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Climate change in the North China Plain: smallholder farmer perceptions and adaptations in Quzhou County, Hebei Province

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ABSTRACT: Climate change is expected to negatively affect production of winter wheat and maize in the North China Plain (NCP). This study examines the perceptions and adaptations to climate change of farmers in Quzhou County in the NCP. Structured interviews were held with 37 smallholder farmers to determine their perceptions of and adaptations to climate change in the past 30 yr. Historical meteorological data (1980 to 2010) showed a significant increase in mean annual temperature of 1.7°C over 30 yr and no significant change in mean annual rainfall, but farmers perceive increasing temperature and decreasing rainfall during this period. We hypothesize that this leads farmers to irrigate more, due to their perception that the changing temperature and precipitation regime is increasing crop water stress. Further increase in annual temperature predicted for the NCP will intensify irrigation and deplete the groundwater reserves used for irrigation in this area. Farmers in the NCP require decision-making tools to develop sustainable irrigation practices for long-term adaptation to climate change.

KEY WORDS: Agriculture · Climate change · Meteorological data · Participatory methods

1. INTRODUCTION

1.1. Context

Climate change is predicted to have far-reaching effects on global agricultural production. Agricultural systems are sensitive to climate change, with negative impacts predicted in terms of yield and revenues, especially in the tropics (Adejuwon et al. 2001, Tol 2002, Challinor & Wheeler 2008, Lobell et al. 2008, Schlenker & Roberts 2009). Adaptation to climate change through crop-breeding programs, cropping system diversification, improved soil management and irrigation practices, and disaster risk management is recommended to sustain agricultural productivity (Adger et al. 2007). National governments and international organizations are promoting technological innovations and management practices that aid in the adaptation of agricultural systems to future climate conditions.

However, smallholder farmers often lack the resources and infrastructure to undertake adaptation measures, which makes them more vulnerable to climate change, being highly reliant on climatic factors for their livelihoods (Morton 2007). Furthermore, the impacts of climate change on smallholder farms are not generalizable, and need to be considered in their specific contexts of biophysical changes and socioeconomic constraints (Morton 2007). The willingness of smallholder farmers to invest their limited resources into climate change adaptation measures depends on whether they perceive that there is a risk, and how they think the risk will affect their livelihood. Further, it can take years to make changes to farming practices, so the success of climate change adaptation measures can be difficult to detect or can be obscured

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by inter-annual climatic variation (Mutimba et al. 2010). A lack of understanding of long-term climate change may lead to inappropriate responses on the part of smallholder farmers. Furthermore, while large-scale agro-economic and biophysical models of the impacts of climate change are useful in guiding the development of broad policy responses, they may be less applicable at regional or community levels. Local constraints and responses are often not fully assessed, or are neglected completely.

Efforts at documenting farmer perceptions and adaptations to climate change reveal some commonalities: in general, farmers have a good understanding of the climatic trends affecting them, and the prevailing perception of increasing temperatures over time is corroborated when perceptions are compared with local weather station data (Hageback et al. 2005, Bryan et al. 2009, Gbetibouo 2009). However, farmers may have difficulty synthesizing and isolating the effect of climate change on their livelihood, as agricultural production is a result of many interacting factors such as soil fertility, input availability, land use, and agricultural policy (Rao et al. 2011). Furthermore, farmers' perceptions may be more strongly influenced by recent events (Bryan et al. 2009), and are often dependent on factors that directly affect staple, high-value specialty and/or culturally significant crops (Vedwan & Rhoades 2001). While farmer perceptions over the long-term may be inaccurate or biased (as human memories are imperfect), acts of adaptation also stem from personal considerations and evaluation of long-term evidence. These include perceived local weather fluctuations, as well as the perceived costs and benefits of adaptation methods. Therefore, it is important to investigate farmers' long-term perceptions, as these may be driving on-farm adaptations.

Interviewing smallholder farmers at the individual farm and household level provides insight into what facilitates or limits adaptation. Adaptation processes are influenced by factors at various scales, from household assets such as wealth and education, to village-level assets such as the provision of irrigation, to institutional and governmental assistance such as the availability of credit and extension services (Paavola 2008, Bryan et al. 2009, Deressa et al. 2009, Gbetibouo 2009, Wheeler et al. 2013).

A better understanding of farmers' perceptions and adaptations to climate change, along with the barriers to adaptation, will be crucial in developing policies that mitigate the potential damages from long-term climate change. It is important to investigate the reasons why some farmers adapt and others do not, especially when their livelihoods, agricultural yields, and incomes are at risk. Long-term perceptions may reveal the decision-making processes that lead some farmers to adapt and others to maintain the status quo. Furthermore, past changes provide a context for anticipating how future adaptation may unfold. It is our belief that an understanding of climate change through the eyes of those affected is vital when documenting and quantifying human responses to climate change.

In China, climate change and its potential effects on agriculture are an important concern, especially given the national policy of self-sufficiency in grain and staple crops. While biophysical and environmental impacts have been assessed, the Chinese government only recently started considering adaptation programs (Wang et al. 2010). These include improving agricultural infrastructure, research, and the development of adaptation technologies (Wang et al. 2010). However, regionally specific policies addressing climate change adaptation are less developed, and farmers are often left to adapt autonomously, without external support (Y. Liu et al. 2010).

