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QUANTITATIVE EVALUATION OF AGRO-METEOROLOGICAL DISASTERS IN CHINA

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Abstract

Disastrous weather directly affects the agricultural production especially in China. Using appropriate statistical analysis on Chinese agro-meteorological disaster data during 1949 to 2012, the rate of meteorological disasters (e.g. droughts, floods, typhoons, hail, and chill-related injuries) and their variance are calculated. Thus, values of various classifications of meteorological disasters have been assigned. Results showed that in the last 64 years, the average rates of impact of agro-meteorological and other disasters in China indicate an increasing trend. The average drought disaster rate has been growing fastest at 1% every 10 years and as such it has the largest effect on production weight and mainly effect the northern territories. In general, agro-meteorological disasters are at medium levels. In the last 10 years, the frequency of major disasters has increased. The research results provide a scientific reference for the analysis of the evolution of agro-meteorological disasters, agricultural disaster prevention and mitigation, food production and yield stability.

Introduction

It is important to study the contributions of climate change and human activities to spatial-temporal changes of crop yield in the fields of climate change and land use change (Pielke 2005, Grekousis *et al*. 2016). Global climate change is one of the issues focused on both international scientific research and international politics because of its important implications on sustainable socio-economic development (Jia 2013). Its impact on agriculture is characterized by multiple dimensions, multiple levels, and the coexistence of positive and negative effects (Turner *et al*. 2007, Li et al. 2010). However, the quantitative assessments of the contributions of global climate change to spatial-temporal changes of agro-meteorological disaster need to be explored for a better understanding of the dynamics of climate changes (Grekousis *et al.* 2016, Ruiz *et al.* 2011). The risk to climate change and variability has increasingly been of concern because of increasing climate extreme events in recent decades (Pielke 2005). Global warming enhances crop production in certain areas of the world, but extreme weather conditions also cause losses in agricultural production, which result in substantial changes in agricultural structures and food production (Wang *et al.* 2007a, Rodrigo *et al.* 2016). Agro-meteorological disasters means adverse weather conditions that cause a measurable decrease of crop yield in the agriculture (Riedell *et al.* 1999). China is a large agricultural country located in the East Asia monsoon region, and the annual fluctuation of climate conditions is evident. Meteorological disasters account for 70% of all natural disasters (Li *et al.* 1999) and the average affected area accounts for 31% of the total farming area. On average, droughts affect 56% of the total affected area, whereas floods (since 1950) affect 24%, and chilly weather (since 1978) affects 6% (Li *et al.* 1999). These three disasters account for 86% of the total meteorological disaster-affected areas. Every year, loss directly caused by agro-meteorological disasters amounts to approximately RMB 100 billion, which is approximately 3 to 6% of the gross national product (Li e*t al.* 2010).

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Agro-meteorological disasters in China are strongly characterized by a high spatiotemporal variability. The last 50 years have witnessed a strong trend towards drought in the north and north-eastern areas of China, and flooding in the basin of the middle and lower reaches of the Yangtze River and south-eastern China. The warming of the climate has led to an advance in crop maturity and a decline in the cold resistance of crops. The latter has magnified the effects of freezing damage during the winter and spring seasons in southern China, and therefore increased the instability of agricultural production. At present, accurately forecasting disastrous weather is difficult, and the increase or decrease of crop yield is primarily subject to climatic conditions (Zhang *et al.* 2010). Quantitatively assessing the impact of agro-meteorological disasters on grain production has important implications for food security.

Along with the development of various kinds of new theories and technologies and the crossing of multiple disciplines, Chinese researchers have launched research on issues such as the impact of agro-meteorological disasters on agricultural production (Wang *et al.* 2007b), the relationship between climate change and the ecological agricultural environment, agro-meteorological disaster evolution (Sun *et al.* 2006), and meteorological disaster warning and defense (Wang *et al.* 2007a). However, these studies are mostly limited to provincial-level administrative units and lack assessment based on a large scale and a long time series. Reports regarding the quantitative evaluation of agro-meteorological disasters are un-common. Here, four kinds of meteorological disasters are discussed based on their significant influence on agricultural production: (i) drought, (ii) flood, (iii) typhoon and hail, and (iv) chill injury. Their occurrence is quantitatively assessed and an inquiry is conducted into the regular pattern of their changes in order to provide a scientific reference for the sustainable development of agriculture and agricultural disaster prevention.

