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The Potential Effects of Climate Change on Summer Season Dairy Cattle Milk Production and Reproduction

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Abstract

The potential direct effects of possible global warming on summer season dairy production and reproduction were evaluated for the United States and Europe. Algorithms used for milk production and conception rate were previously developed and validated. Three widely known global circulation models (GISS, GFDL, and UKMO) were used to represent possible scenarios of future climate. Milk production and conception rate declines were highest under the UKMO model scenario and lowest under the GISS model scenario. Predicted declines for the GCM scenarios are generally higher than either "1 year in 10" probability-based declines or declines based on the abnormally hot summer of 1980 in the United States. The greatest declines (about 10% for the GISS and GFDL scenarios, and about 20% for the UKMO scenario) in the United States are predicted to occur in the Southeast and the Southwest. Substantial declines (up to 35%) in conception rates were also predicted in many

locations, particularly the eastern and southern United States. These areas correspond to areas of high dairy cattle concentration. They already have relatively large summer season milk production declines resulting from normally hot conditions. Thus, the actual impacts of increased production declines may be greater in other areas, which are not accustomed to large summer season declines and therefore may require more extensive mitigation measures.

1. Introduction

The impacts of global warming may be felt in a wide variety of social, economic, and environmental sectors, including coastal infrastructure, marine life, water resources, energy usage, human health, forestry, rangeland ecosystems, crop production, and livestock production (Smith and Tirpak, 1989). In recent years, considerable research has been directed at a preliminary assessment of the potential impacts of climate change on most of these sectors. However, the potential impact of climate change on livestock has not been adequately assessed; only a few studies have been conducted. A study in the early 1970s (Johnson et al., 1975) examined the potential effects on livestock of global cooling resulting from the advent of stratospheric flight. Another study conducted at the Tufts University School of Veterinary Medicine (Stem et al., 1988) examined potential changes in livestock disease patterns due to projected global warming, and found the potential for an increased incidence of animal disease under global warming because of more favorable host environments and the movement of people and animals caused by environmental and climatic changes. Another assessment of the potential effects of climate change on livestock was made at a workshop on climate change impacts sponsored by the National Climate Program Office (Paltridge, 1989). The workshop results predicted a net increase in production costs of less than 1% for livestock in extensive production systems, and an increase of 1 to 3% for intensive production systems, such as dairying. Hahn (1990) has also reported on the potential effects of climate change on livestock, and has done preliminary work with animal biological response functions to quantify these impacts.

The primary objective of the study reported here was to determine the direct effects of projected global warming on summer season (defined as May 1 to September 30) milk production in dairy cattle in the United States and Europe. The impacts on dairy cow conception rates in the United States and Europe also were evaluated. Indirect effects of global warming (e.g., impacts on feed and water availability and quality, disease patterns, etc.) on dairy production and reproduction were not examined. It should also be noted that during the winter, global warming may have beneficial consequences, such as reduced feed, fuel, and ventilation costs, which may counter to some degree the negative impacts experienced during the summer. The study is enhanced by available models relating heat stress to declines in milk production and conception rate. The dairy cattle environment, and thus the ability of cattle to adapt to changing climate, is highly influenced by the actions of the producer because dairy cattle are generally kept in intensive production systems. Producers would benefit from knowing the possible magnitude of milk production and conception rate declines due to global warming in order to assess the economic feasibility of genetic adjustments, environmental modifications, or other actions.

2. Materials and Methods

Extensive research has been conducted on the effects of climatic factors, especially high temperatures, on livestock (Yousef, 1985). For some species, especially dairy cattle, well-developed and tested biological response functions exist to quantify the effects of hot weather stress on animal productivity. Berry et al. (1964) developed a quantitative relationship between declines in dairy cow milk production at various normal levels of production (NL, kg/cow/day) and the Temperature-Humidity Index (THI),¹ which incorporates the effects of air temperature and humidity for a range of $70 \leq \text{THI} \leq 84$:

$$\text{MPD} = -1.075 - 1.736 \text{ NL} + 0.02474 \text{ NL (THI)} \quad (1)$$

where

$$\text{MPD} = \text{absolute decline in milk production (kg/cow/day)}.$$

This model was developed for animals provided with shade but no other heat relief measures. The model has been tested and shown to compare favorably with field results (Hahn, 1969). Hahn and Osburn (1969; 1970) used the algorithm of Berry et al., (1964) to study the economic feasibility of environmental modification for dairy cattle in the summer season. A model relating conception rate (defined in terms of the delivery of a live calf) in dairy cattle to THI also exists (Ingraham, 1974; Hahn, 1981a):

$$\text{CR} = 388.3 - 4.62 \text{ THI} \quad (2)$$

where

$$\text{CR} = \text{conception rate (\% in terms of delivered calf)}.$$

However, this model is not as well tested as the milk production model.