The North China Plain (NCP) in northeast China (31° 24′ to 42° 42′ N, and 110° 18′ to 122° 42′ E) spans Henan, Hebei, Shandong, Beijing, and Tianjin provinces (see Fig. S1 in the Supplement at www.int-res.com/articles/suppl/ c069p261_supp.pdf). The semi-humid continental monsoon conditions in the south gradually shift to a semi-arid climate in the northern range of the NCP (Mo et al. 2009). In terms of agricultural production, the NCP plays a vital role in China's food security, accounting for 20% of arable land, 69% of national wheat production, and 35% of national maize production (S. Liu et al. 2010).

The average size of land holdings in the NCP is 1.3 ha per household, and this area is often split into many non-contiguous plots (Piotrowski 2009). Most seeding and harvesting is done mechanically, though a few farmers elect to seed by hand. Harvesting is mechanized: privately owned combine harvesters and tractors provide service to a few villages, and farmers sign up for a harvesting time when they determine their crop to be ready. This is a relatively inefficient method because the machinery and operator may pass repeatedly by an individual's land holding before their small plots are eventually harvested. Irrigation is also done on a 'sign-up' basis when farmers determine that there is a need for irrigation. Irrigation water is obtained by electrical generator-powered pumps from surface water or groundwater wells, and is applied by flood irrigation. All farmers in the area investigated subscribe to this irrigation practice. Groundwater wells are owned by local governments,

and farmers pay a fee to access these. As both harvesting and irrigation need to be done at specific times in the growing season, the high demand for these resources means that those who sign up late may not receive harvesting or irrigation services at optimal times.

Climate change has already been documented in the NCP: Zhang et al. (2015) found warming trends of +0.57, +0.47, and +0.44°C per decade at 3 sites of the NCP between 1981 and 2011. S. Liu et al. (2010) reported trends of similar magnitudes (+0.98 to +1.13°C) at other sites of the NCP from 1954 to 1995, and Fu et al. (2009) found an overall significant increase of +1.46°C in daily mean temperature between 1958 and 1998 in the NCP. Precipitation, however, has not been documented to have changed significantly during the same time periods (Fu et al. 2009, S. Liu et al. 2010, Zhang et al. 2015). The impact climate change has already had on agricultural production in the NCP is generally negative. Holding other factors constant, Mo et al. (2009), Y. Liu et al. (2010), and Tao & Zhang (2010) have all documented negative yield effects on both winter wheat and maize resulting from climate change in the past 30 yr, with similar effects projected into the future. Guo et al. (2010) do project future gains, for winter wheat if not for maize. However, given the scale, accelerated pace, and uncertainty associated with future climate change, adaptation is seen as necessary.

Zhang et al. (2015) have described some of the challenges facing adaptation to climate change in the NCP, which include the choice of cropping system, water constraints, an aging farm population, and small land holdings. This study addresses the main recommendation of Zhang et al. (2015), which is to obtain more information on farmers' knowledge and perceptions of climate change, specifically by identifying key constraints limiting adaptation. These constraints are identified by the farmers themselves, and include factors such as lack of capital, land, or technical knowledge in terms of adaptation methods.

1.2. Case study

Quzhou County in Hebei Province, with a population of 384 000 and total land area of 667 km^2 (Chen et al. 2006), was chosen for this study because it is considered representative of the NCP in terms of the soil and climatic conditions (Chen et al. 2006, Liu et al. 2006, Qiu et al. 2009, Shen et al. 2009). The cropping system of winter wheat–summer maize in Quzhou is also the predominant cropping system of the NCP, grown on >90% of all cultivated land in each province of the NCP (China Statistical Yearbook 2010). Past and future climate change impacts on farmers in Quzhou thus serve as a case study for the region.

The climate of Quzhou is semi-arid, with a mean annual temperature of 12.5°C and 500 mm of average annual precipitation. The main soil type in Quzhou is silty Luvisol, ranging from silt to sandy silt. There are distinct dry and wet seasons, with the majority of precipitation occurring from July to August, while November to early June constitute the dry season (Chen et al. 2006). The dominant cropping system is a double crop of winter wheat *Triticum aestivum* L.–summer maize *Zea mays* L., though cotton, horticultural crops, greenhouse crops, and livestock are also cultivated on 50 900 ha of land in Quzhou (Kong et al. 2006, Liang et al. 2012). As the climate becomes hotter, crop breeders are developing grain crop varieties that can produce high yields in this region. The collective ownership of farm machinery in Quzhou and the NCP may permit rapid modernization of equipment, allowing smallholder farmers to complete field operations efficiently and at the best time, an example of technological adaptation to climate change.

The objectives of this work are to assess long-term trends in climatic factors affecting farmers in Quzhou County, to determine the impact these trends have had on agricultural production, and to describe the adaptation measures available to farmers along with the constraints limiting the implementation of these methods. This case study in a representative area of the NCP will serve to shed light on the conditions in the region as a whole. The methods of this study include farmer interviews and surveys in 3 villages within Quzhou County, which assess farmers' perceptions of climate change. An analysis of historical weather data (temperature and precipitation) in Quzhou county is conducted in order to determine the existence of trends in the meteorological record data. Comparisons between trends in farmer perceptions and trends in the meteorological recrd reveal the factors that are most important to farmers. By further surveying farmers on the perceived impacts accrued from these climatic changes, and the adaptation strategies available to them, we provide insight into potential adaptation strategies that can be implemented, and the constraints limiting them. While farmer surveys are frequently employed in agronomic studies (Zhen et al. 2006, Feike et al. 2010), to our knowledge, there have been no previous studies conducted in the region of the NCP that have combined farmer surveys and interviews with meteorological data to assess climate change impacts on agricultural production.

