



Will heat stress take its toll on milk production in China?

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Abstract

There are clear signs that milk production growth is leveling off, and recently even declining, in China. Heat stress is one of the main reasons for the recent reduction in milk production. In this study, we computed the change in milk production as a result of heat stress in major milk production areas in China. We constructed a temperature–humidity index (THI) spatial layer to understand the monthly distribution of heat and moisture. We documented specific areas in northern China where cattle were at high risk to heat stress in specific months. THI values exceeded the threshold above which milk production declines during months of June, July, and August. Especially during July, the THI value was higher than the production threshold in recent years (2008 to 2016) and in projected future scenarios (2050 and 2070). THI-based milk yield losses were up from 0.7 to about 4 kg per cow per day in July 2016. These losses are projected to increase from 1.5 to 6.5 kg in 2050 and 2 to 7.2 kg in 2070 (representing production losses between 15 and 50%). These results suggest that climate change will have significant consequences for the dairy sector in major milk-producing areas in China. Our results are useful in identifying areas susceptible to heat stress where adaptive livestock management practices are needed to prevent significant production decreases.

Keywords Cow · Milk production · Climate change · Temperature–humidity index · Heat stress

1 Introduction

The dairy sector is important for economic and food security across many countries (Herrero et al. 2013; Bai et al. 2018b). Millions of farmers worldwide raise approximately 280 million

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dairy cows to produce milk (FAO 2018). The major global economic expansion of milk production started five decades ago with increased consumption of cow's milk, and correspondingly, milk products began being traded in greater number (Wiley 2007). Both milk consumption and production are still increasing around the world. Increasing global demand for dairy continues due to population growth, rising incomes, urbanization, and changing of diet compositions (Kearney 2010; Tilman and Clark 2014) in mega population countries such as China and India (Alexandratos and Bruinsma 2012; Bai et al. 2018a). Driven by changing lifestyles, global milk consumption is projected to increase by about 60% by 2050, with many new consumers coming from China (Bai et al. 2018a, b). Governments promote milk consumption in food-based dietary guidelines and school milk programs because of the efficiency and effectiveness of milk in preventing malnutrition (Wiley 2007). The Chinese population is a particularly good example of this trend, with traditionally low milk consumption per capita (< 2 kg per capita per year in 1961), but by 2016, this number had increased by a factor of 25 (FAO 2018).

Currently, China is the world's leading milk importer, importing 12 million metric tons of raw milk in 2013, a quantity 123 times larger than that in 1961, and equal to 25% of domestic consumption in 2013 (FAO 2018). To meet rapidly increasing demand for dairy products, the growth of the dairy industry is accelerating. Milk production continues to increase (Fig. 1) in response to growing domestic demand, which largely originates from urban areas. According to the FAO, annual growth of per capita consumption of milk in China was about 10% in the 30-year period from 1987 to 2007. Moreover, the dairy sector is a vital contributor to economic growth (Wiley 2007). While the livestock population grew from 142 to 441 million units of livestock between 1980 and 2010, the annual economic value of livestock production increased almost 60-fold from 35 to 2100 billion yuan (Bai et al. 2018b).

Despite these huge expansions in recent decades and continued increased demand for dairy products, there are clear signs that production growth is leveling off. For example, according to the National Bureau of Statistics of China, 2017 milk production decreased 0.8% from 2016 levels. China's current milk production has fallen by 1.3% compared with 2016, mostly attributed to heat stress and small/medium farms exiting operations due to stricter environmental regulations and declining profitability (DAH and NAHS 2018). Heat stress is often identified as one of the major factors responsible for the recent decline in the milk production (Pragna et al. 2016). According to NCCAR (NARCC 2011), in China, temperatures increased an average of 1.4 °C between 1951 and 2009. Both winter and summer temperatures have gradually increased (Zhou and Ren 2010; Li et al. 2015) with more frequent extremely hot days that result in heat-related problems (Xiao-Juan et al. 2013; Wang et al. 2014). With any

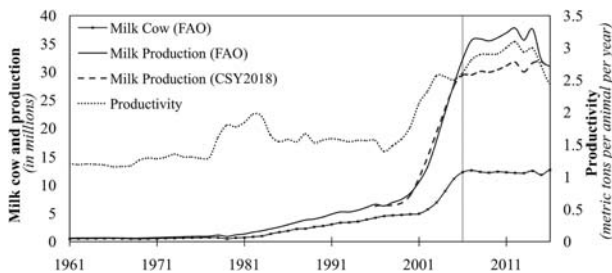


Fig. 1 Cow population (head) and milk production (metric tons) in China according to FAOSTAT database accessed in January 2019 and Chinese Statistics Yearbook 2018. Two data sources show difference after 2006 (vertical line in the figure) till 2017; however, ratio of annual change is consistent

additional warming, it is likely that the frequency and length of heat waves will intensify, resulting in more severe heat stress problems in animals.

