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Adapting the wine industry in China to climate change: challenges and opportunities

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Abstract

Recently, China has become an exciting wine consumer market and one of the most important wine producers. China's domestic wine industry is in the enviable position of contributing approximately 70 % of the total wine consumed with a 1.36 billion population market and the second largest world economy. Current studies of the Chinese wine industry are mostly focused on the wine market. However, global climate change, which affects the quantity, quality and distribution of wine, will have a strong impact on the Chinese domestic wine industry. In this paper, we characterize the impact of climate change in China and establish policy, financial, technical, institutional and collaborative adaptation strategies for the Chinese wine industry.

Key words: climate change, wine industry, China, adaptation strategies

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INTRODUCTION

Global warming is a common challenge for society. The Intergovernmental Panel on Climate Change (IPCC) report presents that increasing mean surface air temperatures over oceans and land have been observed over the last century (IPCC, 2013). Additionally, in several regions of the world it is evident that climate change has affected both terrestrial food production and crop yields (IPCC, 2014). Under climate change, especially in developing countries, such as China, agriculture is the most vulnerable economic sector (Chen S. *et al.*, 2016).

A widespread observation is that climate change will affect both the geographical distribution of the wine industry and the quality of the product. Although wine is not an essential agricultural product for survival, it is closely connected to human history and culture as a significant product of human ingenuity (Mozell and Thach, 2014). Viticulture contributes to the local economy, tourism, industry and natural habitat (Duchene, 2016; Resco *et al.*, 2016). In recent years, China has joined the world's wine world presenting significant suitable regions and diverse climatic sites (De Orduña, 2010; Hannah *et al.*, 2013). A great expansion of Chinese domestic wineries in new regions with increasing capability may be observed (Mozell and Thach, 2014). While there have been continued improvements in the wine industry, it is necessary to recognize the impact of global climate change, which will bring both challenges and opportunities to China.

In this paper, we review the development of the Chinese wine industry and explore how climate change will affect viticulture and the Chinese wine industry. Next, we provide climate change adaptation strategies for the wine industry in China.

MATERIALS AND METHODS

In this study, we use secondary data collected from the International Organization of Vine and Wine (OIV) and the National Bureau of Statistics of China, the China Sugar and Liquor Yearbook, Chinese business information networks and literature review to examine the development of the wine industry in China.

To better understand how climate change will affect the global wine industry, we explore the structural relationship between climate change and vineyards. We attempt to analyze the possible benefits (opportunities) and harms (challenges) of climate change for the Chinese wine industry based on a number of indicators of both climate variables (temperature, accumulated heat, precipitation, water resource, and frost-free period) and climate events (drought, flood, extreme rainstorm, fog, and hail). For the whole country, secondary data are mainly obtained from three sources: 1. Literature review of studies in China; 2. Institutes and organizations, such as the China Meteorological Administration, the National Bureau of Statistics of China and the World Bank; and 3. Government reports and bulletins, such as the Ningxia Statistical Yearbook and the China Flood and Drought Management. For the primary wine-producing provinces, qualitative analyses are made by literature review of Chinese studies.

WINE INDUSTRY IN CHINA

China has a 6,000-year history of grape growing and a 2,000-year history of wine making (Qiu *et al.*, 2013). The Chinese wine history can be traced back to the Han Dynasty when wine was introduced from central Asia. Grapes were planted and wine was produced in the Yellow River region in the northeast (Liu F. and Murphy, 2007). The first Chinese company, Changyu, was established in 1892 in the coastal city of Yantai in Shandong Province (Mitry *et al.*, 2009).

Regionally, China has a large geographical size and distinct topographic situations including grassland areas and semi-arid plateau in the north, oasis and deserts in the northwest, semi-humid basin in the center, forests and plains in the northeast, high-altitude plateau in the southwest and humid coastal areas in the southeast. Vineyards for wine making are widely distributed across the Chinese territory and face a variety of geographical and climatic conditions (Figure 1). The main wine-producing provinces are Xinjiang, Yunnan, Henan, the Central Region including Ningxia, Gansu and Shaanxi, the Bohai Bay Region including Shandong, Hebei and Tianjin, and the Northeast Region including Liaoning, Jilin and Heilongjiang. The Yantai Region of Shandong (1987) and the Ningxia Hui Autonomous Region (2012) are involved with the OIV as observers. Cabernet Sauvignon is the most widely planted wine grape in China with more than 20.000 ha followed by Chardonnay, Cabernet Franc, Syrah, and Pinot (Li H., Li and Yang, 2009).

China's domestic wine production has grown dramatically since the 'reform and opening up' policy in 1978 (Figure 1). According to the OIV, in 2014 China had the eighth largest global wine grape production and the largest global grape production. China has overtaken France as the country with the second largest vineyard area (table grape, wine grape and dried grape) after Spain. In 2015, China had the world's second largest vineyard area (table grape, wine grape and dried grape) and the world's eighth largest wine production (Table 1) (OIV, 2016). Even though the total vineyard area of China is now the second largest in the world, only 10 % are for wine production (Decanterchina, 2016). Hence, further vineyard expansion for wine grape could be expected considering the huge market demand and the vast suitable territory of China.

IMPACT OF CLIMATE CHANGE ON WINE PRODUCTION

The sensitivity of wine production to changing climate factors will pose significant effects on yields and quality, ultimately impacting prices and revenues (Bardaji and Iraizoz, 2015). The decrease in suitable grape planting areas will adversely affect the quantity and quality of wine grapes produced (IPCC, 2014). Figure 2 illustrates the structural relationships between climate change and the wine production process. Vineyard location and climate variables have an immediate impact on grape quality and quantity. The effects of climate variables become apparent during the wine making and the wine storage period. Over the long term, vineyards could be relocated as owners seek more suitable climate conditions in order to maximize grape/wine quantity and quality.

Even though a multitude of individual climate factors have impacts on viticulture, temperature and water supply are the most important factors (Schultz and Jones, 2010).

Temperature plays a key role in viticulture. Each specific grape cultivar has its own range of optimal growing season temperatures, which determine the climate-maturity ripening potential (Table 2) (Jones, 2007). In North China, when the average annual minimum temperature is below -15 °C, it is necessary to adopt the soil-burying method to prevent *Vitis vinifera* from the damage of winter frost, and approximately 90 % of the current vineyards in China need soil-burying (Wang S. *et al.*, 2015). The Soil-Burying Line of China indicating areas with average annual minimum temperature

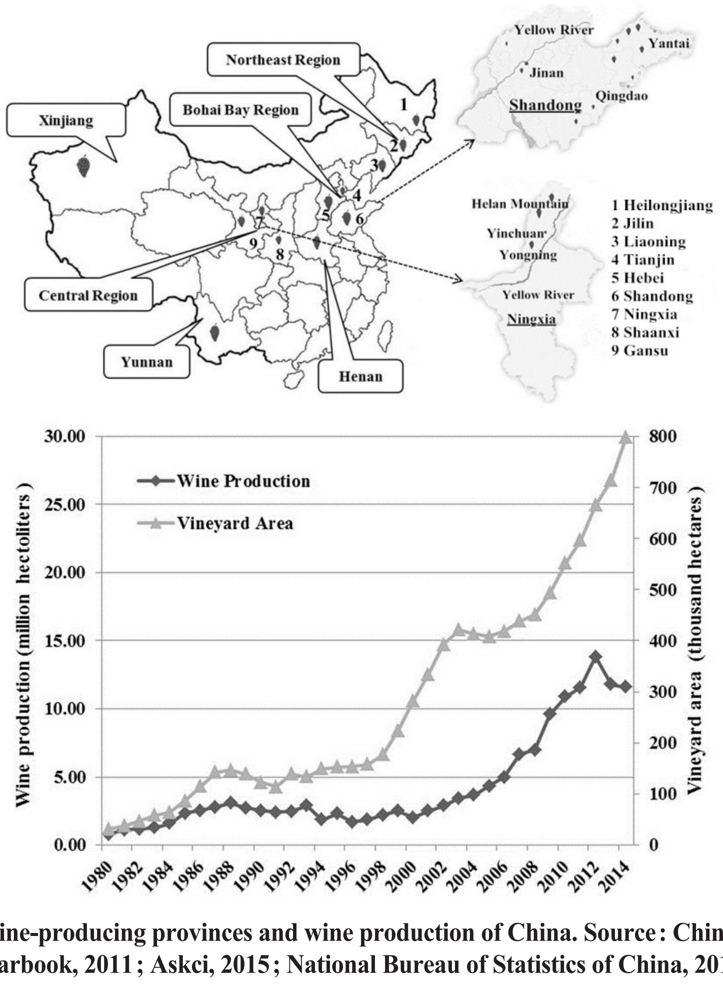

Figure 1. Primary wine-producing provinces and wine production of China. Source: China Sugar and Liquor Yearbook, 2011; Askci, 2015; National Bureau of Statistics of China, 2015.

Table 1. World's grape and wine. Source : OIV, 2016 and calculated by the authors.