Equation 1 was used to evaluate declines in milk production for two levels of production (23 and 33 kg/cow/day) under normal summer conditions and under predicted global warming summer conditions. The difference between declines under the two conditions was also evaluated. The selected production levels represent normal levels for moderate- and high-producing cows, respectively.

To evaluate declines for normal summer conditions, long-term average monthly dry bulb and dew point temperatures for May through September, inclusive, were obtained from the World WeatherDisc (WWD).² WWD is a meteorological data base containing 17 data sets acquired from the archives of the National Climate Data Center, National Center for Atmospheric Research, and other sources, including foreign publications. The data for this study were taken from the World Wide Airfield Summaries (WWAS) data set on WWD. This data set contains climatological data for 5,717 airport locations around the world. The period of record for this data set is variable, but all data are pre-1974. The record length varies from 5 to 73 years. The monthly average dew point temperature was taken directly from WWAS data. The monthly average dry bulb temperature was obtained by averaging the monthly average high and low temperatures from WWAS.

To represent global warming summer conditions, the temperature increases predicted by three Global Circulation Models (GCMs) [GISS (Goddard Institute for Space Studies),

GFDL (Geophysical Fluid Dynamics Laboratory), and UKMO (United Kingdom Meteorological Office)], were added to the average monthly temperature values from WWAS. This procedure was chosen, rather than using the GCMs' prediction of temperature under global warming ($2 \times \text{CO}_2$) conditions, because this estimate of the future climate is not directly comparable to current climate. This method has also been used by other researchers in studying crop yield under global warming conditions (Jenne, 1989).

The GCM data were obtained from the Data Support Section of the National Center for Atmospheric Research in July 1990. The data consisted of each GCM's temperature prediction for: (1) current climate ($1 \times \text{CO}_2$); (2) doubled CO_2 climate ($2 \times \text{CO}_2$); (3) and the temperature increase (i.e., the difference between (1) and (2)). All values are reported on a monthly basis. The current climate is represented by the model's temperature prediction with an atmospheric CO_2 concentration valid sometime before 1970. The concentration used varies between models (315 ppm for GISS, 300 ppm for GFDL, and 320 ppm for UKMO), as discussed by Jenne (1989; 1990). These differences in the concentration of atmospheric CO_2 are probably not significant since the models are individually tuned to adequately simulate the present climate (Jenne, 1989). The doubled CO_2 climate is the model's prediction of temperature with a one-step increase to a doubled atmospheric concentration of CO_2 (i.e., 630 ppm for GISS, 600 ppm for GFDL, and 640 ppm for UKMO).

In selecting the GCM grid points, two criteria were used. The grid point itself had to be on land and the grid box surrounding the grid point could not contain more than 40% ocean. These criteria resulted in 10 grid points for GISS, 27 grid points for GFDL, and 25 grid points for UKMO within the continental United States.

Stations from WWAS were chosen to be as close to the grid points for the Global Circulation Models (GCMs) as possible. The average distance from the GCM grid point to the WWAS station was 70.7 km. The maximum distance between the GCM grid point and the WWAS station was 183.7 km. Four of the WWAS stations chosen did not report dew point data. In these cases, the chosen station was used to obtain the dry bulb temperature, and the next closest station with dew point data was used to obtain the dew point temperature. The error resulting from this should be small since dew point temperature, especially the long-term monthly average value, is a conservative measure that does not change rapidly with distance.

The temperature data obtained from WWAS and the outputs of the GCMs were used to calculate the THI used as an input for the milk production decline model. To obtain the dew point temperature for the THI equation under global warming conditions, three scenarios were considered in order to represent the range of atmospheric moisture conditions predicted for a $2 \times \text{CO}_2$ climate by the GCMs. In the first scenario, a 0.36°C increase in dew point temperature for every 1°C increase in dry bulb temperature was assumed to reflect a more moist atmosphere associated with increased precipitation. This scenario was also used during a National Climate Program Office workshop on the impacts of climate change (Paltridge, 1989) as a convenient approach based on the relationship between dry bulb and dew point temperature in the THI equation. In the second scenario, the dew point temperature was held constant. In the final scenario, the dew point temperature was decreased by 0.36°C for every 1°C increase in the dry bulb temperature to reflect a drier atmosphere associated with decreased precipitation. The first scenario predicted the greatest

declines, since high humidity has a negative effect on milk production under hot conditions. Results from the first scenario were selected for detailed analysis in this article.