Heat stress has clear adverse effects on milk production and reproduction in dairy cattle (Kadzere et al. 2002). A decline in milk yield of lactating cows and buffaloes is observed during hot–dry and hot–humid seasons due to high temperature and humidity (Upadhyay et al. 2007; Thornton 2010). The effects of high temperature and humidity can be summarized in the THI (temperature–humidity index) (Upadhyay et al. 2007), and this index has been shown to be strongly related to milk yield declines above a specific THI threshold. The THI is a measure of the degree of discomfort experienced by an individual animal in warm weather. Mild heat stress starts to occur at a THI value of about 72, and even at “mild” THI values, reproductive losses and decreased milk production have been documented. Recent studies in high-producing cows suggest that early detrimental effects on production can be seen at THI values as low as 68 (Bryant et al. 2007; Zimbelman et al. 2009; Dunn et al. 2014; De Rensis et al. 2015; Polsky and von Keyserlingk 2017). Heat stress both directly (Rhoads et al. 2009; Wheelock et al. 2010) or indirectly decreases milk yield by reduced feed intake (West 2003; Polsky and von Keyserlingk 2017), which also affects milk composition (Upadhyay et al. 2009). Milk protein concentration decreased when cows were exposed to heat stress, while milk fat content may have increased (Gao et al. 2017, 2019). Heat stress not only affects milk production and quality but also impacts the overall health of dairy animals by affecting normal physiology, metabolism, hormones, and the immune system. However, this paper will only focus on heat stress-related milk production issues.

To assess whether indeed heat stress is a key factor in the current stagnation of milk production in China and to assess how heat stress might affect future levels of milk production, this study uses data from the last 10 years to quantify the relationship between THI and cow milk production across northern China and performs scenario analyses to assess what effects climate change might have on milk production in northern China. Specific objectives of this study are

- (i). to develop a spatial layer of temperature–humidity index (THI) and cattle distribution for northern China;
- (ii). to develop a statistical model describing milk production in relation to THI;
- (iii). to quantify the variation in THI over space and time; and
- (iv). to predict how THI might change under climate change and what the consequences for milk production in northern China will be.

2 Methods

2.1 Data

2.1.1 Milk production data

In this study, we concentrated on northern China, which is a major milk-producing region in the country (Electronic Supplementary Material: ESM_1 and ESM_Fig.1), and analyzed monthly milk production and climate information for the provinces of northern China in the period from 2008 to 2016. For this, we used monthly census data collected and compiled by the National Animal Husbandry Service, Ministry of Agriculture and Rural Development

(MARA). Their data traces to milk stations in many different counties across eight provinces in northern China from 2008 to 2016 (ESM_Fig. 2). A total number of dairy cows and milk production data were extracted from the census data, and each data collection center was geospatially referenced using Google Earth. The primary dairy breed is Holstein cows in Northern China and included in our survey and analysis. Very small number of Jersey cows are present in China and they are not preferred in dairy industry as they do not contribute much to the total milk volume.

2.1.2 Climatic data

- (i). Meteorological station data: We obtained daily weather data from the National Climatic Data Center (www.ncdc.noaa.gov), representing 181 stations across northern China (ESM_Fig. 2) for the period of 2008 to 2016.
- (ii). Baseline scenario: Monthly data averaged for the period of 1970 to 2000 from WorldClim (www.worldclim.org) (Fick and Hijmans 2017) were used as the baseline climate scenario.
- (iii). Future scenarios: Climate projections from the global climate model (GCMs) from Beijing Climate Center Climate System Model (BCC-CSM) for 2050 (average for 2041–2060) and 2070 (average for 2061–2080) were used. It is a climatic model developed at the Beijing Climatic Center (BCC) and China Meteorological Administration that couples a global climate–carbon model that incorporates interactive vegetation with a global carbon cycle (Xiao-ge et al. 2013). It is one of the most widely used models in East Asia. The model has been tested in detail for China and has been shown to perform better than other models in reproducing summer surface air temperatures over China (Xiao-ge et al. 2013; Xin et al. 2013).

2.1.3 Data analysis

The analysis consisted of four steps all performed for northern China:

- (i). A gridded map of cow distribution: We used the Maxent model to generate a spatial layer of probability distributions representing variations in cow distribution. The probability distribution is generated using the observed herd sizes of certain locations in combination with the geographical conditions of a location. For this, we used Land Use Land Cover (LULC) information for 2010 (Broxton et al. 2014), elevation, annual average precipitation, annual average maximum temperature, and minimum temperature. With these variables, we modeled cow distribution across northern China.
- (ii). A spatial representation of the temperature–humidity index as an indicator of heat stress: Heat stress results from a combination of factors, including ambient heat and humidity, local air movement, and absorption energy from sunlight (Dunn et al. 2014). The temperature–humidity index (THI) is a simple empirical way to quantify the heat stress experienced by cattle in a systematic way. Different formulations of THI exist. The most widely used formulations include air temperature and relative humidity, but Mader et al. (2006) also included wind speed and solar radiation in their formulation of THI. However, in this study, given the limited availability of the right meteorological information at the right temporal scale, we opted to use the common, simpler approach

that only includes air temperature and humidity (Dikmen and Hansen 2009; Dunn et al. 2014). The index is essentially a quantification of what is often called “effective temperature.” Different formulations of the exact equation exist (Ravagnolo et al. 2000; West et al. 2003; Dikmen and Hansen 2009; Dash et al. 2016), but we used the original formulation by National Research Council of United States (NRC 1981).

$$\text{THI} = 0.5 \times [(1.8 \times T_{\text{air}} + 32) - (0.55 - 0.55 \times \text{RH}) \times (1.8 \times T_{\text{air}} - 26)]$$

where T_{air} is the air temperature in °C and RH is the relative humidity in %. THI increases linearly with air temperature if the relative humidity is constant, and THI is equivalent to air temperature in Fahrenheit if RH equals 100%.