Ranking	Country	Wine (2015) million hectoliters	Country	Vineyard (2015) thousand hectares	Country	Wine grape (2014) million tons
1	Italy	50.0	Spain	1,021	France	6.04
2	France	47.4	China	830	Italy	5.87
3	Spain	37.3	France	786	Spain	5.19
4	USA	22.1	Italy	682	USA	3.20
5	Argentina	13.4	Turkey	497	Argentina	2.03
6	Chile	12.9	USA	419	Australia	1.56
7	Australia	11.9	Argentina	225	China	1.48
8	China	11.5	Iran	225	South Africa	1.46
9	South Africa	11.2	Portugal	217	Chile	1.37
Total	World	274.0	World	7,511	World	36.10

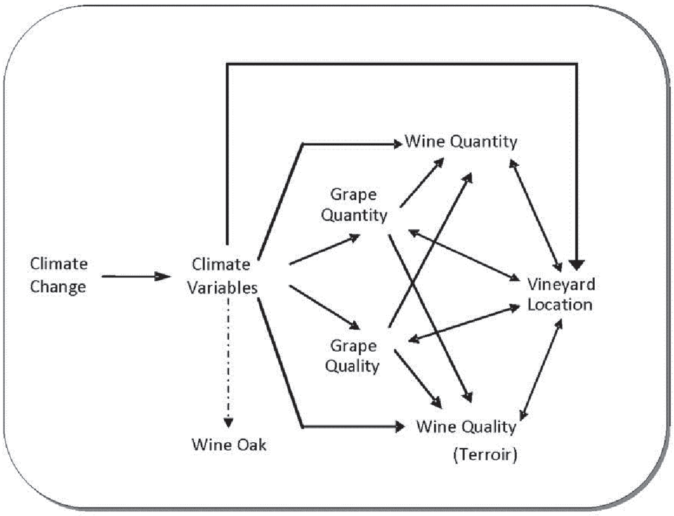

Figure 2. Climate change and the wine production process. Source : Own elaboration.

below -15 °C and requiring soil-burying in winter includes Shandong, Jiangsu, Henan, Shanxi, Shaanxi, Gansu, Sichuan, Yunnan and Tibet from east to west (Li H. *et al.*, 2007b ; Li H., Wang *et al.*, 2007). Soil-burying could lead to increased labor intensity and production cost (Zhang J. *et al.*, 2013).

Grapevine growth is initiated by a prolonged temperature above 10 °C in spring (Jones *et al.*, 2005 ; Holland and Smit, 2014). The sum of mean daily temperature from 1st April to 31st October in the northern hemisphere is an indicator of heat available for wine grape growing defined as the Sum of Average Temperature over the same period (SAT) in viticulture (Jones and Davis, 2000 ; Szymanowski *et al.*, 2007 ; Green and Szymanowski, 2012) (Table 2). Another indicator of heat available for viticulture is the Effective Accumulated Temperature (EAT) or the Growing Degree Days (GDD) which is the sum of the temperature value between mean daily temperature and 10 °C from 1st April to 31st October in the northern hemisphere (Amerine and Winkler, 1944 ; Li H., Li and Yang, 2009 ; Green and Szymanowski, 2012) (Table 2). Currently in China, accumulated temperatures are mainly used in viticulture climatic zoning studies (Li H. *et al.*, 2007b).

Water availability is a limiting factor for the development of viticulture (De la Fuente *et al.*, 2016). Vine grapes need a suitable amount of water during the growing period. In some cases, excessive rainfall can damage vine roots and grapes and cause floods, while in dry areas additional water supply may be provided by irrigation.

Spring frost will damage the grape buds and affect grape yield and quality; autumn frost will affect carbohydrate synthesis and reduce the cold tolerance ability of grapevine in winter (Li H., Wang *et al.*, 2007). The choice of wine grape planting area is also related to the Frost-Free Period (FFP), which is usually defined as the number of consecutive days between the last day with a temperature below 0 °C in spring and the first day with a temperature below 0 °C in autumn (Wolf and Boyer, 2003; Li H. *et al.*, 2007b). The length of the FFP is often defined by the frost timing in the spring and fall and corresponds to approximately 160-200 days in the vast majority of the world's viticulture regions (Wolf and Boyer, 2003; Jones, 2005). Sufficient FFP is needed in the processes of budburst, flowering, grape ripening, nutrient accumulation and grape frost resistance in winter (Wolf and Boyer, 2003; Li H. *et al.*, 2007b; Holland and Smit, 2014) (Table 2).

In viticulture, we should also consider climate events such as extreme rainstorms, flood, drought, fog and hail which will affect grapevine production. Droughts and extreme rainstorms will have negative impacts on wine grape yield (Castex *et al.*, 2015); hail in summer will damage the shoots, leaves and fruits and affect the yield and quality (Li H. *et al.*, 2007a).

TEMPERATURE AND ANNUAL ACCUMULATED TEMPERATURE

In the past century, China has experienced obvious impacts of global warming in annual mean temperature (10.1°C in 2014) (Figure 3). Data from 156 meteorological stations show that in 2010 the average temperature was 1.23°C higher than in 1950 (Li R.L. and Shu, 2013). The surface temperature in eastern China has increased by 1.52°C during 1909-2010 (Zhao P. *et al.*, 2014). The temperature increase varied based on seasonal and geographical factors. The warming rate in winter was 0.04°C per year while it was 0.01°C per year in summer, and the north warmed more quickly than the south during 1960-2010 (Piao *et al.*, 2010). According to data from 520 meteorological stations in China, during 1951-2005 both the accumulated temperature (≥10 °C, ≥0 °C) and its value increased (Miao *et al.*, 2009). The annual effective accumulated temperature (≥10 °C), which is the sum of the temperature value between mean daily temperature and 10 °C for the whole year, generally has an increasing trend after 1985 (Liu S.H. *et al.*, 2013). Since the 1990s, the whole Soil-Burying Line of China, which indicates areas with average annual minimum temperature below -15 °C and with the necessity to have vine soil-burying in winter, has advanced northward, leaving

Table 2. Climate variables for viticulture.

(Source: Amerine and Winkler, 1944; Jones and Davis, 2000; Jones, 2005; Jones, 2007; Szymanowski *et al.*, 2007; Li H., Li and Yang, 2009; Li H., Wang *et al.*, 2009; Green and Szymanowski, 2012.)

Variable	Range of values		Class name or variety
Average Growing Season Temperature (°C) in viticulture (Jones, 2007)	13-15		Cool temperature
	15-17		Intermediate temperature
	17-19		Warm temperature
	19-24		Hot temperature
Sum of Active Temperature (SAT) from 1st April to 31st October in the northern hemisphere in viticulture (Jones and Davis, 2000; Szymanowski *et al.*, 2007; Green and Szymanowski, 2012)	2000-2200		Very early ripening
	2200-2500		Early ripening
	2500-2700		Moderately early ripening
	2700-2900		Late ripening
	>2900		Very late ripening
Effective Accumulated Temperature (EAT)/ Growing Degree Days (GDD) from 1st April to 31st October in the northern hemisphere in viticulture (Amerine and Winkler, 1944; Li H., Li and Yang, 2009)	°C	°F	
	<1371	<2500	Very early maturing grape varieties
	1372-1649	2501-3000	Early maturing grape varieties
	1649-1927	3001-3500	Late maturing grape varieties
	1927-2204	3501-4000	Acid grape varieties
	>2205	>4001	Very acid grape varieties
Frost-Free Period (FFP) (days) in viticulture (Jones, 2005; Li H., Wang *et al.*, 2009)	<160		Unsuitable region
	160-220		Suitable region
	>220		Suitable region but wine quality affected

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vast areas (including some part of Xinjiang) suitable for viticulture without the necessity to have vine burying in winter (Li H., Wang *et al.*, 2007).

From the literature review (Table 3), we can observe a trend of increasing temperature in eight wine-producing provinces (Ningxia, Xinjiang, Shandong, Tianjin, Jilin, Gansu, Hebei, Shaanxi) and an increasing number of days with specific annual active accumulated temperature (≥0 °C, ≥5°C, ≥10 °C) in seven wine-producing provinces (Ningxia, Xinjiang, Shaanxi, Heilongjiang, Gansu, Hebei, Tianjin) over a long period (more than 40 years). Although the literature review does not cover all of the wine-producing provinces, we can see the correlation with the national trend of increasing annual mean

Table 3. Temperature change in Chinese wine-producing provinces.