Material and Methods

The data used in the research consisted of information on the total sown areas of farm crops in China from 1949 to 2012, and crop disasters (such as damaged crop areas, disaster-subjected areas, no-yield areas) such as Hong Kong, Macao, and Taiwan. However, there is no information from 1967 to 1969. The database was obtained from the crop database and query system of the Farming Information network (http://zzys.agri.gov.cn/). The disaster database was jointly established by the Statistical Yearbook of China and Chinese agricultural statistics.

Before 2001, typhoon disaster data were contained in the gale and hail disaster data. This research still uses the combination of these two kinds of data together even after 2001. We defined the disaster-impact rate (M_i) as the ratio of the area of a single kind of crop subjected to disaster and the total farming area. This can reflect the degree of influence of the disasters. Based on the results, the variation values of the disaster-impact rate (Zi) over the years can be obtained (Zhang *et al.* 2007):

$$M_i = X_i / S_i \tag{1}$$

$$\delta = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(M_i - M)^2} \tag{2}$$

$$Z_i = (M_i - M)/\delta \qquad (i\text{=1, 2,…, 61}) \tag{3}$$

Here, X_i stands for the disaster-affected crop area in the *i*th year, S_i refers to the total farming area in the *i*th year, M_i represents the disaster-impact rate of *it*h year, Z_i stands for the variation value of the *i*th year's disaster-impact rate, *M* is the average disaster-impact rate for several years, and δ is the standard deviation.

In the past, some researchers divided disaster degrees mainly on the basis of their experience (Zhang *et al.* 2007). This kind of research method was not easy to conduct in repetitive tests and comparisons with other research results. Thus, this study calculates the variation values of the disaster-impact rates of those four kinds of disasters from 1949 to 2012 with Equation (1), and applies symmetrical-equal-interval method to divide the values into five groups based on their dispersion degree (Zhang *et al.* 2011). The disaster conditions are classified as light, small, medium, big and heavy disaster. The graded assignment method was used to quantify the indexes from 0 to 10 A's for each year's division value of the rate of disaster condition (*ci*). These can be obtained via the interpolation bisection method (Table 1) following the variation values of the disaster-impact rate.

Table1. Classification standards and assignment scope of various kinds of disaster.

Project	Light disaster	Small disaster	Medium disaster	Big disaster	Heavy disaster
Flood	$-1.36<Z_i\leq-0.53$	$-0.53<Z_i\leq0.31$	$0.31<Z_i\leq1.14$	$1.14<Z_i\leq1.98$	$1.98<Z_i\leq2.81$
Drought	$-1.63<Z_i\leq-0.75$	$-0.75<Z_i\leq0.12$	$0.12<Z_i\leq1.00$	$1.00<Z_i\leq1.88$	$1.88<Z_i\leq2.76$
Typhoon and hail	$-1.42<Z_i\leq-0.75$	$-0.75<Z_i\leq-0.09$	$-0.09<Z_i\leq0.58$	$0.58<Z_i\leq1.24$	$1.24<Z_i\leq1.91$
Chill injury	$-0.91<Z_i\leq0.47$	$0.47<Z_i\leq1.85$	$1.85<Z_i\leq3.23$	$3.23<Z_i\leq4.61$	$4.61<Z_i\leq5.99$
Score	$0<C_i\leq2$	$2<C_i\leq4$	$4<C_i\leq6$	$6<C_i\leq8$	$8<C_i\leq10$

By using the grey correlation degree analysis, authors are able to compare quantitatively and analyze the developing tendencies in a systemic dynamic process, and determine the factors' extents of impact on the system's main behavior. Grey correlation uses the geometrical approach between factors. Consequently, the weights of each climatic disaster can be evaluated based on the correlation of their respective disaster-impact rate with total disaster-impact rate. The total disaster-impact rate (x_0) has a system feature sequence that calculates its grey correlation with disaster-impact rates of drought (x_1), flood (x_2), typhoon and hail (x_3), and chill injury (x_4)