We used daily temperature recordings (maximum, minimum, mean, and dew point (see ESM_Fig. 3)) from meteorological station data from northern China to quantify THI. Daily THI values for each station were averaged to monthly THI values for the period of 2008 to 2016. We interpolated the THI values to produce a gridded map of THI with a 1 km² resolution for the whole of China and used the appropriate portion of northern China for further analysis (ESM_1).

(iii). The relationship between milk production and THI: To relate THI values to milk production, two key characteristics are needed to be quantified. The first is the THI threshold above which negative production effects start occurring. This threshold is normally site dependent. Geographical factors affect the thresholds of THI where heat stress occurs and will affect milk production. In general, however, most of the literature follows a standard classification: values between 72 and 78 are representative of mild heat stress; values between 78 and 89 of severe stress; and values between 89 and 98 of extreme stress (St-Pierre et al. 2003; Dunn et al. 2014). Livestock exposed to a THI of 98 or more for a sustained period of time can die. However, these are general guidelines, and logically, the appropriate thresholds depend on which specific formulation of THI has been used in a given study (Dunn et al. 2014).

Second is the shape of the relationship between heat stress and loss of milk production. We follow the approach used by Bohmanova et al. (2007) to estimate milk loss per day due to heat stress. The formula for milk loss (kg/cow/day) due to heat stress is given as:

$$\text{Loss} = \max(\text{THI}_d - \text{THI}_{\text{thr}}, 0) \times 0.37$$

where max() function returns the maxima of its arguments. We used THI=72 as the THI threshold that has been identified by several studies (e.g., St-Pierre et al. 2003; Mauger et al. 2015).

The relationship between total milk production and heat stress and the effects of possible other climatic variables were evaluated using partial least square regression (PLS). We used average monthly milk production information from the census data for the period of 2008–2016 as response variables (Y). Air temperature (maximum and minimum), temperature at dew point, temperature–humidity index, relative humidity, solar radiation, and precipitation were used as independent variables (X). As meteorological stations were not available at all the collection centers, we interpolated monthly average of these climatic variables based on data from the available meteorological stations. We quantified variable importance in the model

projection (VIP), which reflects the importance of each of the model terms and the model coefficients to interpret the direction in which certain predictor variables affected milk production (Tenenhaus et al. 2005; Nokels et al. 2010). Predictor variables with $VIP \geq 0.8$ and standardized coefficient confidence intervals significantly different from zero were kept in the final statistical model explaining variations in milk production.

- (iv). Application of the milk—THI model under current and future climate conditions: To identify potentially susceptible areas where heat stress could have an impact in the future, we combined gridded maps of the spatial cow distribution and THI for further analyses. Maps of monthly THI values were overlaid with the gridded map of cow distribution using the fuzzy overlay method in ArcGIS (ESM_1). Fuzzy overlay analysis is based on set theory in which a set generally corresponds to a class. Fuzzy overlay analysis transforms data values to a common scale, but the transformed values represent the probability of belonging to a specified class. The combining step in fuzzy overlay analysis quantifies each location's probability of belonging to specified sets from various input map layers (Robertson et al. 2004; Barbosa and Real 2012; Qiu et al. 2014). This overlay helps us to understand which parts of northern China combine high livestock distribution with potential susceptibility to heat stress.

3 Results

3.1 Cow distribution and milk production in eight provinces of northern China

Data used from eight provinces of northern China indicated about 80% of national milk production is located in these provinces, with five provinces viz. Inner Mongolia, Heilongjiang, Hebei, Henan, and Shandong provinces together make up about 64% of total milk production. Data indicated a decrease in the cattle population, including milking cows in four provinces, while two provinces, Hebei and Xinjiang, showed an increase in milking cow numbers (detail in ESM_2; ESM_Tables 1 and 2). In all provinces, cow numbers tended to increase in the years between 2008 and 2012, whereas they have decreased in the last 4 years. Data revealed a sharp decline over the last 4 years in provinces like Heilongjiang and Inner Mongolia, and a noticeable decline in Henan, Shandong, Xinjiang, Shaanxi, and Hebei. Total milk production over the 8-year period increased in Hebei and Xinjiang province, while all other provinces showed a decrease in milk production. In Shaanxi, the rate of milk production decrease was largest, at 2780 metric tons of milk per year during the observation period.

Using the cow census information, a gridded map of cow distribution across northern China was prepared (ESM_Fig. 4 and ESM_Fig. 5a). Farming land area and settlement areas were found to be major explaining factors of higher concentration of cow distribution. The highest cow densities were found in Hebei Province as well as in the northern part of Shandong, central part of Shaanxi, southern part of Beijing, northern part of Henan, southwest Heilongjiang, and central part of Inner Mongolia.