Climate variable	Period	Region	Tendency	References	Possible benefits	Possible harms
Temperature	1961-2004	Ningxia	Annual mean temperature ↑ Mean temperature of each season↑	Chen X.G. *et al* ., 2008a	Current cold areas may be suitable to grow grapes that can only grow in warm areas (Moriondo *et al*., 2013). The ripening process accelerates (Holland and Smit, 2010). Less frost events(Jones, 2007). The sugar content increases for some grape varieties in some regions (Mozell and Thach, 2014). The acidity of grape decreases for some grape varieties in some regions (Mozell and Thach, 2014). The alcohol content increases for some grape varieties in some regions (Mozell and Thach, 2014).	The quality and yield of grape may be influenced (Fraga *et al*., 2012; Nicholas and Durham, 2012). The sugar content increases for some grape varieties in some regions (Mozell and Thach, 2014). The acidity of grape decreases for some grape varieties in some regions (Mozell and Thach, 2014). The alcohol content increases for some grape varieties in some regions (Mozell and Thach, 2014). Higher risk of pests and diseases (De Orduña, 2010). Impede photosynthesis and hence respiration process (Ashenfelter and Storchmann, 2016). Fruit burnt (De Orduña, 2010; Hadarits *et al*., 2010). Extreme heat threatens grape survival (Nicholas and Durham, 2012). Higher risk of fire (De Orduña, 2010).
	1960-2009		Frequency of extreme hot days ↑ Frequency of extreme cold days ↓	Zhang M.J. *et al*., 2012		
	1961-2010	Xinjiang	Degree of extreme cold days ↓ Mean temperature of January↑	Pu *et al* ., 2014		
	1950-2009	Shandong	Annual mean temperature ↑	Zhang S.P. *et al*., 2011		
	1955-2007	Tianjin		Liu S.M. *et al*., 2009		
	1961-2010	Jilin		Shen *et al*., 2014		
	1961-2010 1961-2003	Gansu	Annual mean temperature increased 0.29 °C per decade↑	Deng *et al*., 2012		
	1956-2007	Hebei	Annual mean temperature ↑ Mean temperature of each season↑	Liu F.Y. *et al*., 2014		
	1960-2013	Shaanxi		Wang Y.H., 2014		
Annual Active Accumulated Temperature	1961-2005	Ningxia	Annual number of days (≥0 °C , ≥10 °C) ↑	Zhang Z. and Lin, 2008	Longer favorable growth period (Holland and Smit, 2014). More areas may be suitable for grape planting (Li H. *et al*., 2007a; Li H. *et al*., 2007b). The ripening process accelerates (Holland and Smit, 2010). Grape yield may be increased by suitable heat (Jones, 2007).	The quality of grape may be influenced (Jones, 2007; Holland and Smit, 2014). Grape yield may be decreased by excess heat (Jones, 2007). Extreme heat may damage the vine (Holland and Smit, 2014).
	1961-2010	Xinjiang	Annual number of days (≥0 °C) ↑	Pu *et al*., 2013		
	1961-2008	Shaanxi	Annual number of days (≥5 °C) ↑	Wang Y.R. *et al*., 2011		
	1961-2005	Heilongjiang	Annual number of days (≥10 °C) ↑	Ji et al., 2009		
	1961-2003	Gansu	Annual Active Accumulated Temperature (≥0 °C, ≥10 °C) ↑	Liu D.X. *et al*., 2005		
	1956-2007	Hebei		Liu F.Y. *et al*., 2014		
	1955-2007	Tianjin		Liu S.M. *et al*., 2009		

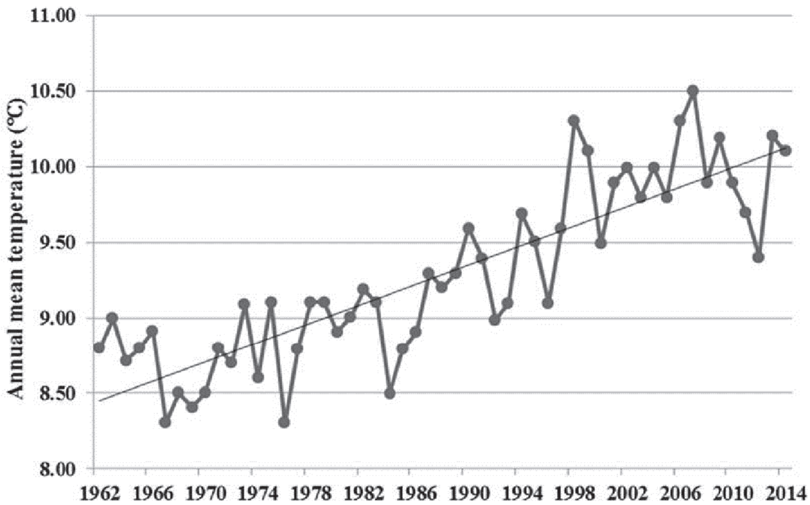

Figure 3. Annual mean temperature of China. Source: China Meteorological Administration, 2015.

temperature (Figure 3). These changes may have caused possible benefits such as an increase in the number of areas suitable for wine grape planting and possible harms such as a reduction in grape and wine quality (Table 3).

PRECIPITATION AND WATER SCARCITY

The precipitation trends have shown distinctive regional and seasonal variations, but there has been a general decreasing trend throughout the entire country. From 1960 to 2010, three periods of precipitation transitions occurred in the 1970s, 1980s and 1990s, and the increase and decrease of precipitation moved along with the latitude (Zhao H.R., 2013 ; Wang Y.J. and Yan, 2014). While southern China has experienced an increasing trend of rainfall in summer and winter, northeastern China has experienced a significant decrease of precipitation in summer and winter (Piao *et al.*, 2010 ; Li R.L. and Shu, 2013).

Approximately 98 % of the surface water in China is recharged by precipitation (Jiang, 2009). From precipitation data of the primary wine regions in 2010 (Figure 4), we can see that the majority of regions have lower precipitation amounts than the national level. In Ningxia, Gansu and Xinjiang, the annual mean precipitation is considerably less than the national level. Changes in precipitation have been observed over long periods (more than 40 years) in six wine-producing provinces (Ningxia, Tianjin, Shandong, Gansu, Shaanxi, Hebei) with decreasing annual amount of precipitation or decreasing annual precipitation days (Table 4). These changes may have positive impacts, such as fewer pests and diseases. However, the changes may also have negative impacts, such as increased drought frequency and increased irrigation cost (Table 4).

In 2013, China ranked 102nd of 176 nations and regions with 2083 cubic meter water resource per capita (World Bank, 2015). This ranking was lower than in many wine-producing countries (Figure 4). With the exception of Heilongjiang, Jilin, Xinjiang and Yunnan, the available water per capita in the other main wine-producing regions is lower than the national average. Xinjiang has vast amounts of water stored in glaciers. Yunnan has an uneven distribution of precipitation, and irrigation is difficult due to the

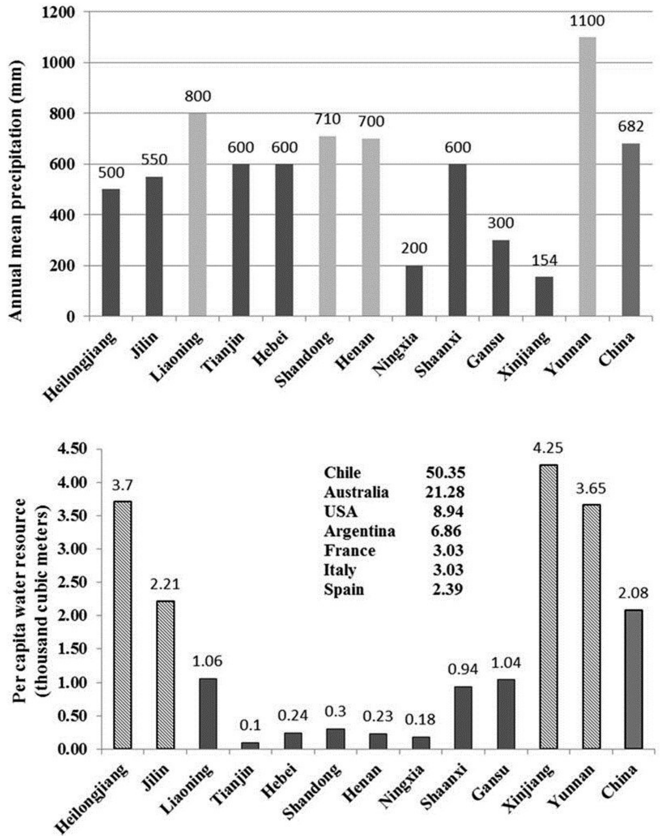

Figure 4. Annual mean precipitations and per capita water resource of China.
Source : National Bureau of Statistics of China, 2015 ; World Bank, 2015.

Table 4. Precipitation change in Chinese wine-producing provinces.

Climate variable	Period	Region	Tendency	References	Possible benefits	Possible harms
Precipitation	1961-2005 1971-2011	Ningxia	Annual precipitation ↓	Chen X.G. *et al.*, 2008b; Tan *et al.*, 2014	The grape growing condition over humid areas may be improved (Jones, 2007).	Higher frequency of drought disaster (Fraga *et al.*, 2012).
	1958-2007	Tianjin	Annual days of precipitation ↓	Li C. *et al.*, 2010	Less pest and disease damages (Fraga *et al.*, 2012).	Higher cost of irrigation and facilities (Jones, 2007).
	1961-2010	Shandong	Annual days of precipitation ↓	Dong *et al.*, 2014	The taste of some grapes may be improved (Fraga *et al.*, 2012).	Grape yield decreases (Lereboullet *et al.*, 2013).
	1961-2010	Gansu	Annual precipitation ↓	Deng *et al.*, 2012		Grape grows slowly (Fraga *et al.*, 2012).
	1960-2013	Shaanxi		Wang Y.H., 2014		Lower grape survival (Jones, 2007).
	1961-2011 1956-2007	Hebei		Xiang *et al.*, 2014; Liu F.Y. *et al.*, 2014		

obstruction of high mountains, all of which lead to water scarcity.

FROST-FREE PERIOD

Chinese studies indicate that between 1964 and 2003, in China, the acreage with a FFP above 160 increased significantly, especially between 1984 and 2003, while the First Frost Day (FFD) was delayed and the Last Frost Day (LFD) was advanced (Li H., Wang *et al.*, 2007; Li H., Wang *et al.*, 2009). The Yongning County, which is bordered by the Yellow River to the west and the Helan Mountain to the east, is one of the main wine-producing regions of Ningxia. Meteorological observations between 1952 and 2013 in Yongning County indicate that the FFP had an increasing trend (164 days in 1952 and 189 days in 2013) and the FFD was delayed (26th Sep in 1952 and 16th Oct in 2013) (Figure 5).