2. MATERIALS METHODS

2.1. Survey construction and analysis

The survey was developed using a 2-step method. In the first step, semi-unstructured interviews were conducted with key informants: 3 village heads, 2 extension workers, and 3 professors at the China Agricultural University. Background information obtained from these informants allowed structured responses to be placed into the appropriate context and aided in the construction and validation of the structured interviews. In the second step, structured interviews were held with 37 households, split between 3 villages: Houlaoying, in the south of Quzhou, and Wangzhuang and Zhangzhuang, in the north. These villages were similar in size (around 1000 inhabitants each). As interview questions involve assessing perceptions of long-term changes in the past 30 yr, participants were residents over the age of 50. The number of structured interviews conducted was based on the concept of data saturation, which stems from grounded theory in qualitative research (Francis et al. 2010, Mason 2010). Data saturation occurs when no new information or themes emerge in later interviews that have not already been discussed in earlier interviews. In this case, the 37 interviews conducted are considered to be representative of farmers' perceptions of climate change in Quzhou county as data saturation was reached.

The 30 yr period was also not chosen arbitrarily. In the early 1980s the Chinese government introduced the Household Responsibility System for agricultural land use, a departure from the socialist policy of collectively owned and managed land that had been in place previously. From 1982 onwards, farmers in the NCP had personal responsibility for their cultivation decisions, and so assessing perceptions in the past 30 yr corresponds to the period when farmers had the ability to make their own land-use and cropping decisions. In each village, interviews were done by the senior author and a graduate student from China Agricultural University who lives and works in the village, to facilitate communication with the interviewees.

The structured questionnaire inquired about agricultural production, sources of income, perceived climatic changes and impacts, and adaptation measures undertaken, and how these have changed over the past 30 yr (Table 1, the full interview questions are provided in the Supplement at www.int-res.com/articles/suppl/c069p261_supp.pdf). The specific variables of interest in the context of climate change are the perceived changes in temperature and precipitation, as these are the most important climatic variables in terms of agricultural production, while also being most tangible to farmers.

Participants who stated that they had noticed changes in climate were then asked whether this had any impact on their production, and whether they undertook any adaptation measures in response, such as switching to drought-resistant varieties, implementing soil conservation methods, switching from crop to livestock production or getting off-farm jobs, among others. We tested for differences in adaptation-undertaking between farmers who perceived climate changes and those who did not using Fisher's exact test of independence.

2.2. Meteorological data analysis

To compare farmers' perceptions with actual climatic trends, weather data from the Xingtai meteorological station, located less than 75 km away from the study villages, was obtained from the China Meteorological Data Sharing Service System (CDC; http://data.cma.cn/data/detail/dataCode/A.0029.0001_130.html, accessed 15 July 2016). Daily records of minimum, maximum, and average temperatures, as well as total daily precipitation, were available from 1954 onwards. Trends in climatic variables since 1980 were assessed through ordinary least-squares linear regression, with the slope of the line evaluated to be different from 0 using Student's *t*-test at 95 and 99% confidence levels. Trends were determined for the daily average temperature as yearly, seasonal,

Table 1. Summary of structured questionnaire assessing farmers' perceptions of the effects of long-term (30 yr, 1980 to 2014) climate change on agricultural production in Quzhou County, North China Plain

Categories of questions	Details
Background	Socio-economic and agricultural details
Natural disasters	Frequency and damage
Weather: broad information	Source of information; perceived general changes; notable weather events
Temperature and rainfall	Importance of these for agricultural production; perceived changes and their impacts
Adaptations	Undertaking of adaptations if impacts felt; opportunities and constraints to adaptations

and maize- and winter wheat-growing season averages, for daily maximum and minimum temperatures as yearly averages, as well as for yearly, seasonal, and growing season total precipitation. Furthermore, extreme weather is important in the context of agroecosystems: temperatures at the extreme ends of the spectrum may have the largest negative effects on crop yields (Schlenker & Roberts 2009), and uneven distribution of rainfall may lead to negative impacts on crops through increased droughts and floods, even if total amounts do not change. Therefore, we conducted an exploratory analysis of change in the distribution of temperature and precipitation, i.e. whether weather is becoming more extreme, as has been observed globally in the IPCC Fifth Assessment Report (AR5) (Stocker et al. 2013). For each year, we counted the number of days when the maximum temperature was ≥1 standard deviation of the overall mean and the daily precipitation was ≤1 standard deviation of the overall mean — an estimate of the occurrence of extreme weather events each year — and used least-squares linear regression to calculate the slope of the trendline for data from 1980 to 2010.

3. RESULTS

3.1. Background

Most farmers interviewed plant the double crop of winter wheat and corn typical of the NCP, which differs from 30 yr ago when a large proportion of farmers cultivated cotton. (For more detailed data on demographic, agricultural, and socio-economic attributes of respondents, see Tables S1, S2 & S3 in the Supplement at www.int-res.com/articles/suppl/c069p261_supp.pdf). The aging farm population is no longer able to meet the high labor requirements of cotton cultivation and economic returns are no longer profitable. Almost all farmers also reserve a small piece of land to grow horticultural crops for personal consumption.

When asked which input was most important for the success of farmers' crops at present (2014) and >30 yr ago (1980s), farmers stated in both cases that water and fertilizer were the most important inputs. Considering a list of inputs, to be ranked from most to least important for crop productivity, farmers selected irrigation and fertilizer as the most important inputs necessary for successful cultivation in 2014. However, in the early 1980s, the most important 'input' was the weather (Fig. 1). This reflects a change in irrigation practices by the farmers of Quzhou: between 1980 and 2014, numerous wells were installed, allowing cultivation to be less dependent on precipitation. This also demonstrates the importance that farmers accord to water resources. Fertilizer use is changing as well: 30 yr ago, organic animal manures and composts were the most common fertilizer sources, while today farmers rely on commercial NPK fertilizers.