3.2 The temperature–humidity index

THI values cross the lower THI threshold from the month of May onwards, and THI values in that month reached up to 79. While most provinces showed maximum THI values lower than 69, parts

of Henan, Shandong, Hebei, and Xinjiang show THI values higher than 70, and THI values of 78 occur in Xinjiang (Fig. 2a). By the month of June, large areas in Henan, Hebei, and Xinjiang showed THI values over 79, indicating potential negative effects for milk productivity (Fig. 2b). The month of July showed the highest THI values, with large areas exceeding the mild heat exposure threshold and several places in northern China exceeding the severe heat exposure threshold. THI values between 79 and 86 were quantified for major parts of northern China, including provinces such as Henan, Shandong, Hebei, and Xinjiang in July (Fig. 2c). Inner Mongolia, Shaanxi, Shanxi, Liaoning, Beijing, and Tianjin also showed higher THI values, ranging between 67 and 82, which indicates mild heat stress conditions. The month of August (Fig. 2d) showed comparatively smaller areas in the same provinces where milk productivity could be affected by heat stress than the ones identified for July, but heat values in those areas are slightly higher than in June. By the month of September, THI values were less than 71 everywhere in northern China, except in few areas in Xinjiang and Henan (Fig. 2e).

3.3 THI and milk production

The PLS regression analysis identified the magnitude and direction of the key relationships determining milk production. As expected, THI was an important explaining factor, but also

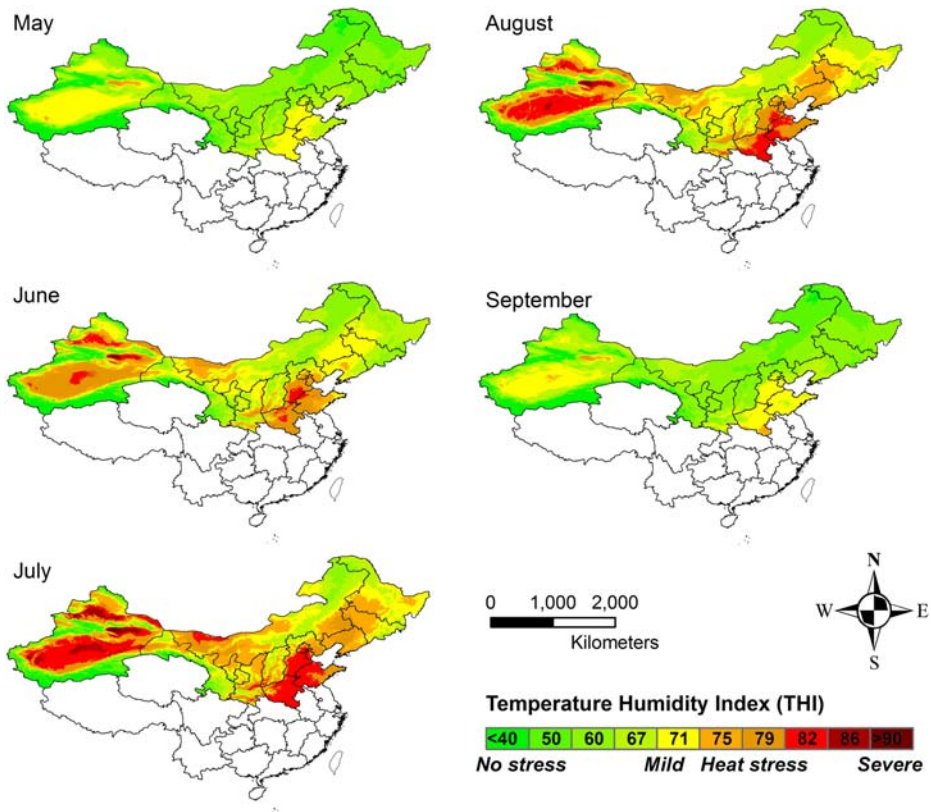


Fig. 2 Spatial distribution of the temperature–humidity index (THI) across northern China during: a May, b June, c July, d August, and e September for the baseline scenario

maximum temperature was an important variable explaining milk production throughout the year. Temperature dew point and minimum temperature contributed to model performance for most of the year, excluding the summer months, whereas solar radiation was less important during March, June, and July (Fig. 3). Relative humidity and precipitation only showed up as significant variables during specific moments of the year, and not during the hottest, summer months of the year. Standardized PLS model coefficients showed that higher THI values had negative effects on milk production throughout the year (Fig. 3). Precipitation showed a negative effect on milk production in several months of the year, excluding June and July.

3.4 THI and milk loss over time

We found noticeable changes in THI distribution over the period 2008 to 2016. As before, the THI values of the month of July (Fig. 4) were highest. The spatial extent of the area with THI > 72 was substantially larger in 2016 compared with 2008, except for the northeastern part of Heilongjiang and Inner Mongolia (Fig. 4a, c). Estimated milk loss per animal in the month of July was highest (up to 120 kg per animal per month), while THI > 72 and related losses in milk production were more varied in the months of June and August (ESM_Fig. 6). Therefore, we only show detailed results in July. Across northern China, total milk loss per cow in July was 10 to 20 kg per animal per month higher in 2016 compared with 2008 (Fig. 4b, d). This difference over 8 years was 0.5 kg per animal per month in June and 10 kg per animal per month in August (ESM_Fig. 7 and ESM_Fig. 8).