Earlier applications of climatological data to equation 1 (Hahn and Osburn, 1969; 1970; Johnson et al., 1975) used daily mean THI values in the milk production decline equation, which is the basis on which the equation was developed. Monthly mean THI values, as used in this study, can introduce some error (Hahn, 1971), but are acceptable for estimating the impacts of global change using GCMs at their current resolution and stage of development. The milk production decline in this study is still predicted on a daily basis, but what it really represents is a daily average for the entire month and not a true daily value. To obtain the total monthly milk production decline (kg/cow), the daily value for each month is simply multiplied by the number of days in the month.

The results from the milk production decline model at some grid points were negative, indicating an increase in milk production over the base level. Such results were defaulted to zero (i.e., no change from normal level) as the empirical model was not validated to project increases in milk production. This occurred at grid points where the temperature and/or humidity were lower than the temperature and humidity used to define the base level in the model. Berry et al. (1964) defined the base level as the normal level of production when the dry bulb temperature is between 10 and 18°C. Humidity was found to have a negligible effect on milk production at temperatures below 25°C (Berry et al., 1964).

The output from the milk production decline model was summed over the season (May 1 to September 30) to give the season total milk production decline from normal levels in kilograms per cow (Hahn and McQuigg, 1970). The decline under normal conditions, the decline under global warming conditions, and the difference between the two were analyzed for each of the GCMs. The difference between the decline under normal and global warming conditions will be discussed in detail. These results were used to create maps with isolines showing declines in milk production for each of the GCMs.

Equation 2 was used to evaluate the additional decline in conception rate in dairy cattle during the summer months which potentially could result from global warming. The methodology used was the same as was used in evaluating milk production decline.

3. Results and Discussion

3.1. Milk Production Decline Results in the United States

The validity of WWAS data was tested by comparing milk production declines predicted from WWAS temperature data with those predicted from long-term climatological data (Table I). Equation 1 was used to predict the milk production declines in both cases, using a 32 kg/day normal production level and a 122-day season (June 1 to September 30). The declines predicted from long-term climatological data are from a study by Hahn (1981b). WWAS data was available for all 11 of the locations used in Hahn's study. Table I shows the seasonal milk production declines (in kg) predicted using Hahn's data and using WWAS data. It also shows the difference between the two values in kilograms and as a percentage of the normal seasonal production. Normal seasonal production is 3904 kilograms (122 days x 32 kg/day). The difference between predictions based on Hahn's data

and on WWAS are relatively small when viewed as a percentage of the total seasonal production. Table I also shows that most predictions based on WWAS are lower than those based on Hahn's long-term climate data. This, coupled with the fact that Hahn's predictions were 4 to 15% lower than actual field declines (Hahn, 1969), shows that our estimate of milk production decline is a conservative one.

Table I. Comparison of seasonal milk production declines predicted using long-term climatological data (from Hahn, 1981b) and declines predicted using WWAS data, based on a 122-day season (June 1 to September 30) and a 32 kg/day normal production level. The difference between Hahn's and WWAS predictions are expressed both in kg/cow/season and as a percentage of the normal seasonal production. Normal seasonal production is $122 \text{ days} \times 32 \text{ kg/day} = 3904 \text{ kg}$.

Location	Milk production decline (kg/cow/season)			
	Hahn	WWAS	Difference (Hahn - WWAS)	
			kg/cow/season	% normal seasonal production
1. Atlanta, GA	197	140	57	1.5%
2. Boise, ID	10	0	10	0.3%
3. Cheyenne, WY	38	0	38	1.0%
4. Columbia, MO	49	71	22	0.6%
5. Dallas, TX	343	465	-122	-3.1%
6. Dayton, OH	87	15	72	1.8%
7. Memphis, TN	191	267	-76	-1.9%
8. Oklahoma City, OK	254	191	63	1.6%
9. Phoenix, AZ	511	472	39	1.0%
10. Sacramento, CA	17	0	17	0.4%
11. Sioux Falls, SD	57	0	57	1.5%