3.2. Farmer perceptions regarding climate change

Most farmers perceived a long-term increase in temperature (67%) and decrease in precipitation (56%) (Fig. 2). It was mostly the same farmers who perceived both warming and drying trends (46% of farmers perceived both trends). Other farmers stated that they perceived more rain, changing duration of hot or cold weather, or more unpredictable weather. Another observation that a few farmers made is that

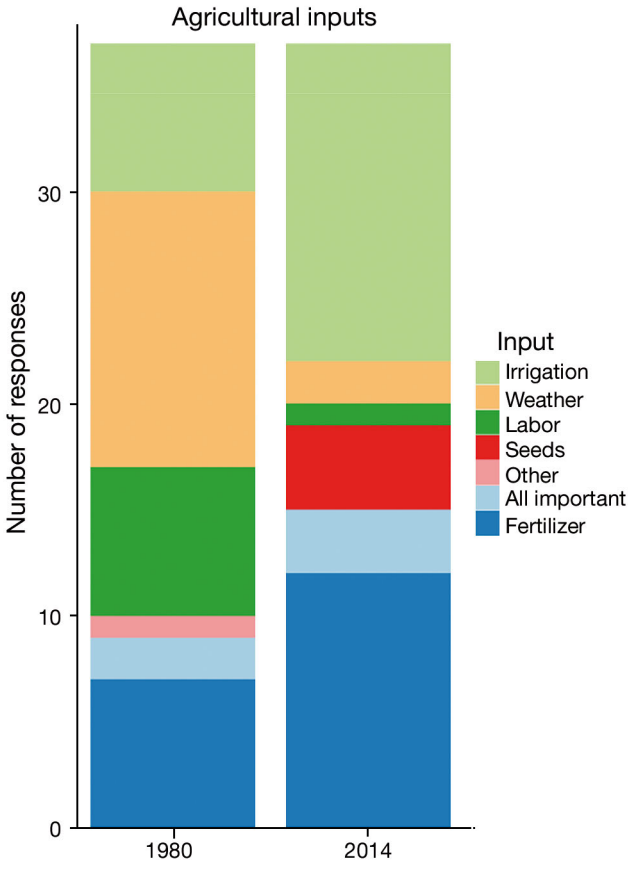

Fig. 1. Most important agricultural inputs for agricultural production in the 1980s and 2014 as stated by farmers interviewed in Quzhou County, North China Plain. 'All important' represents those farmers who stated that all inputs were equally important

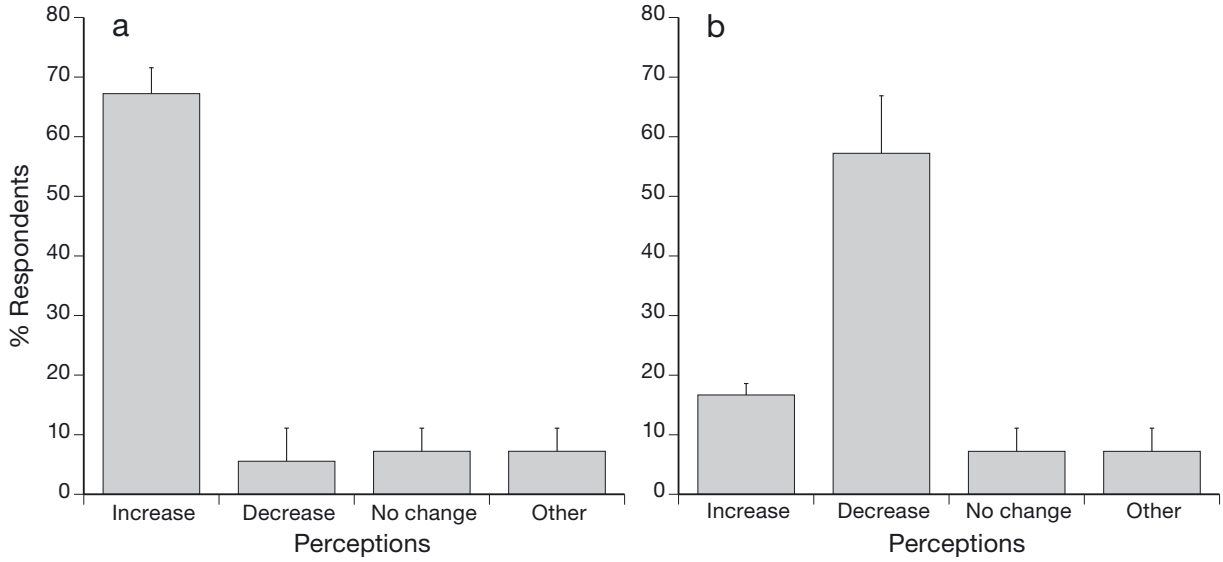

Fig. 2. Number of respondents per village perceiving changes in temperature and precipitation from 1980 to 2014, as a measure of climate change. 'Other' category includes perceptions of change in temperature or precipitation, but not uniformly increasing or decreasing from 1980 to 2014. (a) Perceptions of temperature change, (b) perceptions of precipitation change. Error bars: SE

winters have become warmer and summers are no longer as hot. However, overall, most farmers are noticing greater variability in the weather, with trends of warmer and drier growing seasons the most important and apparent.