Estimating THI using future climate change projections (Fig. 5) showed that the area with THI > 72 increased considerably for the month of July in 2050 and 2070. Large areas across northern China are likely to experience mild heat stress in 2050, with the areas experiencing

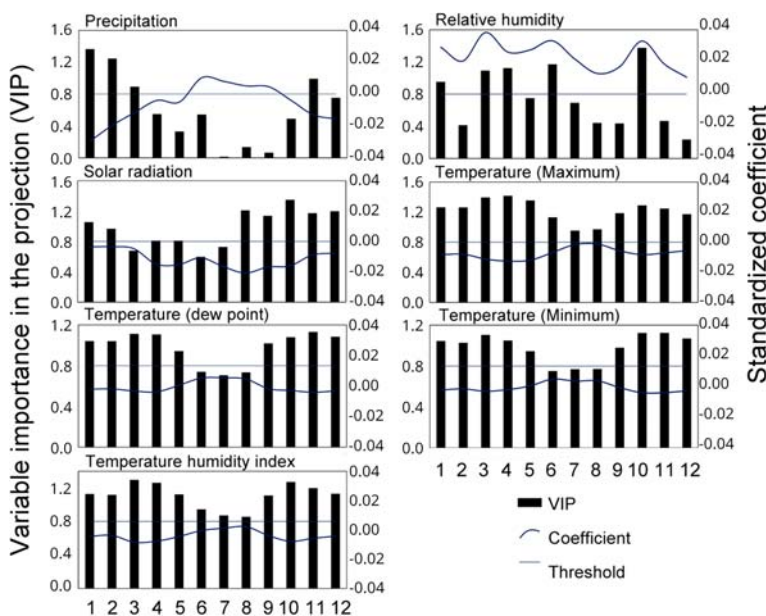


Fig. 3 Response of milk production to climatic variables in PLS regression. Standardized regression coefficients and variable importance in the projection (VIP) plotted against all variables used to explain milk production. The numbers 1 to 12 indicate months from January to December

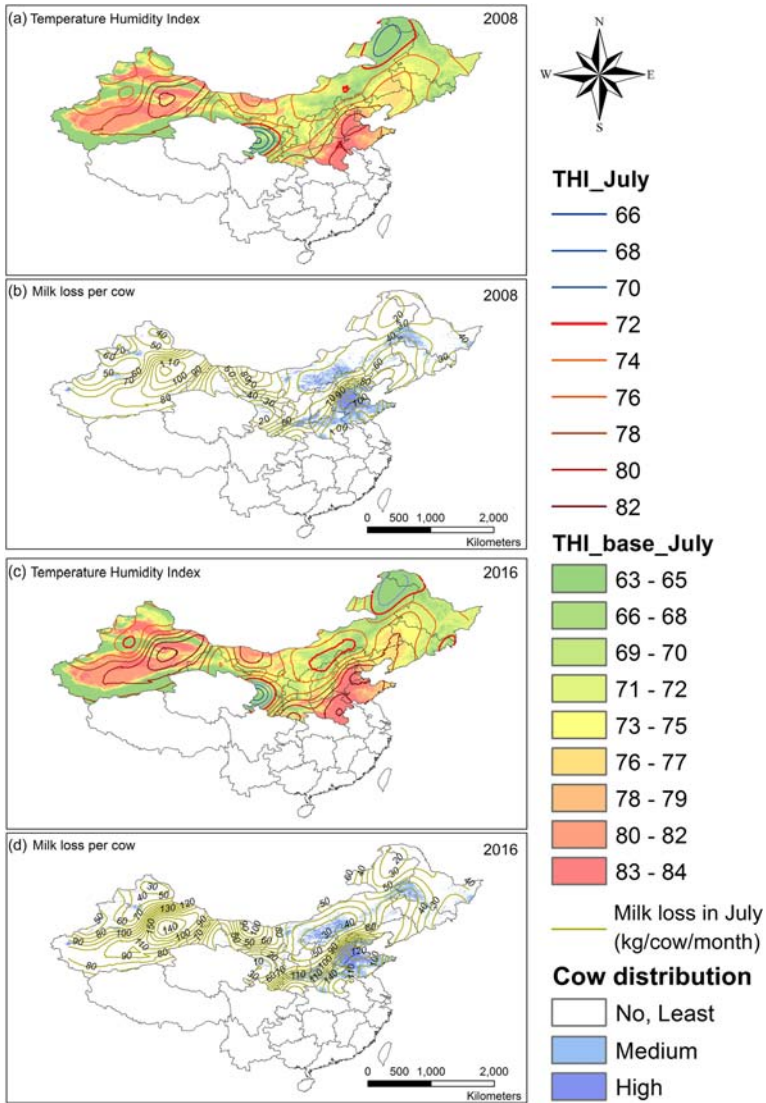


Fig. 4 Spatial distribution of THI (a) in 2008, and (c) in 2016, and estimated milk loss (kg/cow/month) in July across northern China (b) in 2008 and (d) in 2016. Values in the contour line represent estimated milk loss per cow

severe heat stress further expanding in 2070. THI projections varied across different climate change scenarios; as to be expected, the more severe condition was predicted under scenario RCP85 in 2050 and 2070.