The milk production declines predicted under global warming summer conditions were compared with declines predicted on the basis of summer 1980 weather for nine U.S. locations (Table II). The summer of 1980 was an abnormally hot summer, with most of the United States experiencing temperature departures of 1 to 4°C above normal. The data in Table II for summer 1980 declines are from a study by Hahn (1981b) on the impacts of summer 1980 weather on dairy cow performance, which indicated the 1980 impacts generally exceeded "1 year in 10" probability-based decline values. Table II indicates that the impact of the predicted levels of global warming on milk production could be substantially greater than unusually hot periods (heat waves), which are part of the present climate. One reason for this is the GCM's prediction of an average 3 to 7°C dry bulb temperature increase in the continental United States during the summer. This, combined with the increased humidity scenario used in this study, produces longer term heat stress effects greater than that experienced during unusually hot periods in the present climate.

Table II. Comparison of milk production declines predicted for the summer of 1980 (from Hahn, 1981b) and declines predicted for global warming summer conditions using GCM data. (Different GCMs are used to obtain grid points as close to Hahn's stations as possible.)

Location	Milk production decline (kg/cow/season)		
	Summer 1980	GCM	Difference (GCM – 1980)
1. Atlanta, GA (GFDL)	425	615	190
2. Boise, ID (GFDL)	2	0	–2
3. Cheyenne, WY (GFDL)	0	0	0
4. Columbia, MO (GFDL)	282	395	113
5. Dallas, TX (UKMO)	644	871	227
6. Memphis, TN (GISS)	568	778	210
7. Phoenix, AZ (GFDL)	616	1163	547
8. Sacramento, CA (GFDL)	15	177	162
9. Sioux Falls, SD (GISS)	55	147	92

Maps showing the additional decline in milk production due to global warming (i.e., the difference in the declines under normal and global warming conditions) are presented in figures 1 through 3 for all three GCMs. Two normal levels of milk production, 23 and 33 kg/day, are shown for each GCM.

The model output maps based on GISS data (fig. 1) show a general increase from northwest to southeast in additional production loss due to global warming. The area of greatest decline is in the Southeast, centered on Memphis, Tennessee, for both normal production levels. The maximum decline for the 23 kg/day normal production level is 300 kg/season, which represents 9% of the total seasonal milk production (fig. 1a). At the 33 kg/day normal production level, the decline is 500 kg/season or 8% of the total seasonal milk production (fig. 1b). The GISS maps show less detail, and do not reflect orographic influences and other mesoscale features as well as the maps based on GFDL or UKMO model results.

