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Potential climate change effects on warm-season livestock production in the Great Plains

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Abstract Projected production responses were derived for confined swine and beef and for milk-producing dairy cattle based on climate change projections in daily ambient temperature. Milk production from dairy cattle and the number of days to grow swine and beef cattle were simulated. Values were obtained for three central United States transects and three climate scenarios which were based on projected mean daily ambient temperatures associated with a baseline, doubling, and tripling of atmospheric greenhouse gas (CO_2) levels for the period June 1 to October 31. For swine, a slight northwest to southeast gradient is evident. Transect 1 (west side) shows no losses under the doubling scenario and losses up to 22.4% under the tripling scenario. Transect 3 (east side) displays losses of over 70% under the tripling scenario. For beef, positive benefits were simulated in Transect 1 with increasing temperatures, although a northwest to southeast gradient was also evident. For dairy, no positive benefits in milk production were found due to climate effects. Projected production declines ranged from 1% to 7.2%, depending on location. However, ranges in predicted differences were less than those simulated for beef and swine. These simulations suggest regional differences in animal production due

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to climate change will be apparent. For small changes in climate conditions, animals will likely be able to adapt, while larger changes in climate conditions will likely dictate that management strategies be implemented. Exploration of the effects of climate changes on livestock should allow producers to adjust management strategies to reduce potential impact and economic losses due to environmental changes.

1 Introduction

Increased combustion of fossil fuels since the industrial revolution has elevated atmospheric CO_2 levels by about 30% (IPCC 1996). Until the use of alternative energy sources becomes more prevalent, greenhouse gases such as CO_2 are predicted to continue to increase. As a result of these increases in greenhouse gas levels, significant changes in global climate are projected (IPCC 2007). Global-average surface temperature may rise between 2.8°C and 6.4°C with a doubling of the level of atmospheric CO_2 (Meehl et al. 2007). In addition to changes in global-average temperature, modeling results suggest an increased likelihood of extreme heat events and variability in weather patterns (USGCRP 2003; Easterling et al. 2007). An increase of 1.4°C in the mean temperature increases by three times the likelihood of an event of five or more days with temperatures greater than 35°C in the United States Corn Belt (Mearns et al. 1984). Climate change, whether the result of natural variation or anthropogenic activities, will impact agricultural production throughout the world.

Potential direct and indirect impacts of climate change on livestock production have not been thoroughly explored. In the United States, changes in cropping systems and range/forage plant availability and quality, which affects animal production through changes in feed supplies, have been the primary focus of previous studies (McGregor 1993; Easterling et al. 1993; Ehleringer et al. 2002; Morgan et al. 2008). Analyses of direct impacts of climate change on livestock production are few. Projections based on early global change models found that changes in climate would directly lead to reductions in summer season milk production and conception rates in dairy cows in the United States (Klinedinst et al. 1993; Hahn et al. 2005). Nienaber and Hahn (2007) indicated that normal animal behavioral, immunological, and physiological functions are all potentially impaired as a result of thermal challenges. Metabolic and digestive function can also be compromised when animals are exposed to thermal stress (Mader 2003).

Voluntary feed intake (VFI) is the primary factor influencing the production capacity of livestock. Weight gain and/or milk output is directly related to the quantity of feed consumed in excess of the feed needed to maintain the animal. Therefore, an accurate prediction of the feed consumption of livestock under heat stress is a precursor to accurate assessment of changes in production resulting from changes to climatic conditions (Mader and Davis 2004). Intake models must also consider other factors that affect VFI. The animal's weight, age, and sex affect its maintenance energy requirements and therefore its VFI (NRC 2000).

The objective of this study was to assess the effects of projected global-warming induced ambient temperature changes on warm season livestock production. In particular, warm-season responses of confined swine, beef cattle and dairy cattle are considered through the use of mathematical models to quantify daily animal response in terms of VFI and projected production to potential changes in climate. For purposes of this study, only effects of ambient temperature are considered since air temperature is considered the most important environmental determinant of production (NRC 1987).