Many farmers (n = 10) emphasized changes in winter temperatures, stating that 30 yr ago, the ice that formed in the streets was up to 1 m thick, while today there is hardly any ice. This may reflect a perceived lower precipitation where the amount of water available to winter wheat is reduced, changing the water balance, as winter precipitation and snowfall increase soil moisture and recharge groundwater reserves. However, it may also indicate that precipitation is simply not freezing due to warmer winters.

Warmer winter temperatures may be increasing crop pest prevalence. Six farmers voluntarily stated that they noticed more pests in the period from 2010 to 2014 than from 1980 to 1984, and 5 of these individuals stated that pests cause maize yield reduction (the last stated that pesticides were adequate to mitigate pest damage). The link between climate change and crop pests indicates that pest damage will likely increase in a warmer climate, as pests become more active and expand their geographical range (Cannon 1998, Rosenzweig et al. 2001). The farmers themselves were generally not able to give reasons for why pests have increased, with the exception of one who suggested that the use of pesticides has perhaps killed off natural predators. Crop pests were categorized by farmers very broadly, for example, various species of maize pests, including *Ostrinia* and *Sitophilus*, are all referred to as 'corn bugs', and so unfortunately it is impossible to determine from this study whether the incidence of specific pests has increased.

3.3. Weather data

Least-squares regression of daily weather data from the Xingtai weather station shows a significant warming trend (+1.7°C in the mean annual air temperature from 1980 to 2014), but no change in precipitation (Fig. 3, and Fig. S2 in the Supplement at www.int-res.com/articles/suppl/c069p261_supp.pdf). The increase in average temperature appears to be strongly driven by the increase of almost +3°C in the average minimum daily temperature since 1980, whereas the change in average maximum daily temperature was only +0.68°C in the same period. Temperatures during the winter wheat-growing season show a stronger increasing trend (an increase of +0.04°C yr^{-1}, resulting in +1.36°C from 1980 to 2014) than during the maize growing season (+0.03°C yr^{-1} leading to +1.02°C from 1980 to 2014). The increasing temperature and lack of change in precipitation was observed when considering yearly averages, meteorological seasons, and both crop-growing seasons. The only season assessed that showed a non-significant temperature increase was meteorological