In eight wine-producing provinces (Shandong, Ningxia, Shaanxi, Xinjiang, Liaoning, Jilin, Heilongjiang, Tianjin), studies had indicated the increasing trend of FFP over 50 years, delayed FFD, and advanced LFD (Table 5). This finding may provide an opportunity for cultivation of more grape varieties and lead to more areas suitable for viticulture. However, grape quality and grape yield may be affected (Hadarits *et al.*, 2010; Fraga *et al.*, 2012) (Table 5).

EXTREME CLIMATE EVENTS

With the changing climate, there has been an increasing trend in periods of remarkable drought and flood, leading to challenges to agriculture and the Chinese wine industry. The most significant droughts appeared in 1978 and 2000, strongly affecting the crop production in China. Figure 6 indicates total agricultural crop area covered (crop yield loss >10%) and affected (crop yield loss >30%) by drought and flood in China from 1950 to 2014. In the 1990s and 2000s, strong floods caused by heavy rains impacted the entire country. In 1991, 1998, 2003, and 2010, serious floods hit China, leaving vast crop areas affected by flood (Figure 6).

Regionally, increased incidence of extreme rainstorms in Ningxia, Hebei and Xinjiang over a long period may have alleviated the drought problem but may have also increased the risk of flood damage and vineyard destruction (Table 6). Due to the increased severity of drought conditions in five wine-producing provinces (Ningxia, Liaoning, Shaanxi,

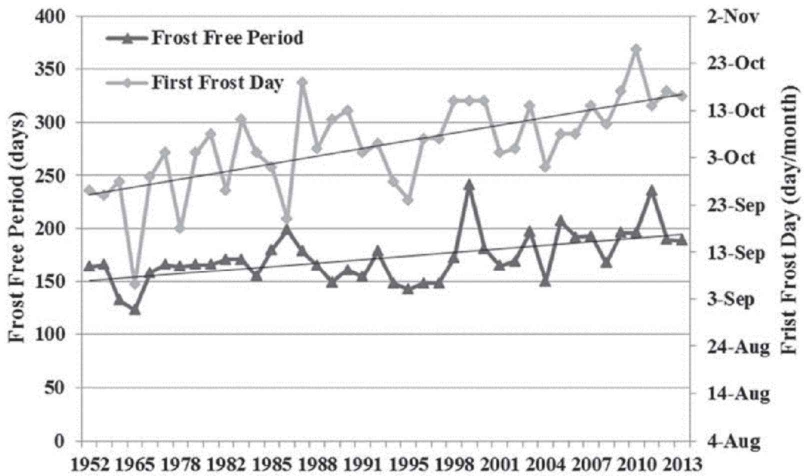

Figure 5. Frost-Free Periods and First Frost Day change in Yongning County, Ningxia, 1952-2013. Source: Ningxia Statistical Yearbook, 1985-2013.

Table 5. Provincial Frost-Free Period change.

Climate Variable	Period	Region	Tendency	References	Possible Benefits	Possible Harms
Frost-Free Period	1961-2008	Shandong	Number of frost-free days ↑ FFD was delayed LFD was advanced	Wang H.Y et al., 2011	More types of grape could be planted (Belliveau et al., 2006). More areas may be suitable for grapes (Belliveau et al., 2006). Less damage to buds and vine (Belliveau et al., 2006; Hadarits et al., 2010).	Grape quality may be affected (Fraga et al., 2012). Grape yield may be affected (Hadarits et al., 2010).
	1961-2010	Ningxia		Zhang L. et al., 2013		
	1961-2010	Shaanxi		Bai et al., 2013		
	1960-2011	Xinjiang		Pan et al., 2013		
	1957-2006 1961-2012	Liaoning		Li J. et al., 2010 Hu et al., 2015		
	1961-2012	Jilin		Hu et al., 2015		
	1961-2012	Heilongjiang		Hu et al., 2015		
	1955-2007	Tianjin		Liu S.M. et al., 2009		

Henan, Yunnan), an increased investment in irrigation infrastructure may be required.

In Ningxia, Xinjiang, Shaanxi and Yunnan, changes in the density and frequency of fog over more than 40 years may have impacted the growth process of grapes. In Ningxia, Tianjin, Hebei and Yunnan, the decreasing frequency of hail may have reduced the damage to vineyards.

CLIMATE CHANGE ADAPTATION STRATEGIES FOR THE CHINESE WINE INDUSTRY

Adaptation strategies can reduce the impacts of climate change and are a major challenge for viticulturists for the coming decades (Van Leeuwen *et al.*, 2007; Iglesias *et al.*, 2012; Ren *et al.*, 2013; Ollat and Touzard, 2014b). Climate change adaptation can be planned at the regional, national, and international level. We provide recommendations to the wine industry for adaptation strategies based on current Chinese climate change policies and studies of wine and adaptation (Figure 7).

1. Policy strategies

In recent years, there have been changes in Chinese government policy to support agriculture in adapting to climate change. China has promulgated a series of laws to promote agricultural development addressing the importance of sustainable water use (China's

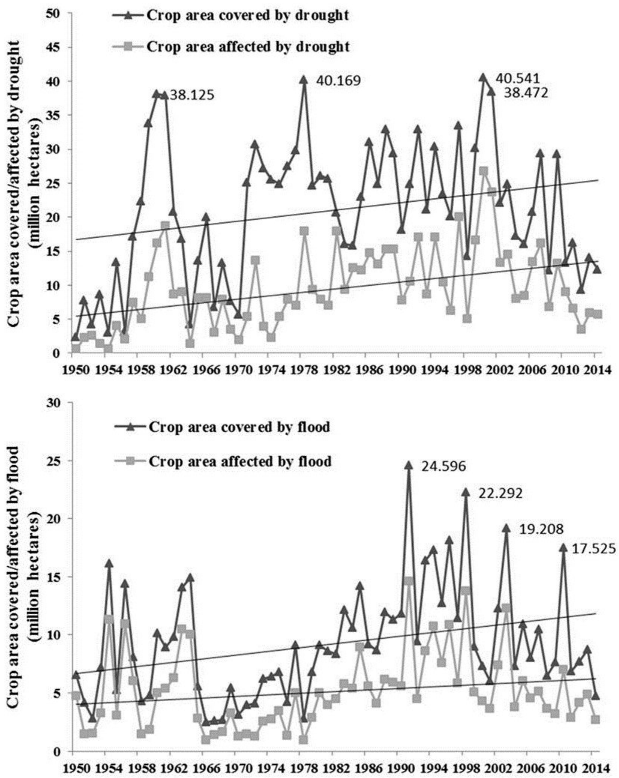

Figure 6. Crop area covered/affected by drought/flood in China.
Source: China Flood and Drought Management, 2009; National Bureau of Statistics of China, 2015.

Policies and Actions for Addressing Climate Change, 2008). It is necessary to establish and improve the laws pertaining to agriculture (China's Policies and Actions for Addressing Climate Change, 2012). The "12th Five-Year (2011-2015) Plan for the Wine Industry of China" has emphasized the importance of sustainability in the development of the Chinese wine industry.

There have also been efforts to address climate change adaption at the regional level, particularly in the Ningxia Province. The climate change situation and challenges in Ningxia have been analyzed and an adaptation and mitigation plan highlighting the urgency to take actions has been proposed (Scheme of Adaptation for Climate Change in Ningxia, 2009). The first wine regional protection regulation of China was approved in Ningxia in 2012 and was intended to ensure an environmental protection for the grape growing/wine-producing regions (Regulation on the protection of Eastern Foot of Helan Mountain Wine Region in Ningxia Hui Autonomous Region, 2012).

However, climate change adaptation legislation targeting the wine industry should be further established and implemented at the national and regional level (China's National Climate Change Programme, 2007).

2. Financial strategies

The Chinese government has invested over 20 billion Yuan in disaster prevention and mitigation capabilities and 1 billion Yuan in dry land water-saving agriculture (China's Policies and Actions on Climate Change, 2014). During the period from 2001 to 2005, the government invested more than 2.5 billion Yuan for climate change-related scientific and technological work (China's Policies and Actions for Addressing Climate Change, 2008). The investments increased to 7 billion Yuan during 2006-2010, and there have been continued increases since. Adequate financial support such as facility investment, agricultural insurance and subsidy for both industrial development and climate change adaptation will be essential for continued growth and development of the grape planting and wine-producing regions of China.

Table 6. Provincial extreme climate events and effects on viticulture.