2 Methods

2.1 Animal production–response models

Production/response models for growing swine and beef cattle, and for milk-producing dairy cattle, were developed based on summary information contained in the most recent National Research Council (NRC) publications outlining the nutrient requirements of the respective animals (NRC 1989, 2000, 1998, 2001) and the predicted feed intake of food animals (NRC 1987). The goal in the development of these production/response models was to incorporate input of climate variables, primarily average daily temperature, to generate an estimate of direct, climate-induced changes in daily VFI. Based on daily VFI, estimates of production output (daily body weight gain or daily milk production) can then be determined. Output data from general circulation model (GCM) scenarios, discussed in subsequent sections, served as climate inputs to these models. Details of the animal production models utilized in this analysis are outlined by Frank et al. (2001).

The swine production model is based on animals with a body weight between 20 and 120 kg (NRC 1998). For the purposes of this study, animals were modeled to grow from 50 to 110 kg. The general swine model is based on the NRC (1998) and describes initial voluntary digestible energy (DE) intake as a function of body weight. The swine production model involves a series of concatenated calculations based on the known metabolic processes which influence body weight gain (Fig. 1). Net animal production is thus calculated on a daily basis as a function of VFI as influenced by ambient temperature. In addition, as body weight increases, the ambient temperature at which optimal productivity occurs declines. Algorithms are utilized to quantify the energy required for thermoregulatory and maintenance processes, in addition to the energy required for protein and fat synthesis. The above mentioned algorithms best describe VFI for temperatures between 15°C and 30°C. Additional algorithms were developed to account for the added decline in VFI when ambient temperatures exceed 30°C based on data reported by Nichols et al. (1980).

The beef production model is valid for yearling feeder cattle (male castrates), growing from 350 to 550 kg (NRC 2000). At model initiation, animals were assumed to have average body condition and received an anabolic implant. The beef model (Fig. 2) is designed to predict daily and accumulated weight gain based on the animal's body weight and ambient temperature. The beef model is based on algorithms which account for energy requirements to maintain the animal and for body weight gain based on an animal breed, gender, and previous plane of nutrition. The net effect is to calculate animal weight gain on a daily basis as a function of bodyweight and thermal conditions on that day.

In the dairy production model a 600 kg cow with an average daily 4% milkfat milk production of 30 kg provides the baseline daily VFI (NRC 1989). Adjustments to this daily VFI were made to account for the effects of temperature based on algorithms

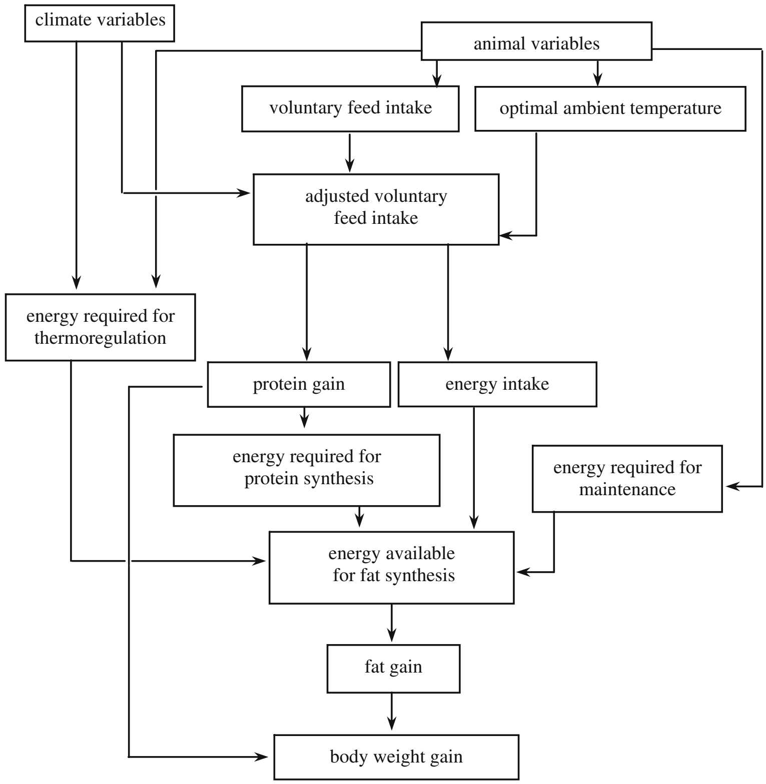

Fig. 1 Conceptual model for development of mathematical swine production/response model

