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REVIEW

Effects of a Hot and Humid Environment on the Performance of Holstein Heifers

Itoko NONAKA[1]*, Naozumi TAKUSARI[2], Kouji HIGUCHI, Osamu ENISHI and Mitsunori KURIHARA[3]

Energy Metabolism Laboratory, National Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization (Tsukuba, Ibaraki 305-0901, Japan)

Abstract

A series of studies were performed to determine the effects of increasing environmental temperature and relative humidity on the performance of Holstein heifers. In heifers of 200 kg body weight, the effects on dry matter intake and daily weight gain were small at 28°C and 60% relative humidity, but dry matter intake and daily weight gain were seen to start declining at 28°C and 80% relative humidity. Moreover, in heifers of 400 kg body weight, even at relative humidity of 60%, dry matter intake and daily weight gain started to decline at 28°C. At 60% relative humidity, the rate of decline in daily weight gain in heifers of 200 kg body weight at 33°C was similar to that of those of 400 kg body weight at 28°C. These results indicated that the influence of high temperature on the performance of heifers intensified at a late stage, and under high relative humidity. An assessment of the impact of global warming on heifer growth performance in the Japanese summer was made using 'Climate change 10 × 10 km mesh data (Japan)', which is one of the models assuming progressive global warming. In the 2060s, compared to the end of the 20th century, areas showing a decline in the rate of body weight gain in heifers will expand from Kanto to the western Hokkaido area, and the rate of decline will accelerate over time from the present to the 2020s, 2040s and 2060s, especially in July and August. As high humidity under hot temperatures significantly affect heifer growth, global warming and high humidity in the Japanese summer will have the negative effect.

Discipline: Animal industry
Additional key words: assessment of global warming, energy and nitrogen metabolism

Introduction

According to the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report[7], environmental temperatures may rise by anything between 1.8 to 4.0°C during the period 2000 to 2100, due to the increasing emission of greenhouse gases. The effects of global warming on the animal industry are likely to include decreased milk and meat production, and reduced reproductive performance during the hot summer periods. Heifers are considered more tolerant of heat stress than mature dairy cattle, because of their greater body surface area relative to their body mass, thus allowing for more efficient heat dissipation[27]. Due to their lower parturition age, the growth rate of heifers has accelerated in Japan in recent years; hence the heat production of heifers has increased in response to the increased nutrient intake. With increasing heat production, regulation of the body temperature becomes difficult, which exacerbates the decline in the heifers' intake. We must determine precisely the effects of heat and humidity on the heifer metabolism to estimate the potential direct effects of global warming on heifer production, and it is also important to confirm this information for current domestic animals, which

Present address:
[1] Livestock and Grassland Research Division, NARO Kyushu Okinawa Agricultural Research Center (Koshi, Kumamoto 861-1192, Japan)
[2] NARO Hokkaido Agricultural Research Center (Sapporo, Hokkaido 062-8555, Japan)
[3] National Institute of Agrobiological Sciences (Tsukuba, Ibaraki 305-0901, Japan)
Corresponding author: witoko69@affrc.go.jp
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have greater genetic potential than livestock of the past.

The objectives for this study were to 1) define the effects of increased environmental temperature and humidity on the physiological and nutritional status of Holstein heifers, and 2) predict the effect of global warming on heifer growth performance during the Japanese summer.

The effects of high temperature and humidity on the performance of Holstein heifers

To investigate the effects of increased environmental temperature and humidity on the physiologic response, energy and nitrogen metabolism, and rumen digestible pattern of Holstein heifers, we performed three sets of experiments. In Experiment 1[16], prepubertal Holstein heifers (n = 4, initial body weight (initial BW) = 198 ± 3 kg, initial age = 7.7 ± 0.2 months) were maintained at three environmental temperatures, 20, 28 and 33°C, in that order in an environmentally controlled room[8] where the relative humidity (RH) was maintained at 60%. The experimental diet consisted of a 50% split of concentrate and roughage respectively, which was sufficient to meet the heifers' energy and protein requirements to achieve a growth rate of 0.8 kg/day based on the Japanese Feeding Standard[13]. Water and mineral licks were available *ad libitum*. In Experiment 2[18], the BW and temperature conditions were the same as in Experiment 1 (n = 4, initial BW = 250 ± 20 kg, initial age = 10.4 ± 1.0 months), but the RH was maintained at 80% (RH80%). In Experiment 3, the environmental variables were the same as in Experiment 1, but the average BW of the heifers was 418 ± 14 kg, and the initial age was 17.1 ± 0.5 months.

Each set of experiments was performed similarly. Briefly, the nitrogen and energy balance was measured on each of the last 4 days of a 14-day treatment period, and a respiration trial was conducted on each of the last 3 days of the treatment period using an open-circuit respiration apparatus[8]. All heifers received humane care as outlined in the 'guide for the care and use of experimental animals' at the National Institute of Livestock and Grassland Science.