Systemic behavioral sequence

$$X_0 = \{x_0(i), i = 1, 2, \ldots, 61\} \tag{4}$$

$$X_i = \{x_k(i), i = 1, 2, \ldots, 61\} \quad k=1, 2, 3, 4 \tag{5}$$

The disaster-impact rate is already a dimensionless method. Thus, the absolute difference of the two-level series can be directly determined:

$$\Delta_i(k) = \left| x_0(k) - x_i(k) \right| \quad (k=1, 2, 3, 4;\ i=1, 2, \ldots\ldots, 61) \tag{6}$$

Then we calculate each correlation coefficient of the comparison sequence and the systemic feature sequence at each moment as follows:

$$\zeta_i(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \qquad (7])$$

In the formula: ρ is the resolution factor with a value of 0.5. This calculates relevancy r_i (Zhang *et al.* 2007):

$$r_k = \frac{1}{61}\sum_{i=1}^{61}\zeta_k(i) \qquad (k=1, 2, 3, 4;\ i=1, 2,\ldots\ldots, 61) \qquad (8)$$

Based on the Correlation Degree r_k, the k-th weight of the impact factor can be calculated as follows:

$$\omega_k = r_k / \sum_{k=1}^{4} r_k \qquad (k=1, 2, 3, 4) \qquad (9)$$

The weight of each meteorological disaster in China is shown in Table 2.

Table 2. Influencing weight of four agro-meteorological disasters.

Impacting factor	Correlation degree (r_k)	Weight (ω_k)
Flood	0.8906	0.2498
Drought	0.9286	0.2605
Typhoon and hail	0.8911	0.2499
Chill injury	0.8549	0.2398

The damage index (*P*) is the sum of the products of the four agricultural climatic disasters' impact weight (W_k). The corresponding damage grade values (*Ck*) can be applied as comprehensive assessment indicators of agricultural climatic disaster. A larger the damage index results in a greater impact inflicted by climatic disaster on agricultural production and heavier disaster conditions, and vice versa.

$$P = \sum_{k=1}^{4}(C_k \cdot W_k) \qquad (k=1, 2, 3, 4) \qquad (10)$$

We divided the damage indexes into five groups using symmetrical-equal-interval method and based on dispersion degree. The classifying standards are shown in Table 3.

Table 3. Classifying standards of the comprehensive disaster condition.

Level	Damage index *P*
Light disaster	$0.34 < P \leq 1.52$
Small "	$1.52 < P \leq 2.69$
Medium "	$2.69 < P \leq 3.87$
Big "	$3.87 < P \leq 5.04$
Heavy "	$5.04 < P \leq 6.22$

Results and Discussion

The average infestation rate of agro-meteorological disasters in China was 11.93%, with an increasing trend displaying an increase of 1.5% during 10 years (Fig. 1). From 1950 to 1959, infestation rates were below average, and the impact of climatic disasters on agricultural production tended to be weaker. From 1960, infestation rates have become higher than the average for the year of 58.5%. This means meteorological disaster has a greater impact on agricultural production. Among them, the 1970 disaster had an infestation rate of only 2.3%, which is the minimum in the last 64 years. This was also the year in which meteorological disasters had the least impact on agricultural production. In 2000, the disaster-impact rate was 22%, the highest in the last 64 years. Meteorological disasters were heaviest mainly due to the large scope of serious drought in China during that time. Approximately 17.1% of China's farmland was affected by this drought.

