The quantitative impacts of drought and flood on crop yields and production in China

Yiting Liu
Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
College of Resources and Environment, University of Chinese Academy of Sciences
Beijing, China
liuyitinggis@126.com

Wenjiao Shi*
Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
College of Resources and Environment, University of Chinese Academy of Sciences
Beijing, China
shiwj@lreis.ac.cn

* Corresponding author: Wenjiao Shi, shiwj@lreis.ac.cn

Abstract—*The disturbance of food production and the reduction of crop yields were observed due to droughts and flood locally and globally in recent decades. Previous studies used crop models to simulate the response of crop yields to some indices of extreme weather. However, most of these studies did not detect the impacts of droughts and floods quantitatively. In this paper, the statistical data of sown area (SA), covered area (CA) and affected area (AA) during 1982-2012, and crop yields and production of maize, rice, wheat and soybean in China during 1979-2015 in provincial level were collected. Using these data, we counted the occurrence frequency of droughts and floods. In different major grain-producing areas (MGPA) of China, the superposed epoch analysis (SEA) method was applied to detect the quantitative impacts of droughts and floods on the crop yields and production during different periods (1982-1997, 1998-2012). The results presented that main crops had a 4.4%-6.8% yield and production reduction due to flood, and wider impacts on production and yield of main crops due to droughts were observed, with decreases ranging from 3.7% to 9.2%. Maize and soybean were more sensitive to drought in the whole China, especially in the NEC, with the significant reduction of 10.4%-17.2% in the NEC and 6.4%-9.2% in the whole China. In China, both droughts and floods affected wheat yield with significant decreases of 4.3% and 6.1%, respectively. Moreover, different types of rice had various responses to droughts and floods. Early rice was sensitive to floods in China and in the mid-lower reaches of the Yangtze River (MLYR), but middle-season rice seemed to be sensitive to both droughts and flood in China. Meanwhile, crops responses during different periods varied, but did not have great difference of reduction between two periods. The spatio-temporal identification of quantitative impacts of drought and flood on crop yields and production in China is essential for applying suitable adaptions, such as better irrigation and basic construction in cropland to decrease the negative effects of droughts and floods on crops to guarantee the food security in China.*

Keywords—*drought, flood, production, crop yields, China, quantitative*

I. Introduction

In recent decades, the disturbance of food production and the reduction of crop yields were observed due to climate disasters, including droughts, floods, storms and extreme heat which had threaten food security locally and globally [1-4]. As a traditional agricultural country, agricultural production is seriously affected by climate disasters in China [5-7], especially droughts and floods, which are major climate disasters in China [8, 9].

In previous studies, the negative effects on crop yield or production were found in recent years [5, 6, 10-12]. Based on the data from agro-meteorological stations, many researchers used climatic indices, such as high temperature degree-days (HDD) and cold temperature degree-days (CDD), to recognize the impacts of climate disasters on agricultural production by the means of linear regression or panel regression [10, 13-15]. Meanwhile, the statistical data of crop production were also used in regression analysis [16, 17].

Crop simulation models have been also applied to study the impacts of extreme climate on crop yields. Although crop simulation models can help us understand more about the mechanism of how climate indices affected crop yield or production, the climatic indices can hardly represent climate disasters, such as droughts or floods. Moreover, many studies have identified crop production variation under climate disasters [3, 18-20], but most of them may underestimate the effects due to the use of the entire world or a nation as study unit [9]. Some of the previous studies used provincial-level and county-level data on crops in China [21-24], but most of them did not identify the quantitative impacts of climate disasters on agricultural production or yields [6] and lacked spatio-temporal analysis [16].

In China, Northeast China (NEC), the Huang-Huai-Hai Plain (HHH) and the mid-lower reaches of the Yangtze River (MLYR) are major grain-producing areas (MGPA), which produced about 74% of the grain in China [25]. In this study, the statistical data of sown area (SA), covered area (CA) and affected area (AA) during 1982-2012 and crop yields and production of maize, rice, wheat and soybean in China during

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1979-2015 were used. We aim (i) to compare the quantitative impacts of droughts and floods on yields and production of different crops in China from 1982 to 2012, (ii) to investigate the impacts of droughts and floods on main crops in the three MGPA and different types of rice in the MLYR, and (iii) to study the responses of main crops to droughts and floods between 1982 and 1997 and between 1998 and 2012 by the superposed epoch analysis (SEA) method [3].