1. The effects of high temperature on the performance of prepubertal heifers (Experiment 1)

The relatively high environmental temperatures of 28 and 33°C increased the rectal temperature by 0.2 and 1.2°C and increased respiration by 23 and 58 breaths per minute, respectively. The body temperature at 28°C was within the normal range, and the body temperature homeostasis was maintained. At 28°C, the dry matter intake (DMI) was similar to that at 20°C, whereas at 33°C, the DMI was lower (P<0.10) by about 9%, but the DM digestibility was higher (P<0.05) at 33°C than at 20°C. The positive effects of high environmental temperature on the digestibility of the feed have been attributed to either the reduction in the passage rate of digesta[2, 5], the changes in feed composition due to decreasing roughage intake[5, 26] or the reduction in DMI[5, 6]. In our experiment, the increase in DM digestibility at 28°C was attributed to the increased retention times of digesta (20 and 28°C; 55.9 and 61.6 h, respectively) due to the slower gastrointestinal motility under heat stress. The increased DM digestibility at 33°C was due to reduced hay consumption (20 and 33°C; 2.91 and 2.38 kg/day, respectively), which led to variation in the forage/concentrate ratio in the diet. The thermal treatments did not affect daily weight gain. At 33°C, energy and nitrogen intake were lower (P<0.10), while energy and nitrogen digestibility were higher at 33 than 20°C. Urinary nitrogen was elevated at 33°C, resulting in lower nitrogen retention. Although energy retention as fat was unchanged (P>0.10) among the treatments, energy retention as protein was lower (P<0.05) at 33 than 20 or 28°C (Fig. 1). One of the reasons may have been decreased protein synthesis due to reduced triiodothyronine (T_3). Thyroid hormones are known to play an important role in the animal's adaptation to environmental changes, and T_3 is related to thermogenesis[1]. A second reason for the reduced protein retention may have been the increased body protein degradation in the hot environment. The reduction in nitrogen retention was associated with a decrease in the RNA concentration in muscle tissue and an increase in the creatinine excretion rate[11]. Muscle catabolism may be the result of reduced feed in-

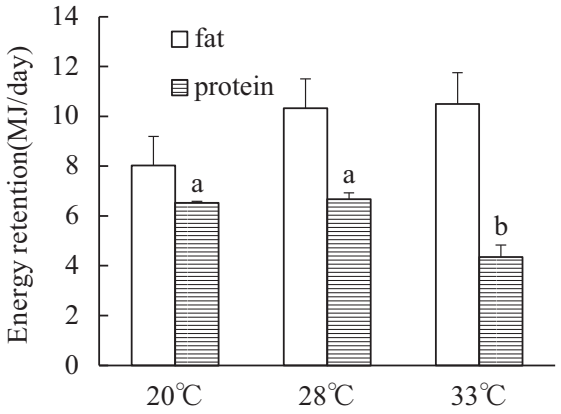

Fig. 1. Energy distribution in heifers exposed to different environmental temperatures (Nonaka et al., 2008)
□ : energy retention as fat; ▤ : energy retention as protein (n=4).
Data represents means ±S.E.
a, b Means in a row with different superscripts differ significantly (P<0.05).

take and stress[21]. These results confirmed that the effects of environmental temperature on prepubertal heifers were severe above 28°C.

2. The effects of high temperature under high humidity on the performance of prepubertal heifers (Experiment 2)

The relatively high environmental temperatures of 28°C with RH80% increased the rectal temperature by 1.3°C and the respiration by 57 breaths per minute, and decreased DMI compared to the temperature, respiration and DMI at 20°C and RH80%. The negative effect of high temperature on heifer performance at 28°C and RH80% exceeded that at 33°C and RH60%. At 33°C and RH80%, meanwhile, the rectal temperature and respiration rate increased by 2.2°C and 73 breaths per minute, respectively. As high environmental humidity disturbed the latent heat dissipation from heifers, even at 28°C, the increase of body temperature contributed to decreased DMI. Energy digestibility at 28°C and RH80% tended to be higher ($P<0.10$) than at 20°C and RH80%, while conversely, gross energy intake and energy retention at 28°C and RH80% were lower ($P<0.05$) than that at 20°C and RH80%. Because gross energy intake at 33°C and RH80% was 50% of that at 20°C and RH80%, energy retention at 33°C and RH80% was negative and the body fat of the heifers was mobilized.

Humidity influences cattle's heat balance, particularly in a hot environment[14]. The average relative humidity in the Hokkaido, Kanto, Tokai and Kyushu regions in July, August and September often exceeds 80%[9]. Study results, including those of the present study, show that humidity as high as RH80% disturbs the heat dissipation of heifers, even at 28°C, and that the effects of high humidity were greater at 33°C.