Fuzzy overlay maps of cow distribution and THI show that livestock farming areas in different counties of Hebei could highly be affected by heat stress (Fig. 6). Higher fuzzy compound scores identify areas where high cow densities and associated high milk production coincide with higher THI values in the future. In such areas, therefore, milk productivity could be at risk. These are not ideal locations for future dairy production from a climate perspective.

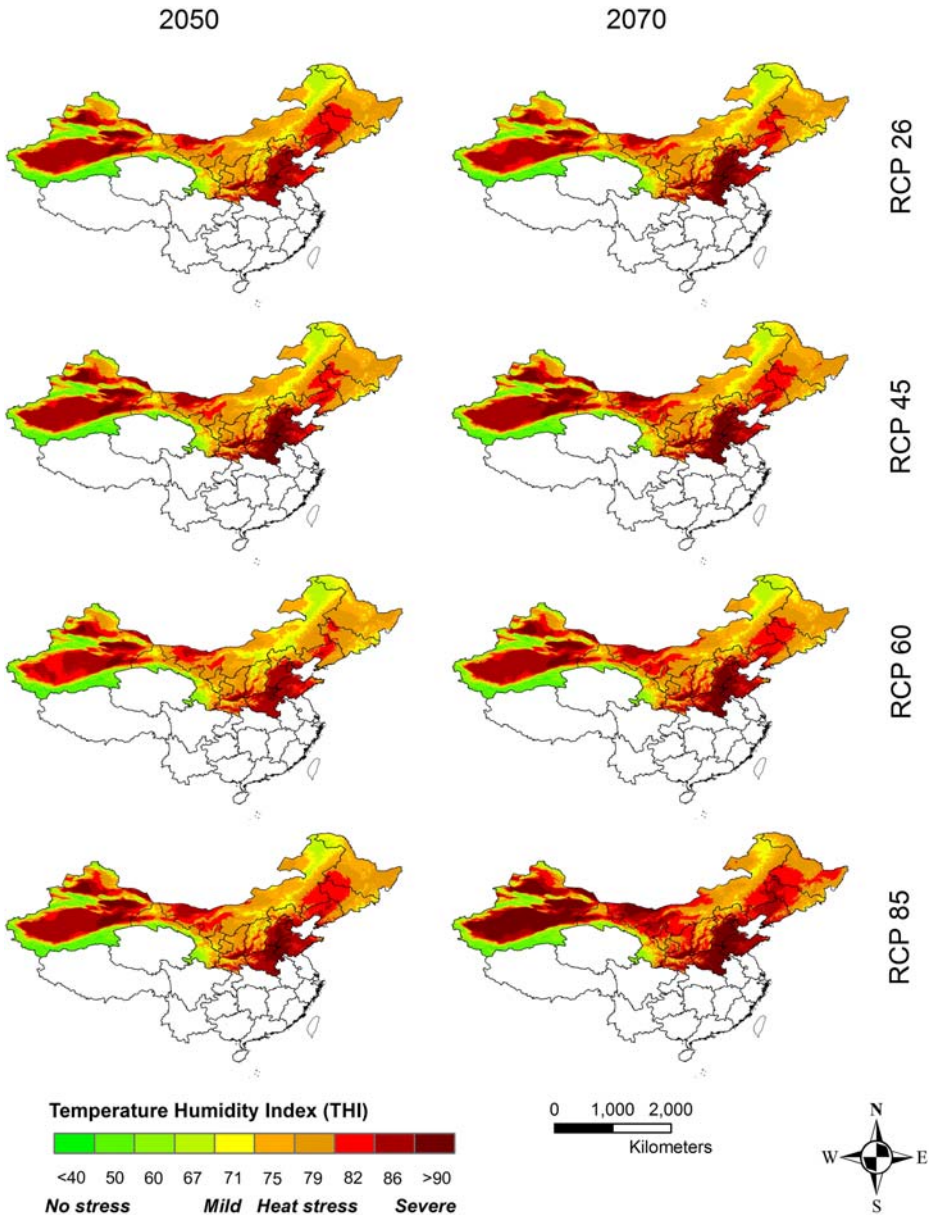


Fig. 5 Spatial distribution of the predicted temperature–humidity index (THI) in 2050 and 2070 across four representative concentration pathways (RCPs) in the month of July

Several current centers of cow and milk production in Shandong, Henan, Shaanxi, and Shanxi are also likely to experience severe heat stress issues in the future.