from Fox and Tylutki (1998). Although this model does account for effects of relative humidity, wind speed, and hours of sunlight, these variables were kept constant since GCM databases for predicting these variables are not as prevalent and possibly not as valid as temperature predictions. Figure 2 is a flow chart that summarizes the steps involved in the mathematical modeling of biometeorological effects on milk production. The dairy model provided by Fox and Tylutki (1998) also includes VFI corrections for night cooling associated with the stress of high daytime ambient temperatures. For purposes of this analysis, algorithms were based on VFI averaged for night cooling and no night cooling conditions. Milk output was determined from the VFI for the defined temperature and cow weight based on energy requirements for maintenance and lactation (NRC 1989).

2.2 General circulation models (GCM)

The objective of climate modeling is to simulate the processes and predict the effects of imposed changes (forcings) and internal interactions of the climate system (Henderson-Sellers and McGuffie 1997). Global circulation models of differing origin make slightly different underlying assumptions about the interactions within the system. These assumptions lead to outputs that are dissimilar among the models.

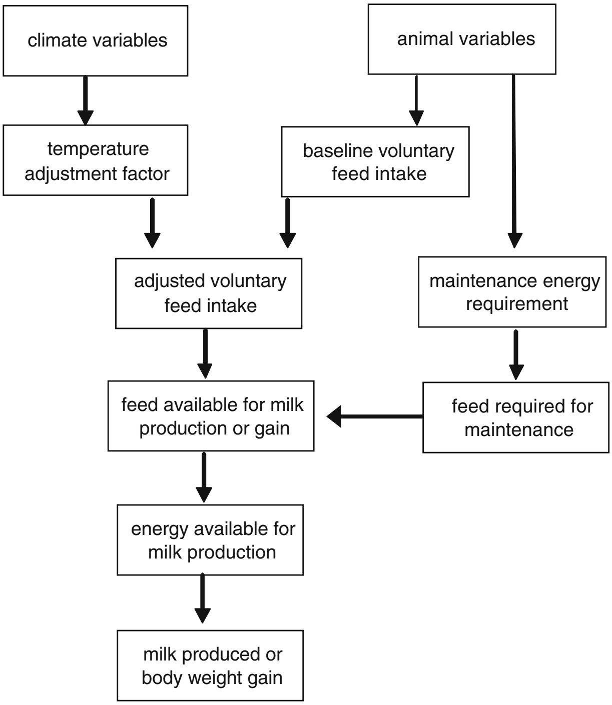

Fig. 2 Conceptual model for development of mathematical beef and dairy production/response model

Thus, this study employs the output of two GCM, the Canadian Global Coupled Model, Version I (CGCMI), and the United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research (Hadley) model, for input to the livestock production/response models. These two models yield predictions about future climatic conditions. For example, both models predict increasing temperatures in the future, but the CGCMI model estimates a more rapid increase (USGCRP 2003). The production response models were run for each climate model with one current and two future climate scenarios: approximating increases in ambient temperature which would be associated with a doubling and tripling of atmospheric CO_2 levels.

The greenhouse gas forcing employed by the CGCMI and the Hadley models correspond approximately to the levels observed from 1850 to 1985 (baseline), and a level representative of an increase of CO_2 at a rate of 1% per year from the present to the year 2100 (CCCMA 2000c). The CO_2 level over the period 2040 to 2060 is therefore representative of an approximate doubling of the baseline level, and an approximate tripling for 2080 to 2100 (CCCMA 2000c). Corresponding temperature changes were projected to average between 1.0°C and 2.0°C and between 2.0°C and 4.0°C for doubling and tripling of CO_2 levels, respectively. Although, regional differences existed between models, these models were selected due to range in temperatures projected. In general, the Hadley model predicts a smaller change in global temperatures than the CGCMI model. The 24-h average temperature (in degrees Celsius) at a height of 2 m is directly available for the CGCMI scenarios (CCCMA 2000a), and serve as input for the livestock models. Additionally, for the dairy model the 24-h average specific humidity and 10-m height wind speed were fixed and determined to be 65% and 3 m/s, respectively. The CGCMI data are available on 3.7° grids, in the central United States (CCCMA 2000b).