II. Materials and Methods

A. Data sources

The study collected the data for 31 provinces (autonomous regions or municipals) of China during 1979-2015, including the yields and production of four main crops (maize, rice, soybean, wheat) and three types of rice (early rice, middle-season rice and late rice), SAs and areas affected (AA) and covered (CA) by droughts and floods during 1982-2012 in provincial-level. The statistical data gathered from China's Statistical Yearbooks and the National Bureau of Statistics.

B. The occurrence of droughts and floods

Covered area (CA) and affected area (AA) stood for the SA where crop yields reduced by more than 10% and 30%, respectively, due to extreme weather disasters [21]. Based on the data of CA and AA, we calculate the ratio of affected area (RAA) and the ratio of covered area (RCA) using (1) and (2) respectively for each province (autonomous region or municipal) in China during 1982-2012.

$$RAA(\%)=AA\times 100/SA \tag{1}$$

$$RCA(\%)=CA\times 100/SA \tag{2}$$

According to the definition of droughts and floods in China, an RAA between 20% and 40% and an RCA between 10% and 20% represent a heavy disaster, an RAA greater than 40% and an RCA greater than 20% mean an extreme disaster [26]. In this study, we defined an RAA greater than 20% and an RCA greater than 10% as a severe drought or flood. Based on the disaster data, we built time-series, including the information of the occurrence year of severe disasters, province ID and disaster type (i.e., drought or flood). Using the time-series data, we count the occurrence frequencies of droughts and floods in the whole China during 1982-2012, and in different regions during different periods.

C. Isolating the response of crop yields and production to droughts and floods

The SEA method was used to isolate the response of crop yields and production to droughts and floods with two types of composites, i.e., real-occurred composite and control composite. We extracted data using a 7-year window, with the year of the disaster occurred in the center (year 0); within this window, crop yields and production data were extracted, including the 3 years preceding the disaster (i.e., years -3, -2, -1), the 3 years following the disaster (i.e., years 1, 2, 3). The 7-year window data was normalized by the means of dividing by the average of the crop yields or production from the previous 3 years and following 3 years. Using the several normalized 7-year window sets, a real-occurred composite was generated. Meanwhile, we randomly selected a year and a province, excluded the true disaster events, and then repeated the steps of creating a real-occurred composite for the times same as the occurrence frequency of drought or flood and obtained the average of the composite. The whole process repeated 1000 times, so we can generate the control composite using the 1000 average value (7 columns, 1000 rows). The crop response to drought or flood was defined by subtracting the average of real-occurred composite in disaster year (year 0) from the average of the control composite in disaster year (year 0).

The detailed description of SEA method and its application in identifying the response of crop yields and production can be found in previous study [3, 27, 28]. After the process above, we can obtain 144 real-occurred composites and 144 control composites.

Meanwhile, the percentage of 1000 control points less than the average of the real-occurred composite in year 0 was calculated. If the percentage was less than 0.5% or more than 99.5%, the decrease or increase in production or yield caused by drought or flood was considered significant.

D. The statistical analyses among the MGPA, different rice types and different periods

The Anderson-Darling test was used to test the normal distribution of the responses of the main crops to droughts and floods in different areas and periods. Meanwhile, the Levene's test was applied to examine whether the sets of individual disaster responses in each group had equal variance. Owing to most of the time-series data in test groups had equal variance and did not have normal distribution, we used the Kruskal-Wallis one-way non-parametric analysis of variance to test the significance of differences among time-series data. If $p<0.05$ in the Kruskal-Wallis test, we considered there was significant difference in the test group, which means significant differences can be found among the responses to droughts or floods in different regions, different types of rice or different periods. Thus, we tested 48 groups for main crops in different region and different periods, and the different type of rice.

