finally selected to depict various world precipitation systems (SPEI-12, SPEI covering the time scale of 12 months) as recommended by Vicente-Serrano et al. (2010a). Details of the SPEI are introduced in the Data in Brief file (Section 1).

2.2. *Land cover data and crop yield data*

Global land cover data from 2000 (GLC2000) with a 5-min spatial resolution was obtained from the European Commission's Joint Research Center. It was separated into 22 types of land cover (Bartholome and Belward, 2005; Liu et al., 2017). To analyze drought across the major global grain producing areas in detail, we selected the 16th land type, which includes the global grain production area (including farmland) from around the world. The geographical positions split the global farmland into 18 global grain production regions (Fig. 2). A stable distribution of the global grain production area was assumed. Crop production in the global grain production areas was approximately equal to the grain output of the country. The crop yield data (from 1961 to 2011) of the specific countries were obtained from the Food and Agriculture Organization (FAO) (http://faostat.fao.org/).

2.3. *Statistics indices*

The Mann–Kendall (MK) method was used to investigate statistical trends of drought. Details for the MK method can be found in the Data in Brief file (Section 2). An additional linear regression method was used to analyze the trends of drought duration, area, severity, and frequency during the time series. The drought area was computed as the sum of the weighted (cosine function of latitude) grid area for the SPEI < -1.0. Drought durations were defined as the number of months with a SPEI < -1.0. The severity was defined as the absolute value of the integral area between the SPEI line and the horizontal axis (SPEI $= 0$) between the start month and the end month of the drought (Lei et al., 2015). The yield change percentage was used to measure the yield change during severe drought years. This was defined as:

$$\Delta_y = \frac{(y_t - \dot{y}_t)}{y_t} \times 100\%$$

where Δ_y represents the yield change percentage during the drought year; y_t represents the actual output during year t; $\dot{y}_t$ represents the polynomial fitting trend yield of year t. The polynomial fitting for each crop yield in each region is shown in the Data in Brief file (Fig. S1).