Climate Event	Period	Region	Tendency	References	Possible Benefits	Possible Harms
Extreme Rainstorm	1961-2005 1961-2010	Ningxia	Annual days of extreme rainstorm ↑ Intensity andamount ↑	Chen X.G. *et al.*, 2008b; Li X. *et al.*, 2013	Alleviated drought problem (Battaglini *et al.* 2009; Fraga *et al.*, 2012).	Greater frequency of flood damage and loss of soil nutritic (Fraga *et al.*, 2012). Destruction of vineyards and more damaged roots and branches (Battaglini *et al.*, 2009). Damage to pollination and frui set (Belliveau *et al.*, 2006).
	1961-2005	Hebei		Gao et al., 2009		
	1901-2010	Xinjiang	Annual frequency of rainstorm ↑	Sun et al., 2011		
Drought	1951-2000	Ningxia	Frequency of drought ↑	Liang *et al.*, 2007	The grape growing conditions over humid areas may be improved (Battaglini *et al.* 2009; Fraga *et al.*, 2012; Holland and Smit, 2014). Less pest and disease damages (Holland and Smit, 2014). Improves the taste of some grapes (Holland and Smit, 2014).	Higher cost of irrigation and facilities (Battaglini *et al.*, 200(Fraga *et al.*, 2012). Decreased grape yield (Hadarit *et al.*, 2010; Ollat *et al.*, 2016). Reduced grape growth (Fraga « *al.*, 2012). Threat to grape survival (Holland and Smit, 2014).
	1961-2004		Especially in winter frequency of drought ↑	Sang *et al.*, 2007		
	1978-2010		Degree of drought ↑ Geographical distribution of drought ↑	Tan *et al.*, 2014		
	1988-2007	Liaoning	Degree of drought ↑	Zhao X.L. *et al.*, 2009		
	1961-2010	Shaanxi		Cai *et al.*, 2013		
	1961-2008	Henan		Zhang H.W. *et al.*, 2009		
	1961-2011	Yunnan	Degree and time duration of drought↑	Zhang W.C.*et al.*, 2013		
Fog	1961-2009	Ningxia	Annual frequency in the north ↑	Zhou *et al.*, 2010	Supplements water and keeps ground heat (Calwineries, 2017). Moderate it can protect grapes from extreme heat (Wine-searcher, 2017).	May impede the photosynthesi process and hence respiration (Progressive viticulture, 2016).
	1961-2003	Xinjiang	Annual frequency after 1987↓	Ma *et al.*, 2005	Fewer obstacles for photosynthesis and respiration (Progressive viticulture, 2016).	
	1960-2010	Shaanxi	Annual frequency after 2000↓	Zhang H.F. *et al.*, 2013		
	1961-2008	Yunnan	Annual frequency↓	Tao *et al.*, 2011b		
Hail	1961-2004 1961-2010	Ningxia	Annual frequency of hail ↓	Wu *et al.*, 2008; Yang *et al.*, 2012	Lower frequency of hail damage (Fraga *et al.*, 2012).	
	1979-2008	Tianjin		Min *et al.*, 2012		
	1979-2008	Hebei				
	1961-2008	Yunnan	Annual and seasonal frequency↓	Tao *et al.*, 2011a		

3. Technical strategies

Water resources are essential for viticulture. Chinese policy has provided several technological measures to enhance the efficiency of water consumption in agriculture (China Water Conservation Technology Policy Outline, 2005). Low carbon agriculture should be promoted and agricultural waste should be recycled for sustainable agriculture. Additionally, additional irrigation facilities should be built and existing facilities should be improved in order to conserve water. It is also proposed that when crops and farming systems are chosen, climate change should be taken into consideration. The need to develop high-quality stress resistant crop varieties is also addressed (China's National Plan on Climate Change 2014-2020, 2014). Furthermore, management practices of pests and diseases should be adapted to new strains or new pathogens (Goulet, 2014).

Climate-based zoning has been attempted for viticulture in order to guide grape planting and wine production. In Xinjiang and Ningxia, the viticulture climatic zoning classification system uses three indexes : FFP, dryness index (from April to September) and mean lowest temperature below -15 °C (Wolf and Boyer, 2003 ; Tonietto and Carbonneau, 2004 ; Wang H. *et al.*, 2010 ; Li H., Wang and Wang, 2011). In the Shaanxi and Jingjintang area, which includes Beijing, Tianjin and some areas of Hebei, the amount of precipitation from July to September is used as an index (Li H. and Meng, 2009 ; Li H., Lan and Wang, 2011). Tonietto and Carbonneau (2004) have provided a Multicriteria Climatic Classification System (Géoviticulture MCC System) for worldwide grape and wine zoning based on classes for three indices : dryness index (DI), heliothermal index (HI) and cool night index (CI). These indices are representative of worldwide viticultural climate variability and are related to the requirements of varieties, vintage quality and typicity of wines. They were calculated to evaluate the worldwide climate for viticulture in 97 grape growing regions from 29 countries

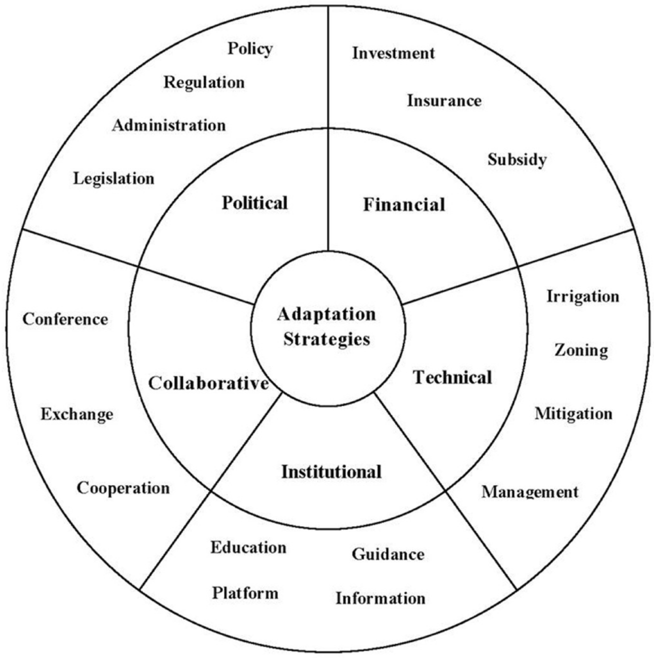

Figure 7. Adaptation strategies for the Chinese wine industry. Source: Own elaboration.

including China. Combining grape zoning methodology with climate change simulations such as climate change scenarios can enhance viticulture adaptation for the future. To deal with the uncertainties of future climatic simulations in climate change impact studies, different climatic scenarios and downscaling methods should be considered (Caubel *et al.*, 2014). Integrated models such as ecophysiological model and the MILA-STICS model can predict complex impacts for climate change (Caubel *et al.*, 2014; Piéri and Lebon, 2014). Multi-scale climatic approaches such as the ANR-TERVICLIM and GICC-TERADCLIM research programmes, which intend to observe and simulate climate and climate change at local scale, can produce a scale assessment of climate change impacts in different wine-producing regions worldwide (Quénol and Bonnardot, 2014).

Mozell and Thach (2014) have provided vineyards and wineries with a series of practical solutions for adapting to climate change. Fifteen solutions for vineyards are provided to offset rising temperatures, water shortages, increases in heat, drought and light intensity and their impacts such as earlier maturation, and increases in the number of pests. Eleven solutions are provided to enhance wine production in order to offset warmer temperatures, increases in sugar and alcohol levels, reduction in acidity, vintage variability, and earlier harvest and ripening.

Further research is needed to assist the Chinese wine industry in adapting to climate change. An interdisciplinary approach will be needed that incorporates improvements in grape resistance, new grape planting and wine making technology, disaster response, climate change adaptation management and social and economic evaluation.

4. Institutional strategies

Institutional changes are indispensable for effective adaptation solutions (Ollat and Touzard, 2014a; Ollat and Touzard, 2014b). The Chinese government has strongly promoted an awareness and understanding of climate change impact in general, but a stronger focus is needed on how climate change impacts the wine industry in particular. The broadcast of climate change knowledge and adaptation for wine producers and wine traders can be promoted by media, materials, forums, campaigns and training during which regional wine associations in China can participate. Wine institutes in universities can assume the responsibility for educating the public. Electronic platforms can be established to broadcast and share information.

5. Collaborative strategies

Climate change demands the attention of the global wine industry. The World Conference on Climate

Change and Wine has been organized three times by the Wine Academy of Spain to address the need for climate change adaptation in viticulture (Li Y.B., 2015). Several investigations of climate change and viticulture are underway in France and other wine-producing countries (Ollat and Touzard, 2014b; Yzarra *et al.*, 2015). In France, the multidisciplinary LACCAVE project (long-term adaptation to climate change in viticulture and enology) involving 23 different laboratories from the National Institute for Agricultural Research of France (INRA), the National Center for Scientific Research (CNRS) and several French universities aims to analyze the impacts of climate change on viticulture and wine and to assess current and design future adaptation strategies (Ollat *et al.*, 2016). With a goal to establish a scientific framework addressing climate change issues in viticulture, this project is organized in seven areas: characterization and perception of climate change; physiological and genetic bases of grapevine adaptation to climate change; development of technical innovations for adaptation to climate change; evaluation of the impact of technical innovation at a territorial scale; analysis of the evolution of economic strategies; data management and analysis; and elaboration of strategic scenarios for 2050 (Ollat and Touzard, 2014b). The importance of communication and cooperation with developed countries and international organizations has been highlighted (China's Policies and Actions for Addressing Climate Change, 2015). As China moves from the insular policies of the past to increased communication and sharing of technology at the international level, the Chinese wine industry will greatly benefit.

CONCLUSIONS

In the last several years, domestic wine production has experienced a dramatic increase in China, boosted by rising consumption and a favorable economic situation. This increase faces important future challenges, a number of them emerging from the impacts of climate change, which may affect the quantity and quality of the wine production and even the vineyard location.