Instead of actual values for the climate variables, the Hadley model provides monthly coefficients that indicate the degree of change from the baseline climate. These Hadley change coefficients were used to modify the daily data from the baseline period. Again, the 24-h average ambient temperature at the 2 m height, 24-h average specific humidity, and average 10-m wind speed provide the climate data necessary for input to the livestock production/response models. The Hadley model data are available for the same grid as the CGCMI. For livestock modeling purposes, specific humidity and wind speed were assumed to be similar among GCM. This facilitates comparison of the production/response model output. Although humidity and wind speed are known to influence animal productivity, the magnitude of the effects of these variables on productivity is not as well documented as the effects of ambient temperature on productivity (Mader et al. 2006). In addition, confidence in regional simulation of these variables was not as high as the confidence in the ambient temperature simulations, therefore, only values simulated for temperature were utilized in the production models. In general increases in wind velocity will enhance summer-time animal productivity, while increases in humidity and/or precipitation will decrease productivity unless it is accompanied by lower ambient temperatures.

To assess the effects of predicted environmental changes on livestock production in the United States, three north–south transects (five grid points each) across the central United States were utilized (Fig. 3). Production output data are presented for the five points along each of the three transects in the central United States. These

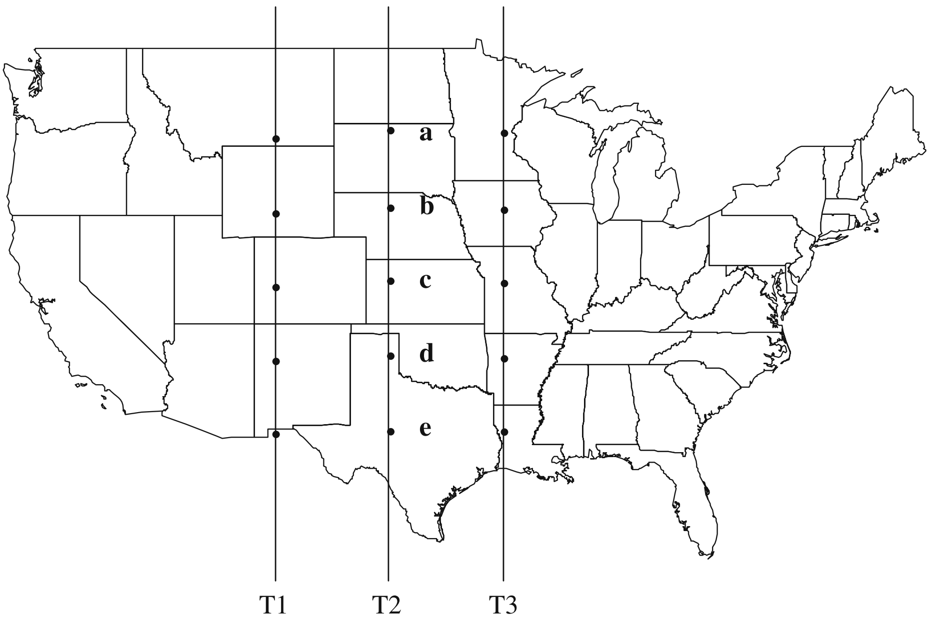

Fig. 3 Points analyzed along three transects in the central United States

points are labeled according to the transect number, T1 (west), T2 (central), T3 (east) and alphabetically from north to south along each transect.

2.3 Model procedures

Input of daily GCM output to the previously described livestock production/response models generated daily production values for each species. Weight gain of beef cattle and swine were calculated daily beginning June 1 and the number of days for the animal to grow to the target weight were determined for each year (climate scenario). For dairy cattle, daily quantities of milk produced (in kilograms) were summed to yield the total production for the season June 1 to October 31.