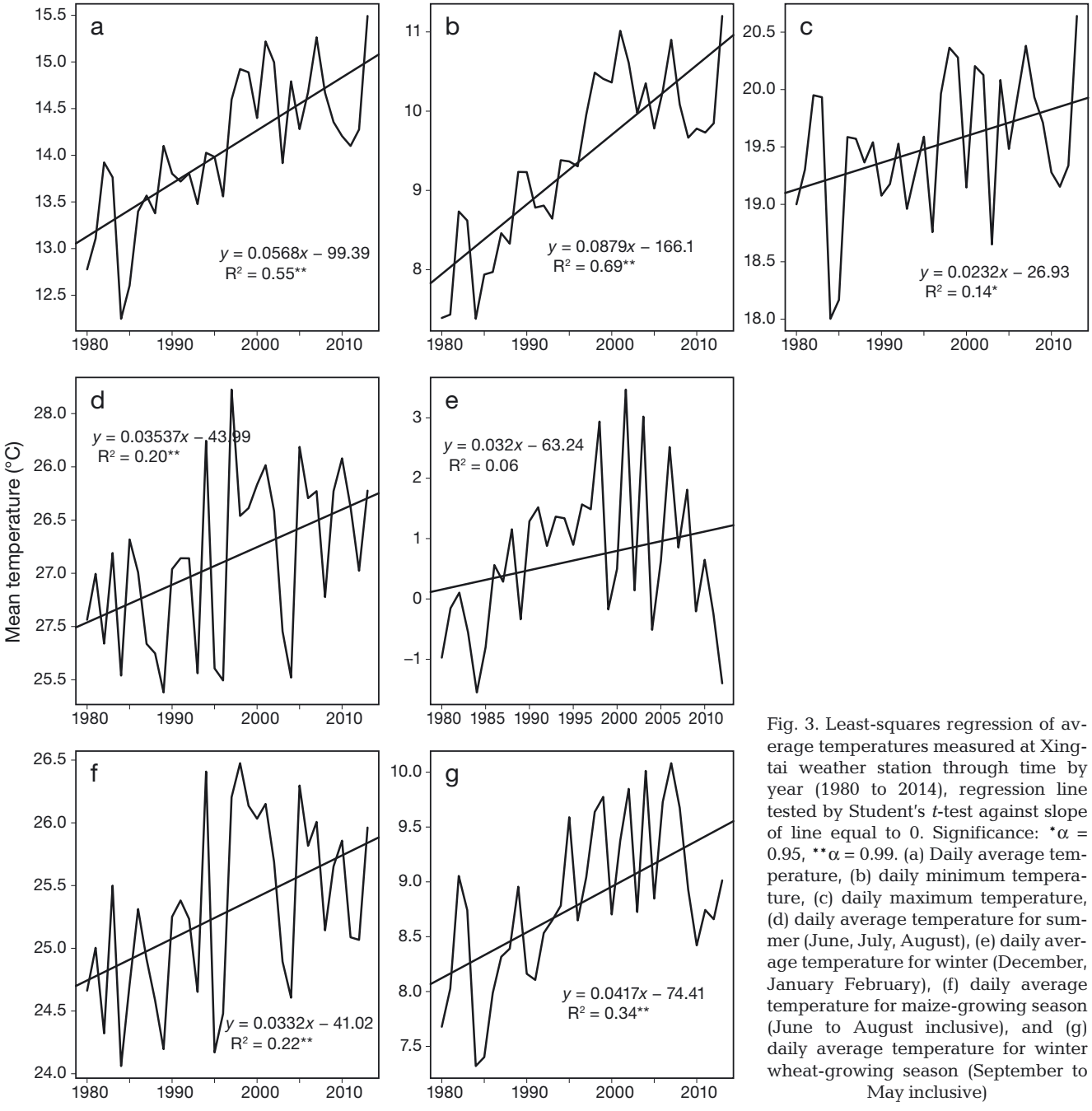

Fig. 3. Least-squares regression of average temperatures measured at Xingtai weather station through time by year (1980 to 2014), regression line tested by Student's *t*-test against slope of line equal to 0. Significance: *α = 0.95, **α = 0.99. (a) Daily average temperature, (b) daily minimum temperature, (c) daily maximum temperature, (d) daily average temperature for summer (June, July, August), (e) daily average temperature for winter (December, January February), (f) daily average temperature for maize-growing season (June to August inclusive), and (g) daily average temperature for winter wheat-growing season (September to May inclusive)

winter (in contrast to farmer perceptions, though changes in minimum temperature may play a stronger role in shaping perceptions here), while all changes in precipitation were non-significant. Extreme weather events have not increased since the early 1980s, as there was no significant change in the number of days when the maximum temperature or maximum rainfall was >1 standard deviation above the mean value (see Fig. S3 in the Supplement).

3.4. Adaptations

In the past 34 yr, farmers of Quzhou have increased irrigation in response to the general perception that the climate is becoming hotter and drier. While potential adaptation measures were described by extension workers and specialists in the field, the majority of them were not undertaken by farmers interviewed for this study. Given the available

options, farmers often decide that irrigation is the best practice to protect crops from the abiotic stresses associated with climate change (for example, 95% of respondents who perceive less rainfall are irrigating more, Table 2). As irrigation is reliant on communal wells, 9 farmers also stated that in the past year, they were not able to irrigate sufficiently when needed and incurred production losses.

Notably, the number of respondents who increased irrigation was significantly larger among the group that believed (mistakenly) in lower precipitation than in the group who did not ($p = 1.65 \times 10^{-5}$, Fisher's exact test). On the other hand, there was no difference in irrigation practices between respondents that perceived increased heat and those who did not ($p = 0.27$, Fisher's exact test). This implies that perceptions regarding precipitation are a good indicator of farmers' irrigation practices.

4. DISCUSSION

4.1. Impacts

The warming trend documented in this study is corroborated by Zhang et al. (2015), who found warming trends of +0.57, +0.47, and +0.44°C per decade at 3 sites of the NCP between 1981 and 2011. S. Liu et al. (2010) reported trends of similar magnitudes (+0.98 to +1.13°C) at other sites of the NCP from 1954 to 1995, and Fu et al. (2009) found an overall significant increase of +1.46°C in daily mean temperature between 1958 and 1998 in the NCP. Our observation of no significant change in precipitation in Quzhou County during the past 30 yr is consistent with other reports from the NCP during the same period (Fu et al. 2009, S. Liu et al. 2010, Zhang et al. 2015).

4.2. Perceptions

Smallholder farmers in the NCP are generally conscious of and able to describe long-term climatic changes. They accurately detected an increase in temperature in their environment, which is related to the 1.7°C increase in the annual average temperature from 1980 to 2014. Some farmers reported warmer winters and cooler summer temperatures, which reflects the fact that temperature changes are strongly controlled by the higher minimum daily temperatures. These have risen by nearly 3°C since 1980, with less change in the maximum daily temperature.

The farmers' belief that rainfall has been decreasing over the past 30 yr is not consistent with the meteorological data. The perception of decreased rainfall may be explained by the fact that while heat and drought stress produce different metabolic responses, the physiological response to both stresses appear similar, resulting in less grain filling and lower yield in cereal crops (Barnabás et al. 2008). In addition, greater soil evaporation under hotter temperature conditions and changes in crop varieties (Savabi & Stockle 2001, Fu et al. 2009, Mo et al. 2009) causes drying and crusting at the soil surface of the farmers' fields. Farmers who observe drier field conditions and crop stress may conclude that these conditions were caused by a decrease in precipitation. Lower rainfall is more directly connected to drought, even if higher minimum daily temperatures are the driving force behind the observations. We note that farmers view precipitation and changes in precipitation through the lens of crop response, as has been reported by Bryan et al. (2009).

The farmers interviewed also recognized the beneficial effects that higher temperatures can have on crop growth; this may explain why not all farmers

Table 2. Impacts reported and adaptation measures undertaken by smallholder farmers according to perceptions of climate change, in Quzhou County, North China Plain. (–) Not applicable. Values are percentages of respondents

	Farmers who perceive increasing temperatures	Farmers who perceive less precipitation
Impacts reported		
Decreased yields	37.1	47.6
Irregular frost kills seedlings	3.7	–
Water shortage	–	95.2
Adaptation measures undertaken		
More irrigation required	70.1	95.2
Shift in seeding or harvesting time (pushed to later)	18.5	–
Soil conservation techniques (leaving residue, conservation tillage)	7	9
Shift to livestock management	3.7	–
Change crop	3.7	–

who perceived higher temperatures altered their farming practices. When they were asked which months are most important in terms of temperature, they stated that higher temperatures were beneficial for both crops, but especially in June, July, and August after corn is seeded. In the participants' minds, the link between higher temperatures and the yield losses is weaker than the deleterious effects on crops resulting from lack of precipitation. In reality, higher temperatures may be providing beneficial growing conditions for crops while at the same time causing drier field conditions.