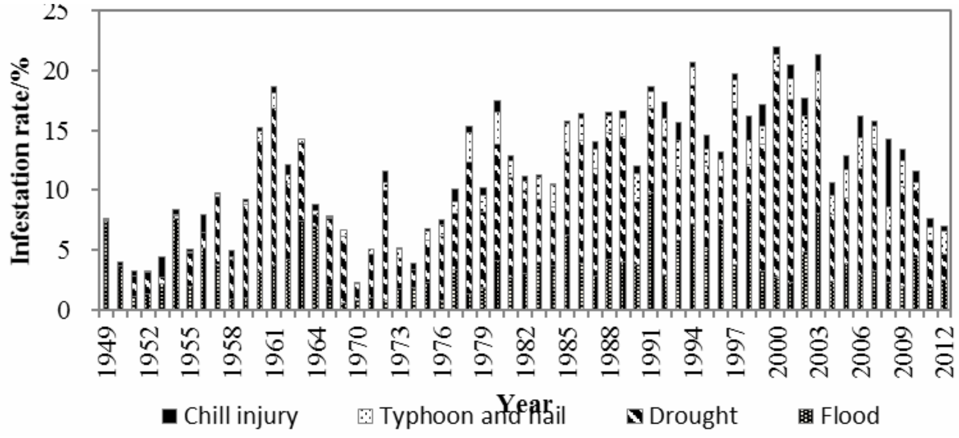

Fig. 1. Changes of meteorological disasters in China from 1949 to 2012 (lacking data for 1967 to1969).

Among these four types of agro-meteorological disasters, drought has the highest average disaster-impact rate at 6.4%. Floods have the second highest at 3.6%, with typhoon and hail following at 1.2%, chill injury ranks the last at 0.7%. In the last 64 years, the disaster-impact rate shows an increasing trend. Among them, drought has the most apparent increasing trend at 1% during 10 years. Typhoon and hail have also increased rapidly, with the rate increasing at 3% in 10 years. Chill injury grows at the rate of 0.2% per 10 years while flood has the lowest rate of increase at 0.1% in 10 years. The impact of drought on agricultural production has evidently increased.

In terms of agro-meteorological disasters in China, the disaster-impact weight of drought was the largest at 26.1%. Typhoon and hail is second at 24.9%, which is close to chill injury at 25%. Flood had the smallest weight at 24%. The weight distribution trends for the four types of disasters vary in each region (Table 4). Based on the division of regions, drought is dominant in north-east China, north China, north-west China, south-west China, south China and central China, while flood is dominant in east and south China.

The disaster weight changes in 64 years (Fig. 2) indicate that flood weights showed a decreasing trend, with an average reduction of 9.2% in 10 years. Other disaster weights increased, among which the most obvious is typhoon and hail's impact weight, which increased at 161.2% in 10 years. The weight of drought increased at 6.8% in 10 years, whereas chill injury increased at 4.1% during 10 years. During 1959 and 1967, the drought weights were high above 0.8. During 1949, 1950, and 1954, drought weights were low at less than 0.1 because of the influence of flood, with a weight higher than 0.9 during these years. In 1972, the weight was less than 0.1.

In the 1950s, agro-meteorological disasters in China were dominated by flood, with an average weight of 53.9%. Drought followed at 37.2%, chill injury at 8.7%, and typhoon and hail at 1.2%. Since the 1960s, drought became dominant among these disasters, followed by floods, typhoon and hail, and chill injury. However, drought weights declined slowly from 57.8% during the 1960s to 52.5% in the 2010s. Flood weight dropped dramatically from 35.1% in the 1960s to 23.9% in the 2010s. The weight of typhoon and hail soared from 4.7% in the 1960s to 12.9% in the 2010s. The weight of chill injury increased from 2.5% in the 1960s to 10.8% in the 2010s. Drought has had the largest impact on agricultural production among the meteorological disasters in most parts of China and there is a growing gap between the supply and demand for agricultural water.

Table 4. Agro-meteorological disaster-impact weight of every province.