For each climate scenario, beef and swine production were simulated and reported as a change in number of days for the animal to reach the target weight. Swine generally reached the final weight early in the study period (July or early August) but beef cattle required more time to reach final weight and in a few cases required the entire study period to reach the target weight (October 31 or 153 days). Dairy production projections were developed in the form of change in kilograms of milk produced per cow for the June 1 to October 31 season.

3 Results

In general, the CGCMI predicts an increase in average daily temperature, a slight decrease in precipitation, little change in humidity, and a slight reduction in wind speed over the baseline period (CCCMA 2000c). The Hadley model also predicts an increase in summer temperature, but suggests a more pronounced decrease in summer precipitation over the region (NCAR 2000). For the transects utilized, an increase in temperature is predicted by CGCMI over the baseline for the extreme southern and central parts of the region. The Hadley model suggests increased summertime temperatures on the average in the northern parts of the region but when compared with the CGCMI, less severe changes in temperature in the south are predicted.

3.1 Swine

The CGCMI scenarios predict a small but beneficial change (0% to −3.3%) in the number of days to grow swine for Transect 1 in the CO_2 doubling scenario and even more benefits (−4.9% to −6.5%) from CO_2 tripling in the northern regions (Table 1). At the southernmost point, the time required to grow swine was drastically increased with the CO_2 tripling scenario (22.4%). Similar trends, but more pronounced losses in production time, are noted for Transects 2 and 3. In general, benefits to climate change were simulated in all cases at the northernmost points. At southern points, greater production losses are found, although the magnitude of the percent increase in production days vary. At transects 2 and 3, the greatest losses occurred at the southernmost point or directly above the southernmost points for both climate change scenarios. A west to east production gradient is also evident with greater losses in the east. Producers face increases in time to slaughter weight as large as 74.1% in eastern parts of the region under the CGCMI CO_2 tripling scenario.

Table 1 Projected percent change in days for swine to grow from 50 to 110 kg beginning June 1 for the central United States for CGCMI and Hadley general circulation models and CO_2 doubling and CO_2 tripling scenarios

Region	T1			T2			T3		
	Change in days, %			Change in days, %			Change in days, %		
	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2
CGCMI									
A	62	−3.2	−6.5	60	−3.3	−5.0	59	−1.7	−1.7
B	61	−3.3	−4.9	59	−3.4	−1.7	59	1.7	16.9
C	60	−3.3	−5.0	58	−1.7	12.1	70	24.3	72.9
D	58	−1.7	1.7	59	5.1	45.8	81	29.6	74.1
E	58	0.0	22.4	61	1.6	36.1	79	19.0	68.4
Hadley									
A	62	0.0	0.0	60	0.0	−1.7	59	0.0	1.7
B	61	−1.6	1.6	59	−1.7	−1.7	59	1.7	11.9
C	60	−1.7	0.0	58	−1.7	3.4	70	9.1	15.7
D	58	−1.7	3.4	59	1.7	13.6	81	13.6	29.7
E	58	0.0	8.6	61	1.6	16.4	79	25.3	40.5

T1, T2, and T3 represent west, central and east transects, respectively, running north and south within the central United States. Regions represent locations along transects in which production output was determined (Fig. 3)

CGCMI Canadian Global Coupled Model, Version I, *Hadley* United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research model

The Hadley scenarios predict a lower magnitude of production change than the CGCMI model (Table 1). A slight northwest to southeast gradient is also evident, however, in this model the southern-most points are impacted the greatest. Transect 1 shows no losses under the Hadley CO_2 doubling scenario and minimal losses under the CO_2 tripling scenario except for the most southern locations. Transect 3 displays losses of up to 40.5% under the Hadley CO_2 tripling scenario.