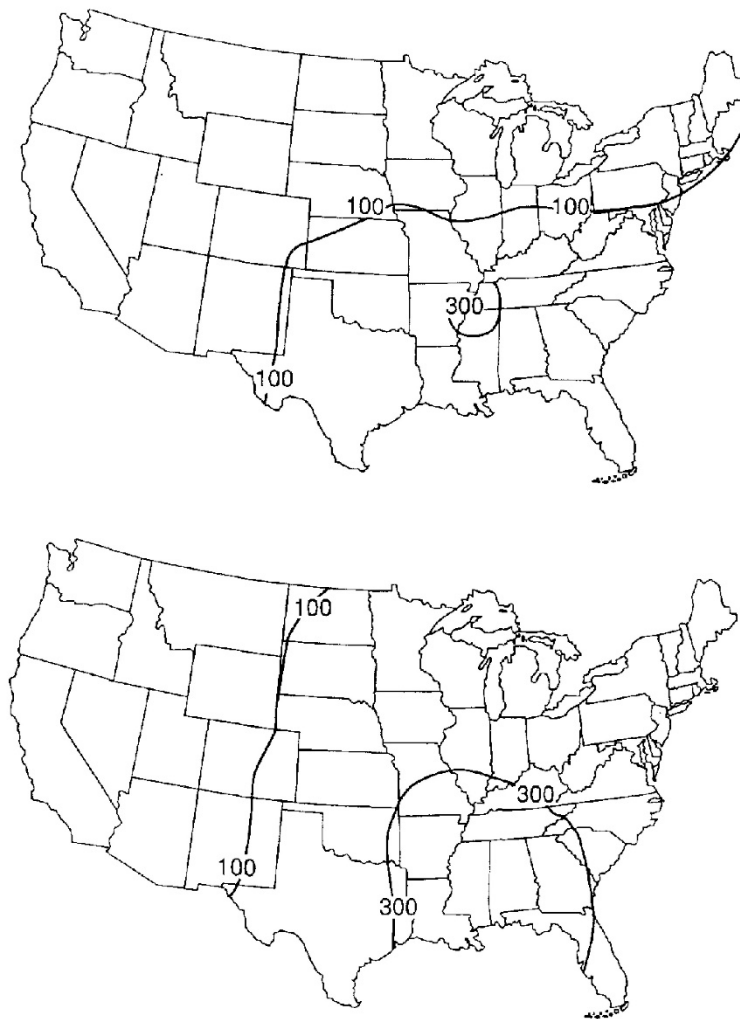


Figure 1. GISS-predicted seasonal (May 1–September 30) milk production declines (kg/cow/season) for two normal levels of milk production (a) 23 kg/day; (b) 33 kg/day under a $2 \times \text{CO}_2 - 1 \times \text{CO}_2$ scenario.

The GFDL output maps (fig. 2) show a general pattern of increasing production loss from north to south. The area of maximum production loss covers most of the extreme southern United States at the 23 kg/day normal production levels (fig. 2a). The maximum decline is 300 kg/season or 9% of the total seasonal production. At the 33 kg/day normal production level, the maximum decline of 700 kg/season or 11% of total seasonal production is predicted to occur in Texas, Louisiana, and Arizona (fig. 2b).

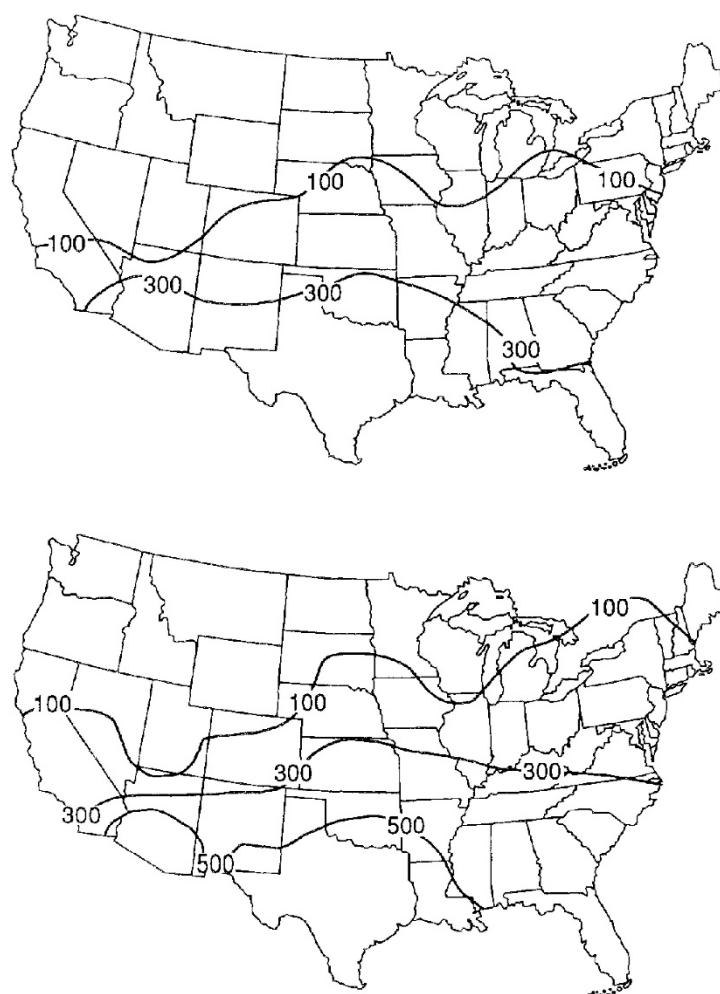


Figure 2. GFDL-predicted seasonal (May 1–September 30) milk production declines (kg/cow/season) for two normal levels of milk production (a) 23 kg/day; (b) 33 kg/day under a $2 \times \text{CO}_2 - 1 \times \text{CO}_2$ scenario.

The general pattern of the isolines on the UKMO output maps (fig. 3) shows an increase from northwest to southeast. The area of maximum decline for both normal production levels is in Alabama. The decline is 700 kg/season or 20% of total season production for the 23 kg/day normal production level (fig. 3a). For the 33 kg/day normal production level, the decline is 1300 kg/season or 20% of the total season production (fig. 3b). The UKMO maps show the largest predicted declines under warming conditions, reflecting the large temperature increase predicted for the Northern Hemisphere under the UKMO global warming scenario.