III. Results

A. The occurrence frequency of droughts and floods during 1982-2012

During the entire study period (1982-2012), there were 188 droughts and 44 floods in China (Table. 1). Half of these disasters occurred in the MGPA, including 96 droughts and 30 floods. The occurrence frequency of disasters was higher in the NEC (especially droughts) than in the HHH and the MLYR. Meanwhile, there were approximately three times as many droughts in the NEC and the HHH than there were floods; however, in the MYLR, the frequencies of drought and flood were similar (i.e., 15 droughts and 10 floods). Compared to the period from 1982 to 1997, a slight decrease in the

TABLE I. THE FREQUENCY OF DROUGHTS AND FLOODS IN CHINA AND THE MGPA DURING DIFFERENT PERIODS (EP: EARLIER PERIOD, 1982-1997; LP: LATER PERIOD, 1998-2012; AP: ENTIRE STUDY PERIOD, 1982-2012)

Region	Drought			Flood		
	EP	LP	AP	EP	LP	AP
NEC	23	29	52	10	4	14
HHH	19	10	29	3	3	6
MLYR	10	5	15	3	7	10
China	96	92	188	24	20	44

number of floods and droughts (especially droughts) occurred in China between 1998 and 2012. In the MGPA, the occurrence frequency of droughts and floods reduced slightly during the later period, with the exception of floods in the MLYR and droughts in the NEC, which occurred 7 times and 29 times, respectively, between 1998 and 2012; in contrast, 3 floods and 23 droughts occurred in the MLYR and the NEC, respectively, between 1982 and 1997.

B. The impacts of droughts and floods on different main crops

During 1982-2012, significant impacts on production and yields of the main crops were observed in China between 1982 and 2012 due to droughts (Fig. 1). Both production and yields of maize, rice, wheat and yield significantly decreased in drought-year. The production and yield reductions of maize (9.1%, 6.8%) and soybean (6.4%, 9.2%) were greater than those of wheat (5.0%, 4.3%) and rice (6.3%, 3.7%). Meanwhile, the production of middle-season rice reduced significantly in drought-year, with decreases of 4.7%. The production of main crops reduced more than did yields due to drought, except for soybean.

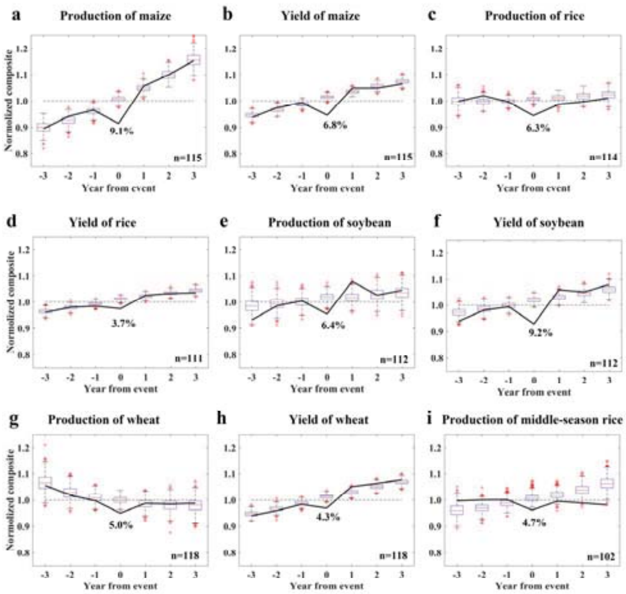

Fig. 1. Normalized composites for droughts over 7-year windows centered on the disaster year. Significant impacts are found in the production and yields of maize (a, b), rice (c, d), soybean (e, f), wheat (g, h) and the production of middle-season rice (i). Box plots represent the distributions of 1000 points of control composite. Crosses depict extreme outliers, and red dashes denote medians. Black lines are the means of the real-occurred composites.