3.2 Beef

Under the CGCMI scenarios, when CO_2 levels were increased, positive benefits were simulated only in Transects 1 and 2, although the northwest to southeast gradient which was simulated for swine is still somewhat evident (Table 2). In Transect 1, the greatest change in days to grow the animal occurred in the southernmost region with the CO_2 levels tripling. However, in Transects 2 and 3, the greatest increases in percent of days to grow are in the middle latitudes which is somewhat different than what was simulated for swine. This may be attributed to differences in temperature occurring later in the season. Swine will mature to market weight earlier in the season and will be affected by temperature gradients occurring in June and July, whereas beef cattle will still be in the growth process later in the season and changing temperature gradients projected for August and September may have a slightly different effect on beef production levels in the various regions. Overall, the magnitude of change was not as great with beef as it was with swine. However, there were not as many benefits derived from climate change in the northern regions in beef production when compared with swine production. For all transects and scenarios, percent change in days required for growth was increased with the Hadley

Table 2 Projected percent change in days for beef cattle to grow from 350 to 550 kg beginning June 1 for the central United States for CGCMI and Hadley general circulation models and CO_2 doubling and CO_2 tripling scenarios

Region	T1			T2			T3		
	Change in days, %			Change in days, %			Change in days, %		
	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2
CGCMI									
A	125	−0.8	−2.4	123	−0.8	0.0	122	0.8	3.3
B	125	−1.6	−2.4	122	0.8	3.3	126	3.2	9.5
C	123	−0.8	−0.8	122	1.6	10.7	138	8.0	10.1
D	121	0.8	4.1	126	4.0	15.9	144	6.3	6.3
E	124	0.8	9.7	128	0.8	12.5	143	5.6	6.9
Hadley									
A	125	2.4	4.0	123	2.4	4.1	122	2.5	3.3
B	125	2.4	4.0	122	2.5	4.1	126	2.4	4.0
C	123	1.6	4.1	122	1.6	4.1	138	2.2	4.3
D	121	1.7	3.3	126	0.8	3.2	144	1.4	3.5
E	124	1.6	3.2	128	0.8	3.1	143	1.4	3.5

T1, T2, and T3 represent west, central and east transects, respectively, running north and south within the central United States Regions represent locations along transects in which production output was determined (Fig. 3)

CGCMI Canadian Global Coupled Model, Version I, *Hadley* United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research model

model (Table 2). In general, the increase was greater in the northern region, but the overall changes were less than 5%.

3.3 Dairy

CGCMI scenarios project production losses throughout the central United States, but without a well defined geographical pattern. The percent change in milk production based on the CGCMI model was slightly greater than the Hadley model (Table 3). As opposed to the beef and swine projections, no benefits in milk production were found due to projected climate change. Differences among transects were also much less. No strong gradient is evident in the three transects. Season length may also be a factor in this calculation. The June to October study period may exclude warm days in May that would adversely affect production and include cool days in October that will have little effect. The pattern simulated could also be indicative of changes in warm season length under modeled climates and not necessarily a response to changes in temperatures of the warm season. On the average, the Hadley scenarios project slightly lower production declines than the CGCMI model. However, relative differences between the models were less than those simulated for beef and swine.

4 Discussion

Predicted impacts of global warming on livestock (primarily dairy cattle) in the United States have been previously evaluated by Hahn et al. (1992) and Klinedinst

Table 3 Percent change in milk production totals (in kilograms) per cow over the June 1 to October 31season for the central United States for CGCMI and Hadley general circulation models and CO_2 doubling and CO_2 tripling scenarios

Region	T1			T2			T3		
	Change in production, %			Change in production, %			Change in production, %		
	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2	Baseline	2x CO_2	3x CO_2
CGCMI									
A	4,957.5	−2.5	−6.4	4,945.2	−2.2	−6.6	5,000.3	−1.8	−6.2
B	4,906.8	−2.3	−7.0	5,222.8	−2.1	−5.1	5,057.8	−2.7	−6.7
C	4,589.8	−1.9	−6.7	4,596.9	−1.2	−5.2	4,741.7	−2.5	−6.8
D	4,462.3	−2.5	−7.5	4,797.4	−1.0	−3.3	4,881.8	−1.7	−5.8
E	4,459.6	−1.5	−5.5	4,496.6	−2.2	−6.4	4,454.4	−2.4	−7.2
Hadley									
A	4,957.5	−3.0	−4.8	4,945.2	−2.9	−4.5	4,798.3	−3.1	−4.0
B	4,906.8	−3.0	−4.7	5,222.8	−3.1	−4.7	4,834.3	−3.1	−4.4
C	4,589.8	−2.4	−4.3	4,596.9	−2.4	−4.4	4,529.8	−2.9	−4.5
D	4,462.3	−1.8	−3.8	4,797.4	−1.4	−3.9	4,679.7	−2.2	−4.1
E	4,459.6	−1.8	−3.8	4,496.6	−1.3	−3.9	4,272.6	−2.1	−4.1