Province	Flood	Drought	Typhon	Chill	Province	Flood	Drought	Typhon	Chill
Beijing	24.8	25.5	25.3	24.4	Hubei	25.2	25.1	25.7	24.7
Tianjin	24.8	26.0	24.9	24.3	Hunan	25.1	25.2	25.0	24.7
Hebei	24.4	26.6	25.5	23.5	Guangdong	26.1	24.9	25.3	23.7
Shanxi	23.9	27.8	25.0	23.4	Guangxi	25.2	25.9	24.9	24.0
Neimenggu	24.2	27.6	24.7	23.5	Hainan	25.9	25.3	24.9	24.0
Liaoning	24.7	26.1	25.0	24.1	Chongqing	25.2	25.9	25.4	23.6
Jilin	24.9	26.6	24.9	23.6	Sichuan	24.8	25.7	25.0	24.5
Heilongjiang	25.0	26.0	25.0	24.0	Guizhou	24.9	25.4	25.2	24.5
Shanghai	25.2	24.9	25.0	25.0	Yunnan	24.5	26.2	25.2	24.2
Jiangsu	25.5	24.9	25.2	24.4	Xizang	24.7	25.4	25.0	24.9
Zhejiang	25.8	24.8	25.1	24.3	Shaanxi	24.6	26.7	25.0	23.7
Anhui	25.9	25.1	25.0	24.1	Gansu	24.7	27.2	24.4	23.7
Fujian	25.8	24.7	25.1	24.4	Qinghai	25.1	26.0	25.1	23.9
Jiangxi	25.5	25.0	24.7	24.8	Ningxia	24.7	26.0	24.7	24.6
Shandong	25.0	26.7	25.0	23.4	Fujian	24.1	26.2	25.1	24.6
Henan	25.0	25.8	24.8	24.4					

The disaster conditions of drought, flood, typhoon and hail, and chill injury were classified during the 1949 to 2012 (Table 5). Among the four kinds of meteorological disasters, small and light disasters of chill injury happened the most frequently, whereas typhoon and hail occurred the least frequently. The heavy and big disasters of typhoon and hail occurred most frequently whereas heavy and big disasters of chill injury happened least frequently. Based on a comprehensive evaluation, the levels of agricultural meteorological disasters in 52.5% of those years were medium and big disasters in China and had a significant effect on agricultural production. According to the standards in Table 3, which conducted an overall assessment of the meteorological disasters in China, the number of medium disasters is the largest at 17 per year; small and large disasters followed at 15 per year.

The disaster analysis of the damage indexes from 1949 to 2012 showed that the 2003 damage index was the largest at 5.6. The damage indexes during 1951 and 1970 were the lowest at 0.4 and 0.3, respectively (Fig. 3). Damage indexes exhibited an increasing trend at 0.5 in 10 years, indicating a significant increase in the levels of impact of meteorological disasters on China's agricultural production. Since 2000, heavy disasters began happening once per year, and big disasters happened four times a year. They account for 100 and 26.7% of the number of disasters happening per year, respectively, and the frequency of major disasters taking place has risen substantially.

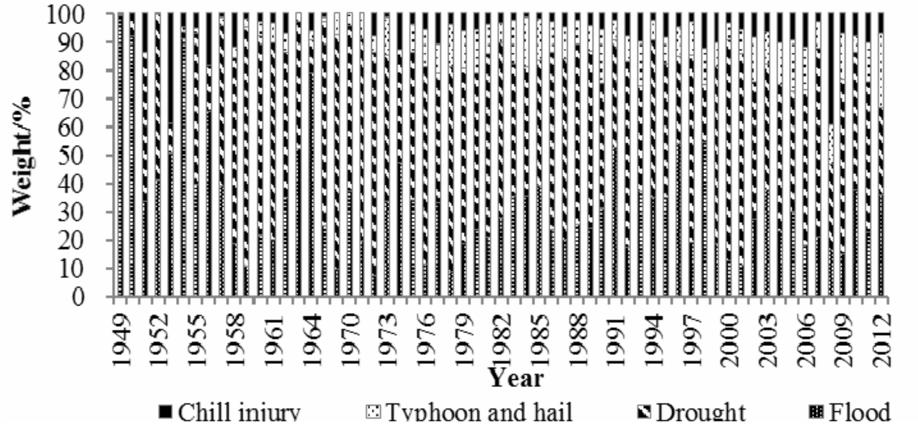

Fig. 2. Changes in the meteorological disaster-impact weight in China from 1949 to 2012.

Table 5. Assessment results of the years of agro-meteorological disasters.