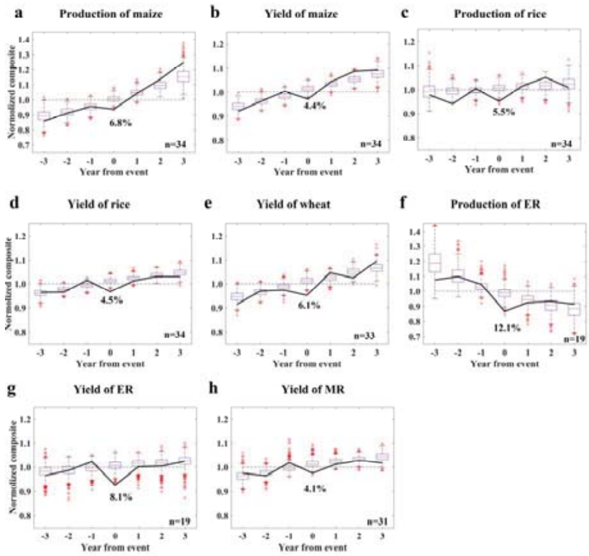

Fig. 2. Normalized composites for floods over 7-year windows centered on the disaster year. Significant impacts are found in the production and yields of maize (a, b), rice (c, d) and early rice (f, g), the yield of wheat (e) and the yield of middle-season rice (h). Box plots represent the distributions of 1000 points of control composite. Crosses depict extreme outliers, and red dashes denote medians. Black lines are the means of the real-occurred composites. (ER: early rice; MR: middle-season rice)

The production and yields of maize and rice, the yield of wheat reduced significantly in flood-year, with 4.4%-6.8% decreases. Maize suffered more yield and production losses than the other crops. Meanwhile, the yield of middle-season rice was also affected by floods significantly, with reductions of 4.1% (Fig. 2). But we hesitate to draw strong conclusions for the yield and production of early rice due to the limited sample size (n=19) which may lead to the failure of the SEA process. Similar to droughts, production reduced more than yield due to flood. Moreover, reductions were greater in drought-year than in flood-year.

C. The impacts of droughts and floods in different regions

Among the three MGPA, the yields and production of main crops suffered more significant reductions in the NEC and HHH than in the MLYR. In the NEC, the yields and production of maize, rice, soybean and the production of wheat decreased significantly, especially maize and soybean, with 10.4%-17.2% reduction in drought year (Fig. 3). In the HHH, a 7.7%-12.9% reduction was found in the production and yields of maize, rice, and the yield of soybean. However, in the MLYR, no significant yield or production decrease was found. Meanwhile, the differences among the MGPA in the percentages of reduction due to droughts were significantly (Fig. 3, $p<0.05$), which meant there was strong spatial heterogeneity of the crop response to droughts in the MGPA. As for different types of rice in the MYLR, no significant reduction was found in yield and production of early rice, middle-season rice and late rice due to drought. In addition, the responses of three types rice to drought in the MLYR showed insignificant difference.

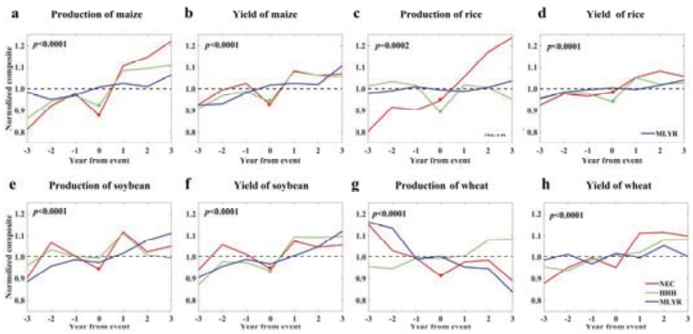

Fig. 3. Impacts of droughts on production and yields of maize (a, b), rice (c, d), soybean (e, f) and wheat (g, h) in the MGPA. Lines with different colors represent the real-occured composites in different regions, significant decrease points are marked with asterisks.