T1, T2, and T3 represent west, central and east transects, respectively, running north and south within the central United States Regions represent locations along transects in which production output was determined (Fig. 3)

CGCMI Canadian Global Coupled Model, Version I, *Hadley* United Kingdom Meteorological Office/Hadley Center for Climate Prediction and Research model

et al. (1993). Based on a summary of these data and using GCM scenarios, projected declines in summer-season total milk production would be as much as 16–30% in southern areas compared with normally-expected declines of 11–16% for the same locations (Hahn and Morgan 1999). These declines in production are slightly greater but still in close agreement with those predicted with data presented herein. Hahn et al. (1992) conducted a further analysis of milk production during successive 10-month lactation periods for cows in the Memphis, Tennessee area comparing declines in seasonal normal periods with those estimated for global warming (GISS scenario) conditions. The smallest effect of global warming was predicted for lactations which begin in the months from July through October (219 kg/cow additional decline), while the largest effect (500 kg/cow decline) occurred in lactations which begin in the months of December, January, February, March, April, and May. These production declines resulting from global warming, while only 2.2% and 5.0% of total production under ideal conditions, would have a noticeable impact on profitability of the dairy enterprise.

Because decreased conception rate results in fewer cows producing milk, and therefore decreased milk production, an analysis of conception rates for dairy cows predicted substantial declines in conception rates under global warming conditions in many locations, particularly the eastern and southern United States (Hahn et al. 1992). Conception rate for the summer season under global warming conditions was 36% lower than under normal summer conditions in the southeastern United States. Response functions for beef cattle and swine performance parameters are not as well defined in the literature as they are for dairy cattle. Amundson et al. (2006) reported that minimum daily temperature was the environmental variable that has the closest relationship to pregnancy rate in beef cattle; however, Amundson et al.

(2006) found that under current central United States weather conditions, cattle do adapt to changing climatic conditions if provided sufficient time.

Data reported in the current study would be indicative of the magnitude of the potential negative effects of climate change as measured during the summer season. Certainly a portion of these negative effects would be offset by enhanced production where global warming produced milder winter conditions. Therefore, projections are needed for year-round animal production. Relationships between temperature and feed intake under both cold and hot environmental conditions have been defined (Mader 2003). Also, the relative effects of wind speed, humidity, and solar radiation on feed intake and predicted animal output are needed as more reliable models become available (Mader et al. 2006).

In general, these data suggest that the greater negative impacts of climate change occur in eastern and/or southern regions of the central United States. However, baseline data for all species indicate that southern regions were already negatively affected by elevated temperatures. Swine, and possibly beef, production appears to show the greatest declines in production when comparing west vs east transects. The data also suggest that positive benefits of climate change may be realized in northern regions of the United States.

For the warm season in the United States (June 1 to October 31), projected changes in climate induced by increasing greenhouse gas levels, primarily manifested as increases in air temperature, will reduce milk production levels in the central United States unless counter-acting measures are taken by producers. Conversely, swine producers in northern areas may experience some benefit to climate effects, however, in southern regions the time required for swine to reach market weights could increase up to 74%. Beef producers, potentially, would need to feed cattle up to 16% longer, however average increases of 4% to 5% would likely be more common. If mitigation strategies were not incorporated into livestock systems, projected economic losses resulting from temperature-induced reductions in production would be significant. Mitigation of these temperature increases through changes in management practices, such as installation of shades, sprinklers, or evaporative cooling devices may be warranted depending on region and the nature of the climate change. Most domestic livestock can easily adapt to small changes in ambient temperature. However, changes in ambient temperature of more than 1°C or 2°C, or an increase in adverse heat events, may require other interventions aside from facility modifications, including changes in herd genetic base and possibly production output expectations.

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