4.3. Adaptations

Adaptation requires planning, labor, and monetary costs. Irrigation, with wells providing access to groundwater, is the least prohibitive of the adaptation measures. Even then, many farmers stated that well irrigation has become quite expensive, citing costs of 750 to 1350 RMB ha^{-1} (50 to 90 RMB mu^{-1}; 1 mu = 667 m^2) per irrigation event. With multiple irrigation events (up to 5 yr^{-1}), and with each mu of cultivated corn or wheat production bringing farmers revenues of 1000 RMB yr^{-1}, the cost of irrigation quickly becomes a significant expense.

The installation of groundwater wells for irrigation from the 1980s onwards appears to have prevented any dramatic yield losses. The fact that irrigation is possible, though at cost, precludes the undertaking of more radical adaptation measures; in other words, farmers take the 'easy way out' by irrigating. Despite the costs and waiting times for irrigation, other strategies are not considered practical, for various reasons (Table 3).

However, water resources in the NCP are particularly vulnerable to climate change and the growing dependence on intensive irrigation in the past 30 yr has exacerbated the situation. The major challenge is that the winter wheat–summer maize double-cropping systems require more water than can be supplied through precipitation (Kendy et al. 2004). Since the 1980s, most rivers in the region have dried up, and groundwater contributes 70% of agricultural water use (Sun et al. 2011). Groundwater reserves and water tables are over-exploited, and have been in decline since 1965, with extraction rates in some regions doubling the sustainable rate of recharge (Mo et al. 2009, Shi et al. 2011, Sun et al. 2011). In Hebei particularly, irrigation for intensive grain production has caused land subsidence as well as the degradation of groundwater quality due to saltwater intrusions (Liu et al. 2001). Furthermore, the water-use efficiency of flood irrigation is quite low: up to 30% of the water available to corn and 40% of the water available to wheat is lost to soil evaporation (Wang et al. 2001).

Of the grain crops currently planted, drought-resistant varieties of corn or winter wheat are not widely available or known in the NCP. Many farmers stated that any water-conserving variety that they know about has lower yields, so they would prefer to incur irrigation costs for a larger yield payoff. Furthermore, farmers are skeptical of new varieties until they test them personally or see them grow successfully on neighboring farms. Farmers can purchase many seed varieties but the lack of reliable information about their performance, and the occasional unscrupulous seed vendor, hamper their confidence in new varieties. For these reasons, they are often hesitant to try new varieties, and instead rely on neighbors (and extension workers, if available) for advice instead. While Y. Liu et al. (2010) state that adoption of new varieties by farmers may represent their autonomous adaptations to climatic trends, they also state that

Table 3. Potential adaptations to climate change available to smallholder farmers in the North China Plain, with main obstacles to undertaking each specific adaptation method

Adaptation	Obstacle
Change in cropping system	Lack of viable alternative
Adapted varieties	Lack of institutional breeding programs specifically targeted at climate change and drought-tolerance
Rainwater harvesting	Not enough land space; investment necessary is too high
Increase irrigation efficiency: change method from flood irrigation	High investment cost; may not lead to groundwater recharge (Kendy et al. 2003)
Shift to livestock	Not enough land and labor, perceived economic risks too high
Conservation tillage	Potentially feasible, but awareness of practice not widesread

there are no institutional plant-breeding or adaptation programs in place for China that directly address issues of climate change and water scarcity. The most important measure to avoid losses in yields, given that future climate change scenarios predict continued warming, will be the development of heat-tolerant varieties that are specifically adapted to local climate conditions (Tao & Zhang 2010).

Rainwater harvesting systems, whether on an individual or communal level, are deemed infeasible because of space availability and difficulty in management. Farmers in the NCP work on a very small land base, and large-scale rainwater harvesting schemes are viewed as too costly to implement and requiring too much land. Furthermore, capturing rainwater would not resolve the depletion of groundwater reserves, as the groundwater in the NCP is replenished by rainfall (Liu et al. 2001).

Changes in agronomic practices can also improve water-use efficiency. Changing irrigation methods from flood irrigation (the most common method used in the NCP in 2014) to a more efficient regime such as pipe delivery in combination with controlled irrigation and mulching, can improve the water-use efficiency of crops and allows farmers to use less water for irrigation (Sun et al. 2010). Furthermore, precision irrigation (in terms of timing and quantity) can reduce water requirements further (Fang et al. 2010). Alternative irrigation methods require a high level of investment or technical support, according to the farmers interviewed. However, techniques of best management practices have been implemented successfully elsewhere in the world: carefully timed application of irrigation with more efficient equipment has led to significant improvements in larger scale farms, for example (Bjornlund et al. 2009). In these areas as in the NCP, there is a financial barrier to investing in improved irrigation equipment, and so education and technical support in terms of irrigation timing will also play an important role.