The analysis of the climate trend in China, which is focused on variables with climate relevance to viticulture, exhibits inconsistent effects, and confirms the relevance of the changes in the primary wine-producing regions.

The literature suggests a general tendency of increasing temperatures and accumulated temperature, water scarcity with higher frequency of extreme events and increasing number of frost-free days, all of which will bring both challenges and opportunities to the young Chinese wine industry.

The identified effects indicate the need for more research at the regional level for an accurate assessment of climate change impact on the Chinese wine industry and a proper design of adaptation measures, considering the specific needs and characteristics of wine production. These specific adaptation measures have to be implemented under the national framework of climate change adaptation and need to consider the coordination of policy, financial, technical, institutional and collaborative strategies.

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REFERENCES

Amerine M.A. and Winkler A.T., 1944. Composition and quality of musts and wines of California grapes. *Hilgardia* **15**, 504-505.

Ashenfelter O. and Storchmann K., 2016. Climate change and wine: a review of the economic implications. *J. Wine Econ.* **11**, 105-138.

Askci, 2015. China Business Intelligence Network. http://www.askci.com/.

Bai Q.F., Li X.M. and Zhu L., 2013. The changes of the frost-free periods from 1961 to 2010 and its impact on apple industry in Shaanxi province. *J. Arid Land Resour. Environ.* **27**, 65-70 (in Chinese).

Bardaji I. and Iraizoz B., 2015. Uneven responses to climate and market influencing the geography of high-quality wine production in Europe. *Reg. Environ. Change* **15**, 79-92.

Battaglini A., Barbeau G., Bindi M. and Badeck F.W., 2009. European winegrowers' perceptions of climate change impact and options for adaptation. *Reg. Environ. Change* **9**, 61-73.

Belliveau S., Smit B. and Bradshaw B., 2006. Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley, Canada. *Glob. Environ. Change* **16**, 364-378.

Cai X.L., Ye D.X., Li X., Zhang C.J. and Wang N., 2013. Analysis of temporal-spatial variation characteristics of drought in Shaanxi Province based on compound meteorological drought index (CI). *Agric. Res. Arid Areas* **31**, 1-8 (in Chinese).

Calwineries, 2017. Climate. Available at http://www.calwineries.com/learn/grape-growing/climate.

Castex V., Tejeda E.M. and Beniston M., 2015. Water availability, use and governance in the wine producing region of Mendoza, Argentina. *Environ. Sci. Policy* **48**, 1-8.

Caubel J., Launay M., Garcia de Cortazar-Atauri I., Ripoche D., Huard F., Buis S. and Brisson N., 2014. A new integrated approach to assess the impacts of climate change on grapevine fungal diseases : the coupled mila-stics model. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 43-52.

Chen S., Chen X.G. and Xu J.T., 2016. Impacts of climate change on agriculture : evidence from China. *J. Environ. Econ. Manage.* **76**, 105-124.

Chen X.G., Conway D., Zheng G.F. and Chen X.J., 2008a. Trends of extreme temperature in Ningxia during 1961-2004. *Adv. Clim. Change Res.* **4**, 73-77 (in Chinese).

Chen X.G., Conway D., Chen X.J. and Zheng G.F., 2008b. Trends of extreme precipitation events in Ningxia during 1961-2005. *Adv. Clim. Change Res.* **4**, 156-160 (in Chinese).

China Flood & Drought Management, 2009 (in Chinese). Publication of China Water & Power Press, 2009. http://mall.cnki.net/magazine/magalist/FHKH2009.htm.

China Meteorological Administration, 2015. http://www.cma.gov.cn/.

China's National Climate Change Programme, 2007. Report of National Development and Reform Commission (NDRC), June 2007. http://en.ndrc.gov.cn/newsrelease/200706/P020070604561191006823.pdf.

China's National Plan on Climate Change 2014-2020, 2014 (in Chinese). Report of National Development and Reform Commission (NDRC), November 2014. http://www.ndrc.gov.cn/zcfb/zcfbtz/201411/W020141104584717807138.pdf.

China's Policies and Actions for Addressing Climate Change, 2008. Report of National Development and Reform Commission (NDRC), October 2008. http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File419.pdf.

China's Policies and Actions for Addressing Climate Change, 2012. Report of National Development and Reform Commission (NDRC), November 2012. http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File1324.pdf.

China's Policies and Actions for Addressing Climate Change, 2015 (in Chinese). Report of National Development and Reform Commission (NDRC), November 2015. http://www.ccchina.gov.cn/archiver/ccchinacn/UpFile/Files/Default/20151120095809029882.pdf.

China's Policies and Actions on Climate Change, 2014. Report of National Development and Reform Commission (NDRC), November 2014. http://en.ccchina.gov.cn/archiver/ccchinaen/UpFile/Files/Default/20141126133727751798.pdf.

China Sugar & Liquor Yearbook, 2011 (in Chinese). Publication of China National Association for Liquor and Spirits Circulation, December 2011. http://tongji.cnki.net/kns55/navi/HomePage.aspx?id=N2012070054&name=YZGTJ&floor=1.

China Water Conservation Technology Policy Outline, 2005. Announcement of National Development and Reform Commission of the People's Republic of China, Ministry of Science and Technology of the People's Republic of China, Ministry of Water Resources of the People's Republic of China, Ministry of Construction of the People's Republic of China, Ministry of Agriculture of the People's Republic of China, April 2005. http://unpan1.un.org/intradoc/groups/public/documents/apcity/unpan036722.pdf.

Decanterchina, 2016. A guide to Chinese wine regions. Available at https://www.decanterchina.com/en/columns/demeis-view-wine-communication-from-a-chinese-winemaker/a-guide-to-chinese-wine-regions.

De la Fuente M., Linares R. and Lissarrague J.R., 2016. Adapting to climate change : the role of canopy management and water use efficiency in vineyards. *Wine Vitic. J.* **31**, 43-46.

Deng Z.Y., Zhang Q., Wang R.Y., Zhao H., Xu J.F., Liu M.C., Zhao H.Y. and Yao Y.B., 2012. The response of plant diseases and pests to climatic warmer-drying and its adaptive technique in the Northwest China. *Adv. Earth Sci.* **27**, 1281-1287 (in Chinese).

De Orduña R.M., 2010. Climate change associated effects on grape and wine quality and production. *Food Res. Int.* **43**, 1844-1855.

Dong X.G., Gu W.Z., Meng X.X. and Liu H.B., 2014. Change features of precipitation events in Shandong Province from 1961 to 2010. *Acta Geogr. Sin.* **69**, 661-671 (in Chinese).

Duchene E., 2016. How can grapevine genetics contribute to the adaptation to climate change? *J. Int. Sci. Vigne Vin* **50**, 113-124.

Fraga H., Malheiro A.C., Moutinho-Pereira J. and Santos J.A., 2012. An overview of climate change impacts on European viticulture. *Food Energy Secur.* **1**, 94-110.

Gao X., Wang H., Yu C.W., Dai X.G. and Shi L.H., 2009. Analysis of extreme precipitation events change for Hebei Province. *Meteorol. Mon.* **35**, 10-15 (in Chinese).

Goulet E., 2014. Climate change and impact on the wine industry: the Val de Loire perspective. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 11-12.

Green D.R. and Szymanowski M., 2012. Monitoring, mapping and modelling the vine and vineyard: collecting, characterising and analysing spatio-temporal data in a small vineyard. In: *Proceedings of the IXth International Terroirs Congress*, **2012**, pp 8-35.

Hadarits M., Smit B. and Diaz H., 2010. Adaptation in viticulture: a case study of producers in the Maule Region of Chile. *J. Wine Res.* **21**, 167-178.

Hannah L., Roehrdanz P.R., Ikegami M., Shepard A.V., Shaw M.R., Tabor G., Zhi L., Marquet P.A. and Hijmans R.J., 2013. Climate change, wine, and conservation. *Proc. Natl. Acad. Sci. USA* **110**, 6909-6912.

Holland T. and Smit B., 2010. Climate change and the wine industry: current research themes and new directions. *J. Wine Res.* **21**, 125-136.

Holland T. and Smit B., 2014. Recent climate change in the Prince Edward County winegrowing region, Ontario, Canada: implications for adaptation in a fledgling wine industry. *Reg. Environ. Change* **14**, 1109-1121.

Hu Q., Pan X.B., Zhang D., Yang N., Li Q.Y. and Shao C.X., 2015. Variation of temperature and frost-free period in different time scales in Northeast China. *Chin. J. Agrometeorol.* **36**, 1-8 (in Chinese).

Iglesias A., Quiroga S., Moneo M. and Garrote L., 2012. From climate change impacts to the development of adaptation strategies: challenges for agriculture in Europe. *Clim. Change* **112**, 143-168.

IPCC, 2013. Observations: atmosphere and surface. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 159-254.

IPCC, 2014. Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 485-533.

Ji S.T., Yang M., Ji Y.H., Wang P., Jiang L.X., Zhu H.X. and Yan P., 2009. Change of accumulated temperature and evolution trends of accumulated temperature zone over last 45 years in Heilongjiang Province. *Chin. J. Agrometeorol.* **30**, 133-137 (in Chinese).

Jiang Y., 2009. China's water scarcity. *J. Environ. Manage.* **90**, 3185-3196.