Among the MGPA, only wheat yield in the NEC and rice production in the MLYR showed significant decrease in flood-year, with reduction of 10.4% and 4.9%, respectively. In addition, the Kruskal-Wallis test showed p<0.05, but we hesitated to draw strong conclusion that there were significant difference among the crop responses to flood, except for wheat yield and rice production, as it was difficult to compare these groups which had no significant yield or production reductions (Fig. 4).

As for different types of rice in the MLYR, only the yield and production of early rice decreased significantly due to flood, with reductions of 11.3% and 8.0%, respectively (Fig. 5). The middle-season rice and late rice had slightly trends of yield and production reduction insignificantly, except for the yield of late rice which showed no response in flood-year.

D. The impacts of droughts and floods during different periods

During 1982-1997, the yields and production of rice, soybean, and maize decreased in drought-year significantly, with the reduction of 2.6%-9.8%. During 1998-2012, the yields and production of wheat, rice, maize and the yield of soybean suffered 5.4%-9.7% reduction in drought-year. The yield and production of rice, maize and the yield of soybean declined between 1982 and 2012 due to drought during both earlier and later period. However, the reductions of yield and production of wheat and the yield of middle-season rice during 1982-2012

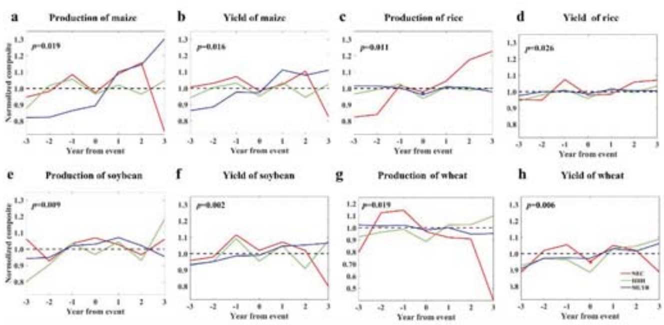

Fig. 4. Impacts of floods on production and yields of maize (a, b), rice (c, d), soybean (e, f) and wheat (g, h) in the MGPA. Lines with different colors represent the real-occured composites in different regions, significant decrease points are marked with asterisks.

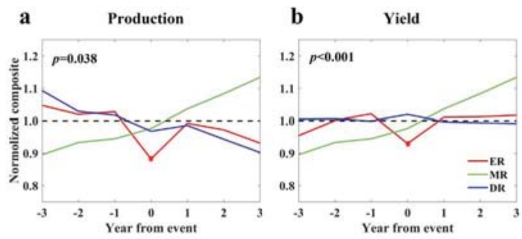

Fig. 5. Impacts of floods on the production of different types of rice (a) and the yields of different types of rice (b) in the MLYR. , Lines with different colors are the means of the RS composites of different rice type, with significant decrease points marked with asterisks. (ER: early rice, MR: middle-season rice, LR: late rice.)

were mainly due to the significant reduction in the later period, and the soybean production was due to the reduction in the earlier period.

As for flood, during 1982-1997, the yield and production of maize, the yield of rice and middle-season rice, and the production of wheat were significantly affected by flood, with 4.1%-10.6% reduction. During 1998-2012, the yield of wheat and rice, and the production of early rice decreased 5.2%-12.9% significantly. Maize yield and production, middle-season rice reduced significantly during 1982-2012 due to the significant reduction in earlier period. Rice yield affected by flood during the entire study period and the earlier and later periods. Wheat yield reduction during 1982-2012 was mainly due to the significant decrease in the later period.