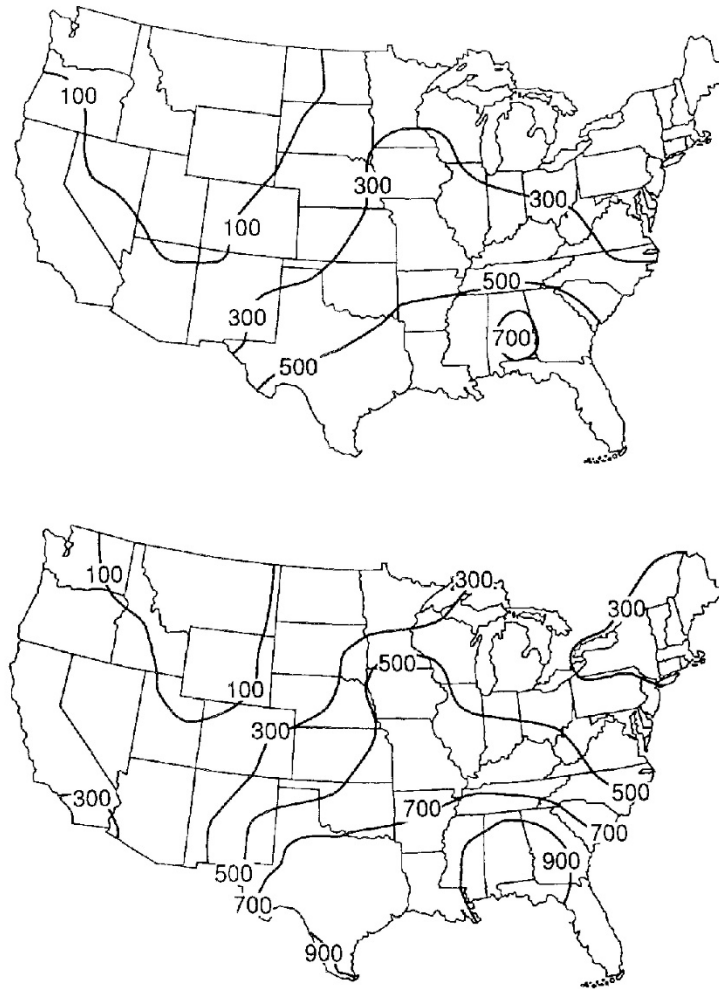


Figure 3. UKMO-predicted seasonal (May 1–September 30) milk production declines (kg/cow/ season) for two normal levels of milk production (a) 23 kg/day; (b) 33 kg/day under a $2 \times \text{CO}_2 - 1 \times \text{CO}_2$ scenario.

To assess the uncertainty in the milk production decline predictions, three types of error were considered: (1) spatial error resulting from the distance between the GCM grid points where temperature changes were predicted and the WWAS stations where average temperatures were compiled for current climate; (2) time error due to the uncertainty about the period of record for the WWAS temperature data sets; and (3) error in the milk production decline model. The milk production decline model was previously compared with field data (Hahn, 1969), and the results showed model predictions to be 4 to 15% lower than the actual declines. An error of +15% of each isoline value was used to account for possible error in the milk production model. The total uncertainty associated with each isoline value, resulting from space, time, and model errors, is shown in Table III.

Table III. Uncertainty in milk production decline isolines

Normal milk production level of 23 kg/day	
Isoline (decline in kg/cow)	Uncertainty (kg/cow)
100	-76 to +91
300	-76 to +121
500	-76 to +151
700	-76 to +181
Normal milk production level of 33 kg/day	
Isoline (decline in kg/cow)	Uncertainty (kg/cow)
100	-110 to +125
300	-110 to +155
500	-110 to +185
700	-110 to +215
900	-110 to +245

The largest milk production declines under global warming conditions are predicted to occur in the southeastern and southwestern United States. These regions contain several pockets of high dairy cattle concentrations (fig. 4). This indicates the potential for a significant impact from global warming on the overall United States dairy industry. For example, under the GFDL scenario with a normal production level of 33 kg/day (fig. 2b), the 500 and 300 kg/cow/season decline isolines cover most of the southeastern and southwestern United States. Multiplying the approximate number of cows within each isoline (US Department of Commerce, 1989) times the seasonal production decline per cow times 80% to represent the approximate percentage of cows milking at any given time (Whittemore, 1980), gives a total of 800 million kg of milk lost per season in this region due to global warming. This represents 49% of the total seasonal loss of milk production in the United States due to global warming under the GFDL scenario.