Jones G.V., 2005. Climate change in the western United States grape growing regions. *Acta Hortic.* **689**, 41-60.

Jones G.V., 2007. Climate change: observations, projections, and general implications for viticulture and wine production. In: *Proceedings of the XIIth Conference on Climate and Viticulture*, International Organization of Vine and Wine (OIV), Zaragoza (Spain), pp 55-66.

Jones G.V. and Davis R.E., 2000. Climate influences on grapevine phenology, grape composition and wine production and quality for Bordeaux, France. *Am. J. Enol. Vitic.* **51**, 249-261.

Jones G.V., White M.A., Cooper O.R. and Storchmann K., 2005. Climate change and global wine quality. *Clim. Change* **73**, 319-343.

Lereboullet A.L., Bardsley D. and Beltrando G., 2013. Assessing vulnerability and framing adaptive options of two Mediterranean wine growing regions facing climate change: Roussillon (France) and McLaren Vale (Australia). *EchoGéo* **23**, 1-16.

Li C., Liu D.Y. and Huang H., 2010. Characteristics of precipitation and precipitation days from 1958 to 2007 in Tianjin. *J. Meteorol. Environ.* **26**, 8-11 (in Chinese).

Li H., Lan Y.F. and Wang H., 2011. Study on viticultural climatic zoning in Jingjintang area. *J. Northwest Agric. Forest. Univ. (Nat Sci Ed)* **39**, 159-166 (in Chinese).

Li H., Li J.G. and Yang H.C., 2009. Review of grape and wine industry development in recent 30 years of

China's reforming and opening-up. *Mod. Food Sci. Technol.* **25**, 341-347 (in Chinese).

Li H. and Meng J., 2009. Climatic zoning indexes and the viticultural climatic zoning in Shaanxi Province. *Sci. Technol. Rev.* **27**, 78-83 (in Chinese).

Li H., Wang H., Fang Y.L. and Huo X.S., 2007a. Study on the viticulture climatic zoning in China (I). *Sci. Technol. Rev.* **25**, 63-68 (in Chinese).

Li H., Wang H., Fang Y.L. and Huo X.S., 2007b. Study on the viticulture climatic zoning in China (II). *Sci. Technol. Rev.* **25**, 57-64 (in Chinese).

Li H., Wang H. and Wang H., 2011. Study on the viticultural climatic zoning of Xinjiang Uygur Autonomous Region. *Sci. Technol. Rev.* **29**, 70-73 (in Chinese).

Li H., Wang H., You J., Huo X.S. and Wang Y.Q., 2007. Relationship between frost indexes and viticulture zoning in China in recent 45 years. *Sci. Technol. Rev.* **25**, 16-22 (in Chinese).

Li H., Wang Y.J., Meng J., Wang H., You J., Huo X.S. and Wang Y.Q., 2009. The effect of climate change on the climatic zoning for wine grapes in China. *Acta Hortic. Sin.* **36**, 313-320 (in Chinese).

Li J., Yan X.Y. and Wang Y., 2010. Variations of frost under the background of climate change in Liaoning Province in recent 50 years. *Meteorol. Mon.* **36**, 38-45 (in Chinese).

Li R.L. and Shu G., 2013. Impacts of climate change on agriculture and adaptive strategies in China. *J. Integr. Agric.* **12**, 1402-1408.

Li X., Zhen G.F., Na L. and Wang S.Y., 2013. Analysis on spatial and temporal changes of extreme precipitation events in Ningxia in recent 50 years. *J. Anhui Agric. Sci.* **41**, 3533-3535, 3578 (in Chinese).

Li Y.B., 2015. Impact of global climate change on European wine industry and the revelation to China. *Liquor-Making Sci. Technol.* **5**, 126-129 (in Chinese).

Liang X., Feng J.M., Zhang Z. and Zheng G.F., 2007. A study on drought climate change and its causes. *J. Arid Land Resour. Environ.* **21**, 68-74 (in Chinese).

Liu D.X., Dong A.X., Zhang P.L. and Fei X.L., 2005. Impact of climate warming on agriculture in Gansu Province. *Prog. Geogr.* **24**, 49-58 (in Chinese).

Liu F. and Murphy J., 2007. A qualitative study of Chinese wine consumption and purchasing: implications for Australian wines. *Int. J. Wine Bus. Res.* **19**, 98-113.

Liu F.Y., Xiao S.R., Liu H. and Mu Z.Y., 2014. Research of impacts of climate change on agriculture in Hebei Region. *Geogr. Geo-Inf. Sci.* **30**, 122-126 (in Chinese).

Liu S.H., Yan D.H., Weng B.S., Xing Z.Q. and Wang G., 2013. Spatiotemporal evolution of effective accumulated temperature ≥10 °C in China in recent 50 years. *Arid Zone Res.* **30**, 689-696 (in Chinese).

Liu S.M., Gao H. and Li Z.F., 2009. Impacts of climate warming on crops planting structure in Tianjin. *Chin. J. Agrometeorol.* **30**, 42-46 (in Chinese).

Ma Y., Ren Y.Y., Chen C.Y. and Chu C.J., 2005. Change characteristic of fog and analysis on weather process of heavy fog in Xinjiang in nearly 40 years. *Arid Land Geogr.* **28**, 474-478 (in Chinese).

Miao Q.L., Yuan Y., Wang Y. and Duan C.F., 2009. Impact of climate warming on the distribution of China's thermal resources. *J. Nat. Resour.* **24**, 934-944 (in Chinese).

Min J.J., Cao X.Z., Duan Y.H., Liu H.Z. and Wang S.G., 2012. Analysis on the climate characteristics of hail and its break in Beijing, Tianjin and Hebei during recent 30 years. *Meteorol. Mon.* **38**, 189-196 (in Chinese).

Mitry D.J., Smith D.E. and Jenster P.V., 2009. China's role in global competition in the wine industry: a new contestant and future trends. *Int. J. Wine Res.* **1**, 19-25.

Moriondo M., Jones G.V., Bois B., Dibari C., Ferrise R., Trombi G. and Bindi M., 2013. Projected shifts of wine regions in response to climate change. *Clim. Change* **119**, 825-839.

Mozell M.R. and Thach L., 2014. The impact of climate change on the global wine industry: challenges & solutions. *Wine Econ. Policy* **3**, 81-89.

National Bureau of Statistics of the People's Republic of China, 2015 (in Chinese). http://www.stats.gov.cn/tjsj/.

Nicholas K.A. and Durham W.H., 2012. Farm-scale adaptation and vulnerability to environmental stresses: insights from winegrowing in Northern California. *Glob. Environ. Change* **22**, 483-494.

Ningxia Statistical Yearbook 1985-2013 (in Chinese). Publication of China Statistics Press. 1985-2013. http://tongji.cnki.net/kns55/navi/HomePage.aspx?id=N2013100032&name=YNXTJ&floor=1.

OIV, 2016. International Organization of Vine and Wine. http://www.oiv.int/.

Ollat N. and Touzard J.M., 2014a. Impacts and adaptation to climate change: new challenges for the French wine industry. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 75-78.

Ollat N. and Touzard J.M., 2014b. Long-term adaptation to climate change in viticulture and enology: the Laccave project. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 1-7.

Ollat N., Touzard J.M. and Van Leeuwen C., 2016. Climate change impacts and adaptations: new challenges for the wine industry. *J. Wine Econ.* **11**, 139-149.

Pan S.K., Zhang M.J., Wang B.L. and Ma X.N., 2013. Changes of the first frost dates, last frost dates and duration of frost-free season in Xinjiang during the period of 1960-2011. *Arid Zone Res.* **30**, 735-742 (in Chinese).

Piao S.L., Ciais P., Huang Y., Shen Z., Peng S.S., Li J.S., Zhou L.P., Liu H.Y., Ma Y.C., Ding Y.H., Friedlingstein P., Liu C.Z., Tan K., Yu Y.Q., Zhang T.Y. and Fang J.Y., 2010. The impacts of climate change on water resources and agriculture in China. *Nature* **467**, 43-51.

Piéri P. and Lebon E., 2014. Modelling the future impacts of climate change on French vineyards. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 33-41.

Progressive Viticulture, 2016. Comparative wine growing climatology. Available at http://www.progressivevit.com/comparative-wine-growing-climatology/.

Pu Z.C., Zhang S.Q., Li J.L., Xu W.X. and Wang M.Q., 2013. Spatiotemporal change of duration and accumulated temperature of temperature ≥ 0 °C in Xinjiang in recent 50 years. *Arid Zone Res.* **30**, 781-788 (in Chinese).

Pu Z.C., Zhang S.Q., Li J.L., Xu W.X., Wang M.Q. and Yili H., 2014. Spatial-temporal variation of heat resources in winter of Xinjiang near 50 years. *Agric. Res. Arid Areas* **322**, 40-46 (in Chinese).

Qiu H.Q. Z., Yuan J.X., Ye B. H.B. and Hung K., 2013. Wine tourism phenomena in China: an emerging market. *Int. J. Contemp. Hosp. Manage.* **25**, 1115-1134.

Quénol H. and Bonnardot V., 2014. A multi-scale climatic analysis of viticultural terroirs in the context of climate change: the "TERADCLIM" project. *J. Int. Sci. Vigne Vin*, **Laccave Special Issue**, 23-32.