Better soil management through tillage practices and nutrient management also have the capacity to improve water use efficiency. Hatfield et al. (2001) found that across countries, climates, and regions, tillage management can improve water-use efficiency by 25 to 40%. However, tillage practices such as conservation or zero tillage were discussed by extension workers in the NCP but are not practiced widely by the farmers interviewed in Quzhou. The current practice of removing or burning crop residues before seeding, common throughout the NCP, is believed to favor crop growth (Zhou et al. 2001). However, this practice diminishes long-term soil quality by reducing the proportion and size of soil macro-aggregates, increasing bulk density, and critically, by reducing the availability of water and nutrients (Qin et al. 2007). He et al. (2011) have shown that no-tillage practices in the NCP significantly improved crop yields through enhanced water storage, nutrient availability, and soil organic matter accumulation, especially in dry years. Mulching winter wheat with residues from harvested maize can also improve water-use efficiency (Zhang et al. 2005), though this may also negatively impact winter wheat yields by keeping soil temperature low in spring (Chen et al. 2005, Li et al. 2008). Implementing these tillage and mulching practices could reduce the effect of heat stress on wheat and corn crops by maintaining soil moisture and reducing the need for irrigation. As interviewed farmers were skeptical of the benefits of alternative tillage practices, educational and demonstration plots through extension may be necessary. Furthermore, farmers stressed the need for appropriate seeding technology for practices like no-till, as well as their lack of ability to invest in these technologies. As such, support will be needed to aid farmers in undertaking changes in tillage practice.

In the long run, the water demand of the cropping system is much greater than the water inputs through rainfall and groundwater recharge, and as such, the region remains in a negative water balance that cannot be overcome by changing irrigation methods (Kendy et al. 2003). While water-efficient crops and practices are necessary, the water balance deficit is not insignificant because yearly total evapotranspiration is about 300 mm greater than precipitation (Liu et al. 2002). Meanwhile, alternative cropping systems have also been proposed, including a 2 yr/3 crop system, as well as a wheat monoculture (Meng et al. 2012). These reduce water and resource strain, but also involve economic trade-offs. Kendy et al. (2004) suggested a millet and cotton system to keep the water table stable and reduce the water deficit. However, this is not feasible economically due to low prices for millet and cotton and an insufficient labor supply, as stated by 8 farmers. Guo et al. (2013) found that a 3 harvest per 2 yr cropping system can reduce water stress; however, this reduces economic returns substantially. The double-cropping maize–wheat system is the most profitable system for farmers who are already facing low economic returns, but it depletes water resources because farmers perceive (accurately) that irrigation is currently necessary to reach their yield targets.

4.4. Implications

The findings here shed light on how farmers in the NCP will be affected and adapt to climate change in the near future. Climate change models predict that temperatures will continue to rise for the next 10 yr in the NCP (Piao et al. 2010). Changes in precipitation are uncertain: depending on which IPCC scenario is selected, the predictions show that both increasing and decreasing scenarios are possible (Mo et al. 2009, Piao et al. 2010, Chen et al. 2013). This does not mean that water resources are sufficient in the foreseeable future. For instance, due to the interaction between crop physiology and increasing temperatures, Mo et al. (2009) predict that water use efficiency for summer maize will decline under all climate change scenarios. Assuming no change in cropping systems and constraints, farmers in the NCP will demand more groundwater for irrigation in a hotter future climate. This is worrisome because farmers in the NCP already require an unsustainable amount of groundwater to meet their actual and perceived needs for irrigation. Policymakers must support adaptation practices that encourage sustainable and responsible water use, as has been suggested by Liu et al. (2001), Kendy et al. (2004), Liu et al. (2008), and Hu et al. (2010).

The findings from the Quzhou County case study are informative in terms of policy and agricultural adaptations to future climatic changes. Without knowing the level of knowledge and constraints, Zhang et al. (2015) stated that farmers must be aware of climate change, and be willing to adopt innovative solutions. This study shows that farmers are indeed aware of the climatic changes affecting their crops and are responding based on their perceptions of the crop responses and the resources available to them. Rather, it is not a question of willingness to adapt innovatively, but the constraints that impede farmers' ability to implement practices that consider the externalities associated with water use. Pragmatically, this study suggests that priority be given to promote soil conservation methods at the farm level that promote soil moisture retention, as well as improved education on how and when to irrigate. At the institutional level, the development of adapted heat-tolerant wheat and maize varieties would provide more options at a regional scale. We believe that this paper identifies policy levers in terms of revealing the most important constraints to adaptation. Water use needs to be addressed in a way such that the costs of undertaking changes will not exacerbate the shrinking groundwater reserves nor negatively impact farmers' livelihoods. This is currently the most important challenge to sustainable adaptation to climate change for the smallholders of the NCP. Governments and institutions will need to invest in the appropriate agronomic technologies and educational outreach in order to provide support to farmers in addressing these issues.

5. CONCLUSIONS

Farmers in the NCP are aware of climate change, though the substantial temperature increase (+1.7°C from 1980 to 2014) creates drier conditions at the soil surface and heat-stress responses in crops that we hypothesize is then perceived to be due to a lack of water. Thus, farmers are often attributing these observations to lower rainfall, although long-term weather station data shows a non-significant change in precipitation over the past 30 yr. Irrigation is seen as the best adaptation measure to combat the crop heat stress, and indeed, increased irrigation is only practiced when there is a perception of long-term precipitation decrease. However, this practice may not be sustainable nor conducive to future long-term adaptation given the limited groundwater resources in the area. Smallholder farmers require information provision and decision-making support (such as being informed of optimal practices: when to irrigate, soil management practices, new crop varieties) along with policy and institutional support to adapt their agronomic practices to future climatic conditions. The most promising adaptations may be the implementation of soil conservation practices at the farm level and the development of adapted heat-tolerant crop varieties at an institutional level. Policymakers, including local village governments, need to be aware that reliance on irrigation is not a panacea to combat the ongoing climate change in this area. Decision-makers have an important role in encouraging the development and implementation of long-term sustainable adaptation strategies for smallholder farmers in the NCP.

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