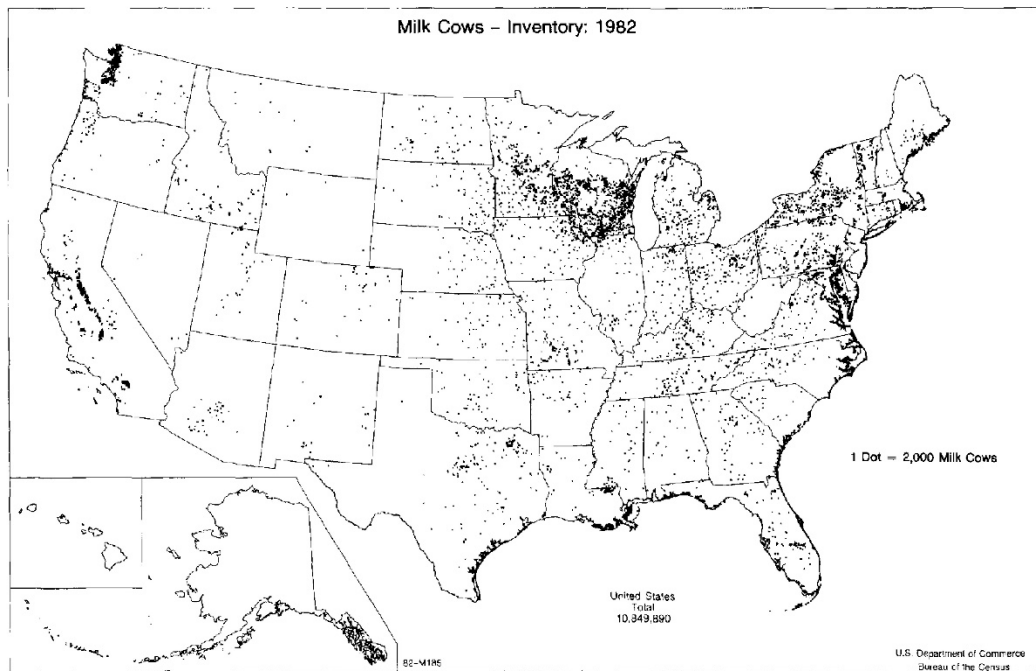


Figure 4. Distribution of dairy cattle in the United States (US Department of Commerce, 1984).

The southeastern and southwestern United States, however, have the potential to experience large summer season milk production declines under the present climate unless adequate environmental modifications, such as evaporative cooling or air conditioning, are used. Because of existing environmental modifications, these areas may be reasonably well prepared to deal with large production declines due to global warming since they already have the facilities and management skills to mitigate production losses resulting from heat stress. Therefore, production declines in the southeastern and southwestern United States may be less than originally predicted after management practices are taken into account.

Regions that usually experience little or no milk production decline due to heat stress, such as the northeastern and upper midwestern United States, are also projected to have notable milk production declines under some global warming scenarios. The declines in these areas will be smaller in magnitude than those in the southeastern and southwestern United States. However, the economic impact on the dairy industry in the northeastern and upper midwestern United States may be more significant since dairy farmers here are not accustomed to dealing with large summer production losses from heat stress and, therefore, have not adopted environmental modifications. Thus, economic losses in these regions would include both production losses and adaptation costs as producers gradually adapt to increased heat stress by developing appropriate management practices or coping strategies.

The importance of adaptations and adjustments by producers is often overlooked when assessing the impact of global warming on agriculture, resulting in an overestimation of

the impacts (Easterling et al., 1989). Hahn (1990) pointed to the importance of animal adaptations and adjustments by livestock producers in determining the actual impact of global warming. These adjustments and adaptations can be simple farm-level changes, or they can be broader institutional-level policy changes. These adaptations are beneficial to the agricultural community as a whole but may involve significant dislocation costs (e.g., moving to a cooler location, applying environmental modification, etc.) for certain livestock producers. Milk production declines predicted under global warming conditions may be reduced further because of the effect of possible adaptation by animals and genetic selection for heat tolerant animals by producers.

Other factors, however, may cause production declines to be greater than predicted by the current model. For example, the probability of extreme high-temperature events (heat waves) will increase as the mean temperature increases (Mearns et al., 1984). For example, a 1.7°C increase in mean temperature (holding variance and autocorrelation constant) will result in the likelihood of the occurrence of five consecutive days with maximum temperatures of at least 35°C being three times greater at some locations (Mearns et al., 1984). An increase in the number of heat waves could significantly increase the negative impacts of global warming, especially on livestock.