Regulation on the Protection of Eastern Foot of Helan Mountain Wine Region in Ningxia Hui Autonomous Region, 2012 (in Chinese). Gazette of Ningxia Government, May 2012. http://61.181.156.156:8080/kcms/detail/detail.aspx?QueryID=16&CurRec=2&DbCode=cjfz&dbname=CJFZLAST&filename=NXZB201224003.

Ren Y.J., Cui J.X., Wan S.Q., Liu M., Chen Z.H., Liao Y.F. and Wang J.J., 2013. Climate change impacts on central China and adaptation measures. *Adv. Clim. Change Res.* **4**, 215-222.

Resco P., Iglesias A., Bardaji I. and Sotes V., 2016. Exploring adaptation choices for grapevine regions in Spain. *Reg. Environ. Change* **16**, 979-993.

Sang J.R., Liu Y.L. and Shu Z.L., 2007. Response of severe drought events in Ningxia to climate change during recent 44 years. *J. Desert Res.* **27**, 878-882 (in Chinese).

Scheme of Adaptation for Climate Change in Ningxia, 2009 (in Chinese). Gazette of Ningxia Government, November 2009. http://wenku.baidu.com/link?url=oDcPd4zVYo-LTN7AMOrTcngFzvjzj3XDzvOTZqR6UowwGdsjwEtE82G1sv7uSLsrM1Hh_nN4ThStHG2z-hEUmtA9X2VbV2EYZlMi7cO1DrW.

Schultz H.R. and Jones G.V., 2010. Climate induced historic and future changes in viticulture. *J. Wine Res.* **21**, 137-145.

Shen X.J., Wu Z.F. and Du H.B., 2014. Characteristics of climatic change in semiarid region of western Jilin in recent 50a. *J. Arid Land Resour. Environ.* **28**, 190-196 (in Chinese).

Sun G.L., Chen Y.M. and Li W.H., 2011. Interannual and interdecadal variations of extreme hydrological events and response to climate change in Xinjiang. *Sci. Geogr. Sin.* **31**, 1389-1395 (in Chinese).

Szymanowski M., Kryza M. and Smaza M., 2007. A GIS approach to spatialize selected climatological parameters for wine-growing in Lower Silesia, Poland. In: Střelcová K, Škvarenina J, Blaženec M (eds) *Proceedings of the "Bioclimatology and natural hazards" International Scientific Conference*, Poľana nad Detvou (Slovakia), ISBN 978-80-228-17-60-8.

Tan C.P., Yang J.P., Qin D.H. and Li M., 2014. Climatic background of persistent drought in Ningxia Hui Autonomous Region, China. *J. Desert Res.* **34**, 518-526 (in Chinese).

Tao Y., Duan X., Duan C.C. and Duan W., 2011a. Change characteristic of Yunnan hail. *Plateau Meteorol.* **30**, 1108-1118 (in Chinese).

Tao Y., Duan X., Duan C.C., Duan W. and Ren J.Z., 2011b. The change characteristics of fog in Yunnan during the nearly 50 years. *J. Yunnan Univ.* **33**, 308-316 (in Chinese).

The 12th Five-Year (2011-2015) Plan for the Wine Industry of China (in Chinese). Report of the Ministry of Industry and Information Technology of China, 2012. http://www.miit.gov.cn /n1146295

/n1652858/n1652930/n3757019/c3757851/part/3757852.pdf.

Tonietto J. and Carbonneau A., 2004. A multicriteria climatic classification system for grape-growing regions worldwide. *Agric. Forest Meteorol.* **124**, 81-97.

Van Leeuwen C., Bois B., Pieri P. and Gaudillère J.-P., 2007. Climate as a terroir component. In : *Proceedings of the XIIth Conference on Climate and Viticulture*, Zaragoza (Spain), pp 1-12.

Wang H., Wang L.G., Song H.H., Yan Y. and Li H., 2010. Climatic zoning of grapevine in Ningxia Hui Autonomous Region. *Sci. Technol. Rev.* **28**, 21-24 (in Chinese).

Wang H.Y., Gao H.J. and Zhang X., 2011. Analysis on the climate variation characteristics of frost in Shandong Province. *J. Anhui Agric. Sci.* **39**, 9062-9063 (in Chinese).

Wang S., Li H. and Wang H., 2015. Wind erosion prevention effect of suspending shoots on wires after winter pruning in soil-burying zones over-wintering. *Trans. Chin. Soc. Agric. Eng.* **31**, 206-212 (in Chinese).

Wang Y.H., 2014. Analysis on spatial and temporal variation characteristics of temperature and precipitation in Shaanxi Province. *J. Inner Mongolia For. Sci. Technol.* **40**, 33-39 (in Chinese).

Wang Y.J. and Yan F., 2014. Regional differentiation and decadal change of precipitation in China in 1960-2010. *Prog. Geogr.* **33**, 1354-1363 (in Chinese).

Wang Y.R., Liao Y.C. and Mao M.C., 2011. Change of the accumulated temperature above 5 °C critical temperature in Shaanxi during past 48 years. *Acta Agric. Boreal Occident Sin.* **20**, 201-206 (in Chinese).

Wine-searcher, 2017. Rutherford wine. Available at http://www.wine-searcher.com/regions-rutherford.

Wolf T.K. and Boyer J.D., 2003. Vineyard Site Selection. Virginia Tech, Virginia State University.

World Bank, 2015. World Bank Group, Data. http://data.worldbank.org/.

Wu Y.J., Li Y.E., Liu Y.T. and Huang Y., 2008. Changes of meteorological disasters and their impacts on grain crop yield in Ningxia. *Chin. J. Agrometeorol.* **29**, 491-495 (in Chinese).

Xiang L., Hao L.S., An Y.G., Zhang J. and Liu M.M., 2014. Time-spatial distribution and variational characteristics of rainfall in Hebei Province in 51 years. *Arid Land Geogr.* **37**, 56-65 (in Chinese).

Yang K., Sang J.R., Li Y.C., Su Z.S. and Chen X.J., 2012. Analysis of climatic and extreme features of hail in Ningxia in recent 50 years. *J. Arid Meteorol.* **30**, 609-614 (in Chinese).

Yzarra W., Sanabria J., Caceres H., Solis O. and Lhomme J.P., 2015. Impact of climate change on some grapevine varieties grown in Peru for Pisco production. *J. Int. Sci. Vigne Vin* **49**, 103-112.

Zhang H.F., Zhang K.X., Pan L.J. and Qian Q.R., 2013. Characteristics of fog spatial-temporal patterns and atmospheric circulation in last 51 years over Shaanxi Province. *Meteorol. Sci. Technol.* **41**, 702-712 (in Chinese).

Zhang H.W., Lin M.M., Xu M.H., Li Y.N., Feng X., Pang T. and Sun J.Y., 2009. Impact and counter measures for climate warming on arid disaster in Henan. *Meteorol. Environ. Sci.* **32**, 239-241 (in Chinese).

Zhang J., Wang H., Dong X.Y., Zhao X.H., Liang S. and Li H., 2013. Technical and economic assessment on crawled cordon training in the soil-bury over-wintering zone based on the survey data of grape growers in Xiaxian, Shanxi Province. *J. Northwest Forest. Univ.* **28**, 94-99 (in Chinese).

Zhang L., Zhang X.Y., Li H.Y., Yuan H.Y. and Wang J., 2013. Characteristics of frost-free days changes over Ningxia from 1961 to 2010. *Ecol. Environ. Sci.* **22**, 801-805 (in Chinese).

Zhang M.J., Wang B.L., Wei J.L., Wang S.J., Ma Q. and Li X.F., 2012. Extreme event changes of air temperature in Ningxia in recent 50 years. *J. Nat. Disaster* **21**, 152-160 (in Chinese).

Zhang S.P., Zhang X., Wang H.J., Xiang Z. and Du Z.L., 2011. Influence of climate change on precipitation and extreme climate in Shandong Province. *J. China Hydrol.* **31**, 62-65 (in Chinese).

Zhang W.C., Zheng J.M. and Ren J.Z., 2013. Climate characteristics of extreme drought events in Yunnan. *J. Catastrophology* **28**, 59-64 (in Chinese).

Zhang Z. and Lin L., 2008. Study on the accumulative temperature and the precipitation in the period of the accumulative temperature in Ningxia. *Agric. Res. Arid Areas* **26**, 231-234, 239 (in Chinese).

Zhao H.R., 2013. Temporal and spatial variations and transition of precipitation in China during 1960-2010. *Trop. Geogr.* **33**, 414-419 (in Chinese).

Zhao P., Jones P., Cao L.J., Yan Z.W., Zha S.Y., Zhu Y.N., Yu Y. and Tang G.L., 2014. Trend of surface air temperature in eastern China and associated large-scale climate variability over the last 100 years. *J. Clim.* **27**, 4693-4703.

Zhao X.L., Li L.G., Jia Q.Y., Xie Y.B. and Zhou G.S., 2009. Analysis of main agrometeorological disasters from 1988 to 2007 in Liaoning Province. *J. Meteorol. Environ.* **25**, 33-37 (in Chinese).

Zhou C.F., Chen N. and Zhang G.P., 2010. Temporal and spatial distribution characteristic and forecast methods research of fog in Ningxia. *J. Anhui Agri. Sci.* **38**, 17074-17078 (in Chinese).