Project	Flood	Drought	Typhoon and hail	Chill injury	Annual assessment level
Light disaster	22	15	18	48	13
Small "	24	20	10	12	15
Medium "	5	14	15	0	17
Big "	7	10	8	1	15
Heavy "	3	2	10	0	1

It was observed that each type of agro-meteorological disaster in China tends to increase significantly (Grekousis *et al.* 2015, Turner *et al.* 2007), which corresponds with Wang *et al* (2007a). Among them, drought occurred more frequently and affected the development of agriculture the most. Drought has become a major factor that affects agricultural stability and food security. This is in line with Yang *et al.* (2007). Since the 1980s, precipitation in China has been unevenly distributed, with little rain falling in the north and much rain falling in the south. This situation is compounded by the drought and water shortage occurring in the north and constant flooding in the south. Moreover, basins have witnessed a decline of precipitation with varying extents in the north. In particular, the northern part of the Yangtze River basin and the Yellow River basin, located 35° to 40° N (Deng *et al.* 2007), experience serious droughts consistent with the overall trends of precipitation in those regions (Li *et al.* 2010). In addition, the number of days with precipitation has significantly reduced in north-east China and north China. With further changes in the climate, drought disaster has begun to pose a significant impact on moreareas more frequently.

Flooding mainly occurs in the south-eastern parts of China, the Yangtze river basin, the Yellow River basin, and the Huaihe River basin (Yang *et al.* 2007). Since the 1990s, floods in China have increased significantly. Flooding in the Huaihe River and Taihu Lake basins began in 1991. In the Yangtze river basin, Songhua River basin, and Nenjiang river basin, flooding began in 1998, and in the Huaihe river basin, flooding began in 2003. These floods have caused serious disasters, which imply a fluctuating tendency for flood disasters during climatic warming (Li *et al.* 2010).

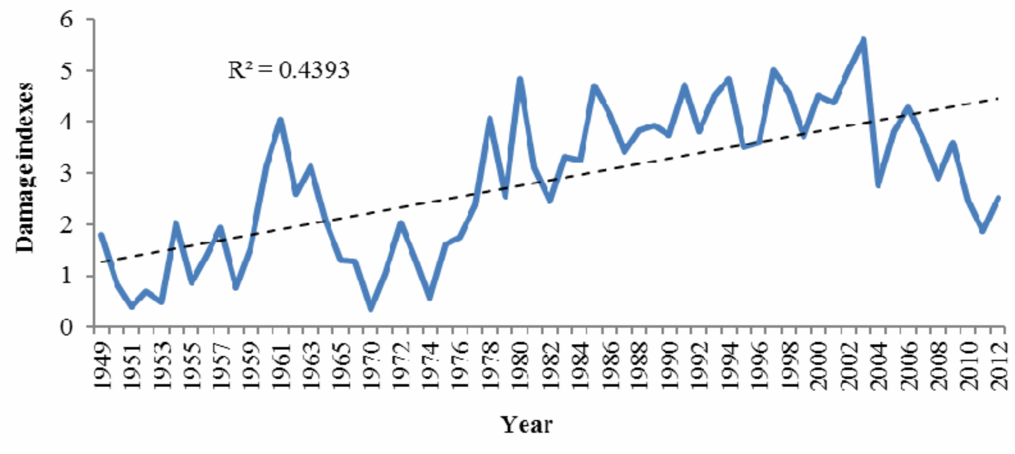

Fig. 3. Changes of indexes of meteorological disasters in China from 1949 to 2012.

Despite the smaller impact area of typhoon and hail disaster, local disaster conditions are still serious because of apparent regional distribution. Losses resulting from cumulative disasters are relatively heavy as well. Climate change has caused a decrease in the average wind speed of many areas (Jia 2013), but typhoon disasters are related primarily to the gales rather than the average wind speed, so uncertain ties regarding the changes in the characteristics of typhoon disasters remain at large. Hail disaster has occurred all over the country, but most frequently on the Qinghai-Tibet Plateau and Qilian Mountains.