TABLE II. THE RESPONSE TO DROUGHTS AND FLOODS OF CROPS DURING DIFFERENT PERIODS (EP: EARLIER PERIOD, 1982-1997; LP: LATER PERIOD, 1998-2012; MR: MIDDLE-SEASON RICE; ER: EARLY RICE)

Disaster type	Period	Crop	Index	Change percentage	Sample size
Drought	LP	Wheat	Production	8.8%	50
Drought	LP	Wheat	Yield	7.0%	50
Drought	EP	Rice	Production	5.9%	65
Drought	LP	Rice	Production	6.9%	49
Drought	EP	Rice	Yield	2.6%	65
Drought	LP	Rice	Yield	5.4%	46
Drought	EP	Maize	Production	8.9%	66
Drought	LP	Maize	Production	9.7%	49
Drought	EP	Maize	Yield	6.9%	66
Drought	LP	Maize	Yield	6.8%	48
Drought	EP	Soybean	Production	8.7%	63
Drought	EP	Soybean	Yield	9.8%	63
Drought	LP	Soybean	Yield	8.5%	48
Drought	LP	MR	Production	6.5%	45
Drought	LP	MR	Yield	6.5%	45
Flood	EP	Wheat	Production	9.0%	17

Flood	LP	Wheat	Yield	6.7%	14
Flood	EP	Rice	Yield	4.1%	17
Flood	LP	Rice	Yield	5.2%	15
Flood	EP	Maize	Production	10.6%	17
Flood	EP	Maize	Yield	6.2%	17
Flood	EP	MR	Yield	6.2%	9
Flood	LP	ER	Production	12.9%	9

IV. DISCUSSION

A. *Different responses of main crops during different periods and in different regions.*

During 1982-2012, droughts and floods caused different impacts on the yields and production of main crops. Drought had wider impacts on the crops than floods with greater yield or production reduction in disaster year for the same crop, which indicated droughts caused more negative effects on main crops than did floods in the whole China.

Maize and soybean [9, 29] had more yield and production deficit significantly from drought than wheat and rice did. As in the maize growing regions, drought was the most frequent disaster [30], and a lower maize yield was relative to the reduction of precipitation and the increase of temperature which highly correlate to the drought during the growing period [31, 32]. Meanwhile, drought stress happening from initial flowering period and seed fill period in soybean significantly decreased branch seed yield [16, 17, 33, 34]. Among the MGPA, the NEC was affected more by droughts than by floods [15, 35], with greater yield and production reduction than those in the HHH and MLYR .

Previous study showed droughts and floods were two main climate disasters which caused the yield reduction [5]. However, since better irrigation and drought-tolerant cultivars were applied in the HHH, wheat planted in this region can adapt to climate disasters, especially droughts [21].

Rice was sensitive to both drought and flood during growing period [36-38]. The different responses of different types of rice in MLYR may be relative to the difference of the growing period. The general growing period of early rice was from April to July, middle-season rice was from April to August, droughts and floods had high occurrence during these two periods; late rice was between July and October, when the precipitation reduced after July, especially after September [23, 39-41].

B. *Study limitationss*

There are some limitations of our study. First, we defined the heavy and extreme droughts and floods, which led to the insufficiently large sample size of floods and may cause the incomplete elimination of impacts caused by other indicators (such as policy changes, economic shocks, etc.) [3]. Moreover, the spatio-temporal responses of crop yield and production to different grades of droughts and floods are required further study.

V. CONCLUSION

The impacts of droughts and floods on the yields and production of maize, rice, soybean and wheat were different, different responses were also found during different periods, throughout China, and among the three MGPA by applying the SEA method.

Main crops had a 4.4%-6.8% yield or production reduction due to flood, and wider impacts on production and yield of main crops due to droughts were observed, with decreases ranging from 3.7% to 9.2%. Maize and soybean were more sensitive to drought in the whole China, especially in the NEC, with the significant reduction of 10.4%-17.2% in the NEC and 6.4%-9.2% in the whole China. In China, wheat yield was affected by both droughts and floods, with significant decreases of 4.3% and 6.1%, respectively. Moreover, different types of rice had various responses to droughts and floods. Early rice was sensitive to floods in China and in the MLYR, but middle-season rice seemed to be sensitive to both droughts and flood in China. Meanwhile, crops response in different periods varied, but had no great reduction difference between two periods. Based on the study, pertinence strategies (such as better irrigation and basic construction in cropland, etc.) should be applied urgently to protect main crops from suffering serious reduction from droughts and floods for the stability of crop production and food security in China.

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