Applying the baseline climate change scenarios showed that substantial milk productivity losses can be expected at the provincial level, increasing from 1 kg/cow/day in the Heilongjiang and Inner Mongolia regions, and around 4 kg/cow/day in Henan, Shandong, and Tianjin

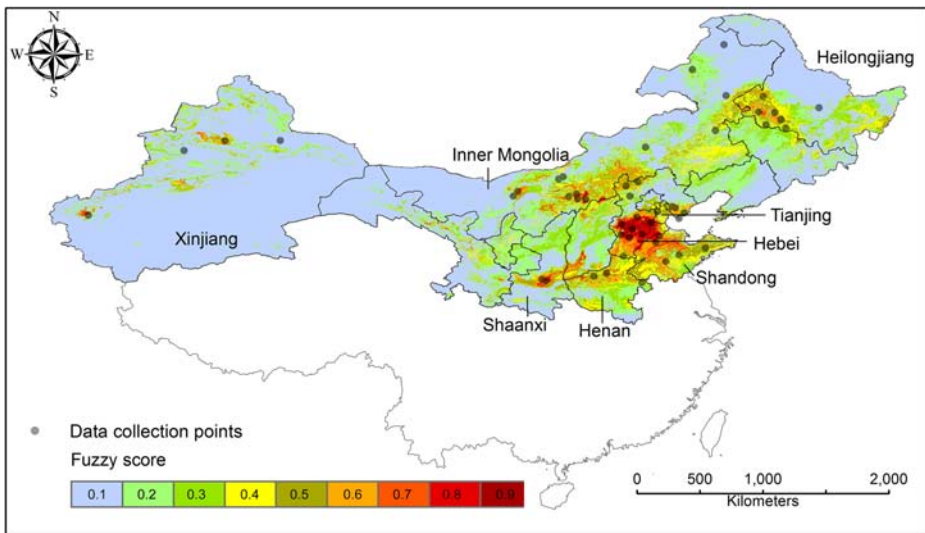


Fig. 6 Spatial distribution of areas with high cow densities and predicted temperature–humidity index values (THI > 72)

in 2016 to values between 3 and 8 kg/cow/day in these regions in 2070 (Fig. 7). These values also show that inter-regional variations in northern China are expected to increase under future climate scenarios by 2050 and 2070. By 2070, dairy cattle in Heilongjiang and Inner Mongolia will experience levels of heat stress similar to Henan, Shandong, and Shaanxi.

4 Discussion and conclusion

China has experienced continuous growth of the economically important dairy sector at both farm and processing levels over the last 30 years. Moreover, China's post-1995 livestock transition has been unique in terms of scale and speed. The increasing demand for milk in China has impacted and will continue to impact global dairy-related GHG emissions, cattle-related land use, and trade (Bai et al. 2018a, b). Our analysis showed that this growth, and even sustaining the current production levels, is under threat because of climate change and its associated predicted temperature rise.

Results show that higher THI values are associated with substantially lower milk production. High temperature and humidity as well as direct and indirect solar radiation are the main environmental factors that stress livestock (Kadzere et al. 2002; Silanikove and Koluman 2015). Based on the output of the model, we developed in this study, it is clear that the combined effects of various climatic factors are important for predicting milk production. The combined effects of temperature and humidity, both varying considerably across the geography of northern China, result in significant variations in the sensitivity of milk production. Research results from elsewhere revealed a decline in milk yield of lactating cows and buffaloes during hot–dry and hot–humid seasons due to high temperature and humidity (Upadhyay et al. 2009; Bernabucci et al. 2014; Bertocchi et al. 2014). However, various studies show the hot–dry environment is relatively less harmful than hot–humid (Bouraoui et al. 2002; Aggarwal and Upadhyay 2013; Silanikove and Koluman 2015). Depending upon

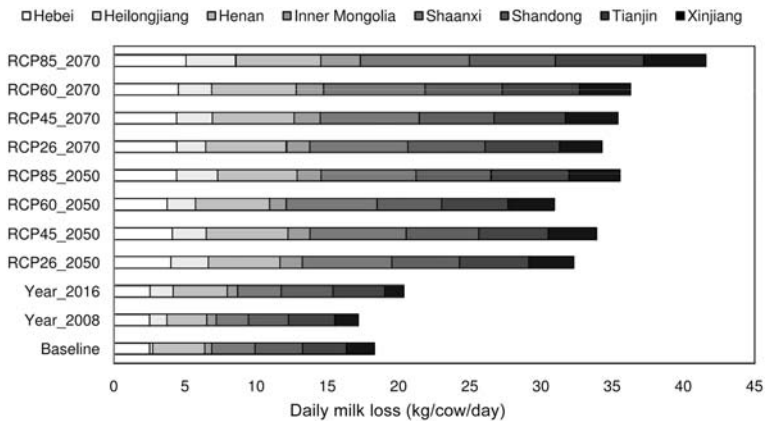


Fig. 7 Estimated daily milk loss (kg/cow/day) for July across northern China in different climatic scenarios

geography, farm-specific climates can affect the quantity of milk produced by a cow (Allore et al. 1997; Yano et al. 2014; Pragna et al. 2016). Typically cow breeds that produce high quantities of milk are more heat sensitive, and as temperatures increase, their milk production decreases. Extreme weather events place even more stress on cows, negatively affecting cow performance particularly through reduced feed intake and milk yield (Aggarwal and Upadhyay 2013; Pragna et al. 2016; Wildridge et al. 2018), an effect that we could not factor into this analysis. What we could show, however, is that already at the current moment, there are indications that milk production levels in northern China are leveling off, and analyses indicate that one of the key causes of this saturation is the negative heat stress effects on milk productivity.