Indirect effects of global warming, such as increased disease vectors, may have additional negative impacts on milk production. Other indirect effects, such as longer growing and pasture seasons in northern regions, may buffer the effects of global warming on milk production. Still other indirect effects, such as possible changes in feed quality, and water availability and quality, will have undetermined effects on milk production. Due to their uncertainty and complexity, these indirect effects were outside the scope of this study. Therefore, the reader is cautioned to remember that this study considers only the potential *direct* effects of global warming on milk production.

3.2. Milk Production Decline Results in Europe

Possible milk production losses in Europe due to potential global warming were also analyzed. The results for Europe from all three GCMs showed relatively minor losses. The GISS and GFDL models predicted losses only in southern France, and these losses were less than 100 kg/season at the 33 kg/day normal production level. The UKMO model predicted losses in Spain of 100 kg/season at the 23 kg/day normal production level and 400 kg/season at the 33 kg/day nominal production level. These results indicate that the effect of global warming might be much greater on milk production in the United States than in Europe. However, as discussed above for the northern United States, the effect of the declines in Europe may be greater than the numbers indicate since European dairy farmers are not routinely faced with adverse high temperatures, as discussed in the previous section for the northern United States.

3.3. Conception Rate Decline Results

The potential decline in conception rate resulting from global warming was also analyzed using the model (equation 2) developed by Hahn (1981a) based on the work of Ingraham (1974). The conception rate model results showed substantial declines in conception rates under global warming conditions in many locations, particularly the eastern and southern

United States and also in southern Europe. Conception rate for the summer season under global warming conditions was a maximum of 36% lower than under normal summer conditions in the southeastern United States. In southern Europe, it was up to 30% lower than normal. This is important economically to dairy farmers because low herd conception rate means fewer calves will be available either for marketing or to raise for herd replacements. It also increases the length of the dry period (time when the cow is not producing milk), thus reducing herd milk production levels. Therefore, extra cooling measures may be economically feasible for dairy cattle around breeding time, especially in southern Europe, where economic loss from conception rate declines may be greater than losses from milk production declines under global warming conditions. Stott and Wiersma (1976) improved the conception rate of cattle cooled for 12 hours before and 4 to 6 days after insemination in early summer in Arizona; however, prolonged heat stress may cause physiological changes that are not reversible by short term cooling. Even so, short term cooling may be economically feasible in areas and seasons where the cattle have not already been subject to prolonged heat stress.

4. Conclusions

The potential direct effects of possible global warming on summer season dairy production and reproduction in the United States and Europe were examined. The direct effects on milk production were modeled using an algorithm developed by Berry et al. (1964) and validated by Hahn (1969). Conception rate was modeled using an algorithm developed by Hahn (1981a). Three Global Circulation Models (GCMs)—GISS, GFDL, and UKMO—were used to represent possible scenarios of future climate. Milk production and conception rate declines were greatest under the UKMO model scenario, and the least under the GISS model scenario. The results also indicate that milk production declines would be considerably greater in the United States than in Europe, and that such predicted declines for the GCM scenarios would be generally higher than either “1 year in 10” probability based declines or declines based on the abnormally hot summer of 1980. Several areas predicted to have maximum or high milk production decline correspond to areas of high dairy cattle concentration in the United States. This indicates the potential for a notable impact from global warming on summer season productivity for the overall United States dairy industry. The greatest declines in the United States are predicted to occur in the Southeast and the Southwest. These areas are already accustomed to relatively large summer season milk production declines, resulting from their normally warm summer season climate. Thus, the actual impacts of increased production declines may be greater in other areas, such as the northeastern United States, the midwestern United States, and Europe, which are not accustomed to large summer season declines and therefore have not adopted potential mitigation measures.

Conception rate declines were predicted to be greater in the United States than in Europe. However, several stations in southern Europe may have considerable seasonal conception rate declines. Conception rate decline may be of more concern from an economic perspective in southern Europe than milk production decline.

As refinements in GCMs occur, the impacts of global warming on milk production and reproduction will need to be reassessed.

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Notes

1. THI is a derived statistic computed from the equation (Bosen, 1959): $THI = T_{db} + 0.36 T_{dp} + 41.2$; where: T_{db} = dry bulb temperature in °C, T_{dp} = dew point temperature in °C.
2. WWD, version 1.0, September 15, 1989; WeatherDisc Associates, Inc., 4584 NE 89th, Seattle, WA 98115, (206) 524-4314.

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