Chill damage primarily occurred in north-east China, north China, and south China. During the last hundred years, temperature has increased by 1.43°C in 100 years in Northeast China. This is twice that of the rate of global warming (Sun *et al.* 2006), and has given rise to temporal and spatial changes in agricultural climatic resources. With climate warming, there are still extreme climatic events. Climate warming in winter leads to a greater potential for chill injury. Scholars believe that since the 1980s, the intensity and frequency of chill injury on crops in North China have decreased due to climate warming (Wang 2009). However, this study has found no tendency for decline in the intensity and frequency of chill injury (Wang *et al.* 2009), mainly because in other previous studies, the data of typhoon disasters after 2010 were not combined with the data of hail and wind disasters.

Agro-meteorological disasters have displayed an increasing tendency in the amount of medium disasters, whereas small disasters are decreasing in number. Moreover, the affected areas and the intensity of the disasters are increasing as well. However, the effects of these disasters on the agricultural production system still depend on the responses of these institutions to the effects of environmental stress (Tan *et al.* 2005). Natural factors have a major effect on the changes in grain yield per unit area (Fig. 4) (Grekousis *et al.* 2015). In addition, the indirect impact of climate on agriculture is also reflected in the conditions of diseases, pests, and weeds and their effect on food production. Crop diseases and pests disasters in China also indicate an annual increase (the grain of the investigation training center of China 2009). At last, it is necessary to point out that interdisciplinary research, such as integration of natural and human factors, is now needed more than ever in order to reveal mechanism of agro-meteorological disasters by using geographical information system, remote sensing technology, and geostatistics method (Grekousis and Mountrakis 2015).

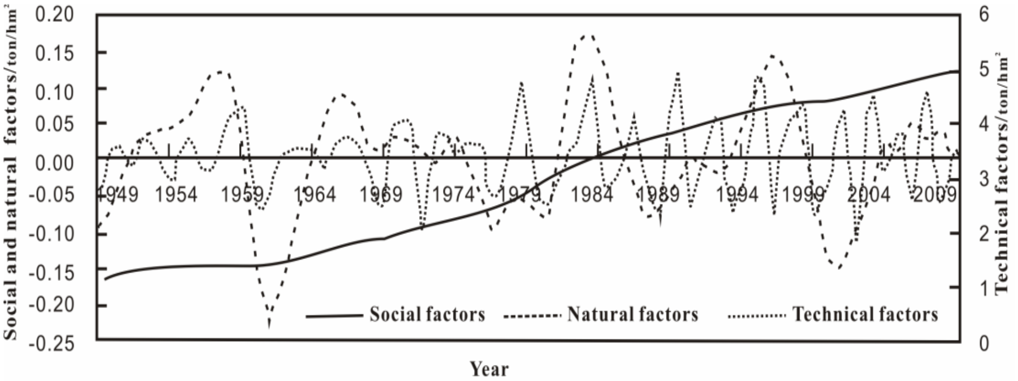

Fig. 4. Crop yield under the influence of technical, social, and natural factors in China between 1949 and 2010 (Yang 2012) (Separate crop yield into long-term tendency and short-term fluctuation with hp-filter; separate short-term fluctuation yield into fluctuation yield caused by social factors and natural factors with three-year moving average method).

By using the data of agro-meteorological disasters in China in a period of 64 years, we analyzed the disaster-impact rates, variation values, and impacting weights of drought, flood, typhoon and hail, and chill injury. In this research the impact of these four types of meteorological disasters on agricultural production was also assessed.

In the context of climate warming, an increase in the intensity and frequency of agro-meteorological disasters has occurred. Extreme weather events have particularly threatened China's food security. The average disaster-impact rate of agro-meteorological disasters in China is at 11.9%, which indicates an increasing trend. All four meteorological disasters have increased, with the drought disaster-impact rate indicating the most significant change.

Drought had the highest impact weight of all the agro-meteorological disasters in China. Floods had the lowest impact weight and exhibits a decreasing trend, whereas all the other disaster weights show an increase. The impacting weight of disasters in China varies per region. It is necessary to focus on the occurrence and development of regional agro-meteorological disasters in line with local conditions and launch relevant monitoring work.

The average level of agro-meteorological disasters in China is mainly on a medium disaster level, and this has heavily affected agricultural production. Damage indexes show an increasing trend, indicating that meteorological disasters are posing greater hazards on national agricultural production. Since 2000, the frequency of big disasters has increased sharply.

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