The increasing concern with the thermal comfort of milk cows is realistic not only for the tropics but also for temperate zones where high temperatures are becoming an issue (Nardone et al. 2010). Recently, in temperate zones in Germany, Italy, and the USA, heat stress has been identified as a major factor that negatively affects milk production, reproduction, and the health of dairy cows (Bruegemann et al. 2012; Bernabucci et al. 2014; Bertocchi et al. 2014; Silanikove and Koloman 2015). Two direct causes of body temperature rise that can lead to heat stress problems were identified: (1) metabolic heat production increases with high milk yield and (2) changes in the global climate (Hansen 2007).

Our model identifies areas where milking cows might be susceptible to heat stress. We found that during summer months, THI exceeded the value of 72 every year, a value that is considered a threshold for heat stress (St-Pierre et al. 2003; Dunn et al. 2014). The fuzzy suitability maps generated in this work provide additional information based on livestock and THI distribution across space, and they are useful to inform concerned stakeholders regarding climatic threats. The results from fuzzy models were demonstrated to be not only robust (Hall et al. 1992; Qiu et al. 2014; Ranjitkar et al. 2016) but also useful in land use planning, meteorological applications, and decision-making (Mesgari et al. 2008; Hattab et al. 2013; Berhanu et al. 2016).

According to our results, milking cows were likely to experience heat stress in several important milk-producing areas. With predicted rises in air temperature as shown in one of the IPCC5 scenarios for 2050 and 2070, cattle in these areas will be exposed to even higher levels of heat stress. These areas might, therefore, become unsuitable for sustainable livestock production in the future. However, uncertainties are always a part of such climate prediction

modeling. Still, the predicted decreases in milk productivity, and thereby total milk production, are substantial. Current production is likely to decline somewhere between 12 and 47% by 2050 and between 17 and 52% by 2070 across the different RCP scenarios.

Although spatial analysis revealed large changes in THI values across the simulated 50-year timespan and the earlier mentioned increases in milk production losses, the results for the collection centers did show significant variations. In this context, it is important to discuss changes in the management system of the dairy sector in China. Smallholder milk producers have generally left the sector because of management issues affecting their profitability and efficiency problems (DAH and NAHS 2018). To address these issues, the Chinese Government has issued regulations for promoting the revitalization of the dairy industry. All promoted management efforts are supposed to increase the productivity and efficiency of milk production. However, our data, as well as national data, show a significant decline in milk production in most provinces during the period of 2008–2016. Providing more facilities to increase investment in the dairy sector resulted in livestock production in China becoming more dependent on feed imports (Bai et al. 2018b). Overfeeding concentrated diets that are low in fiber to increase intake of energy and increase milk production increase the risk of subacute ruminal acidosis (SARA) (Abdela 2016). High temperature (and heat stress) increases cow's metabolism up to 25%, leading the body to enter a state of negative energy balance that further damages animal health and welfare and could further lower rumen pH in dairy cows, also increasing the possibility of SARA and inflammation, such as mastitis (Baumgard and Rhoads 2012; Gao et al. 2017). Heat stress directly alters and impairs various tissues or organs of the reproductive system in both sexes of the animal, leading to poor reproduction (Polsky and von Keyserlingk 2017). Due to multiple effects on dairy animals, heat stress could compromise animals' feed intake, milk production, composition, and reproductive efficiency, ultimately reducing profitability for dairy farmers and potentially further imposing a significant economic burden on the existing livestock production system (Aggarwal and Upadhyay 2013) by increasing management costs. This could have significant ramifications for the global dairy market. If the increase in Chinese domestic demand continues its current pace, imports could grow significantly. It is therefore imperative that the Chinese Government takes into account the potential negative effects of climate change on milk productions in its policies aiming to strengthen the national dairy industry.

It is important to understand where heat stress could have the biggest impacts in order to try to mitigate the consequential decline in milk production. Regulations for promoting the revitalization of the dairy industry could consider relocating existing farms and better plan where new major dairy farm establishment should operate. Factors to include in such planning are (1) low THI values; (2) feed availability, especially high-quality local forages, like alfalfa and corn silage; (3) water availability; (4) land availability to produce the high-quality forages, as well as recycle the manure (integrated crop–livestock approach); and (5) farming scale. An “ideal farm” is one that can utilize local resources without environmental and economic burden. In addition, timed artificial insemination (TAI) is also a useful way to mitigate heat stress issues (Dash et al. 2016). Practically, in order to avoid the heat stress-related reduction in milk production in summer, the farmer can shift the reproduction cycle of cows through TAI. However, tradeoffs of applying TAI on a large scale in China include (1) a general shortage of milk supply in the summer, which would increase milk prices across the country during this period and (2) a surplus of milk supply in winter and spring

that might increase wastage of milk during these months. Such variable milk production is also not preferable from a milk-processing point of view.

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