3. The effects of high temperature on the performance of after-puberty heifers (Experiment 3)

Rectal temperature and respiration rate rose ($P<0.05$) with increasing environmental temperature (20, 28 and 33°C; 38.7, 39.4 and 40.3°C and 39, 85 and 107 breaths per minute, respectively). DMI dropped significantly with increasing environmental temperature (20, 28, 33°C) to 8.8, 7.9 and 5.6 kg, respectively. The retention time of the feed at 33°C was significantly longer than those at 20°C and 28°C. The feed digestibility of DM, energy and nitrogen at 33°C was higher than those at 20 and 28°C. The increased feed digestibility at 33°C was due to the reduced passage rate of digesta[2, 5], the changes in feed composition[5, 26] and the reduction of DMI[5, 6]. Heat production dropped ($P<0.05$) with increasing environmental temperature (20, 28 and 33°C; 0.78, 0.71 and 0.59 MJ/day/$BW^{0.75}$, respectively). In Experiment 1, the heat production of 200 kg BW heifers decreased (20, 28 and 33°C; 0.83, 0.77 and 0.70 MJ/day/$BW^{0.75}$, respectively), as did that of 400 kg BW heifers. However, the heat production of BW heifers of 400 kg metabolic body weight was lower than that of 200 kg BW heifers, while the rate of decline in the heat production of 400 kg BW heifers at 33°C compared to that at 20 or 28°C exceeded that of 200 kg BW heifers. The difference is probably attributable to the fact that smaller heifers have a greater body surface area relative to their body mass, thus allowing more efficient dissipation. The influence of high environmental temperature on heifers was larger in the late stages of growth (about 400 kg BW) than the prior stage (about 200 kg BW).

Heifers are considered more tolerant of heat stress than mature dairy cattle, because the energy requirement of the former per body weight is smaller than that of cows, and heifers' body surface is greater relative to their body mass, thus allowing for more efficient heat dissipation[27]. However, our experiment clarified that heat stress adversely affects fast-growing heifers, especially when coupled with high humidity or during a late stage of growth.

Prediction of the effect of global warming on heifer growth performance during the Japanese summer

The Japanese summer is humid as well as hot. In the summer of 2010, the average daily temperature in August was 2.25°C higher than the average temperature for the period 1971-2000, and animal production decreased in summer. It is increasingly important to comprehend and estimate the effects of heat stress on animal production, due to concern over global warming. The potential influence of global warming on agriculture in Japan is being evaluated in several agricultural fields, for example rice[31] and fruit trees[23]. To date, there have been assessments in the animal production of broilers[29], growing pigs[25] and cows[12], but no assessment of heifers. This study was performed to assess the impact of global warming on heifer growth performance in the Japanese summer[17].

The animal experiment was conducted in the Environmental Laboratory (Experiments 1 and 3 in this report) at our institution. The relation between ambient temperature and daily weight gain is shown in Fig. 2. As the environmental temperature rose, the daily weight gain decreased, with a more marked decline in heifers that were older or heavier at the start of the experiments. The relation between ambient temperature and predicted

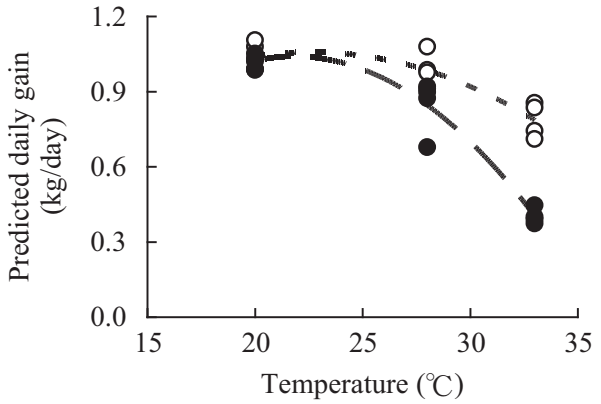

Fig. 2. Relation between ambient temperature and predicted daily weight gain of heifers (Nonaka et al., 2010)

○ : early stage heifers (8 months old), ● : late stage heifers (15 months old)

daily body weight gain was investigated (200 and 400 kg BW, the data of Experiments 1 and 3) ; $y = -0.371x^2 + 16.4x - 79.8$, y = daily gain (daily gain at 20°C and RH60% = 100%), x = temperature (°C). At 26.4 and 28.8°C, the predicted daily weight gain decreased by 5 and 15%, respectively, compared to the results at 20.0°C and RH60%.

We used "Climate change 10 × 10 km mesh data (Japan)[30]" as the data of climate prediction in future for our analysis. This climate scenario adapted four Atmosphere-Ocean General Circulation Models, such as the ECHAM4/OPYC3 model of the German climate center (DKRZ), the CGCM1 model of the Canadian Centre for Climate Modeling and Analysis (CCCma), the CSIRO-Mk2 model of the Commonwealth Scientific and Industrial Research Organization (CSIRO), and the CCSR/NIES model of the Center for Climate System Research,

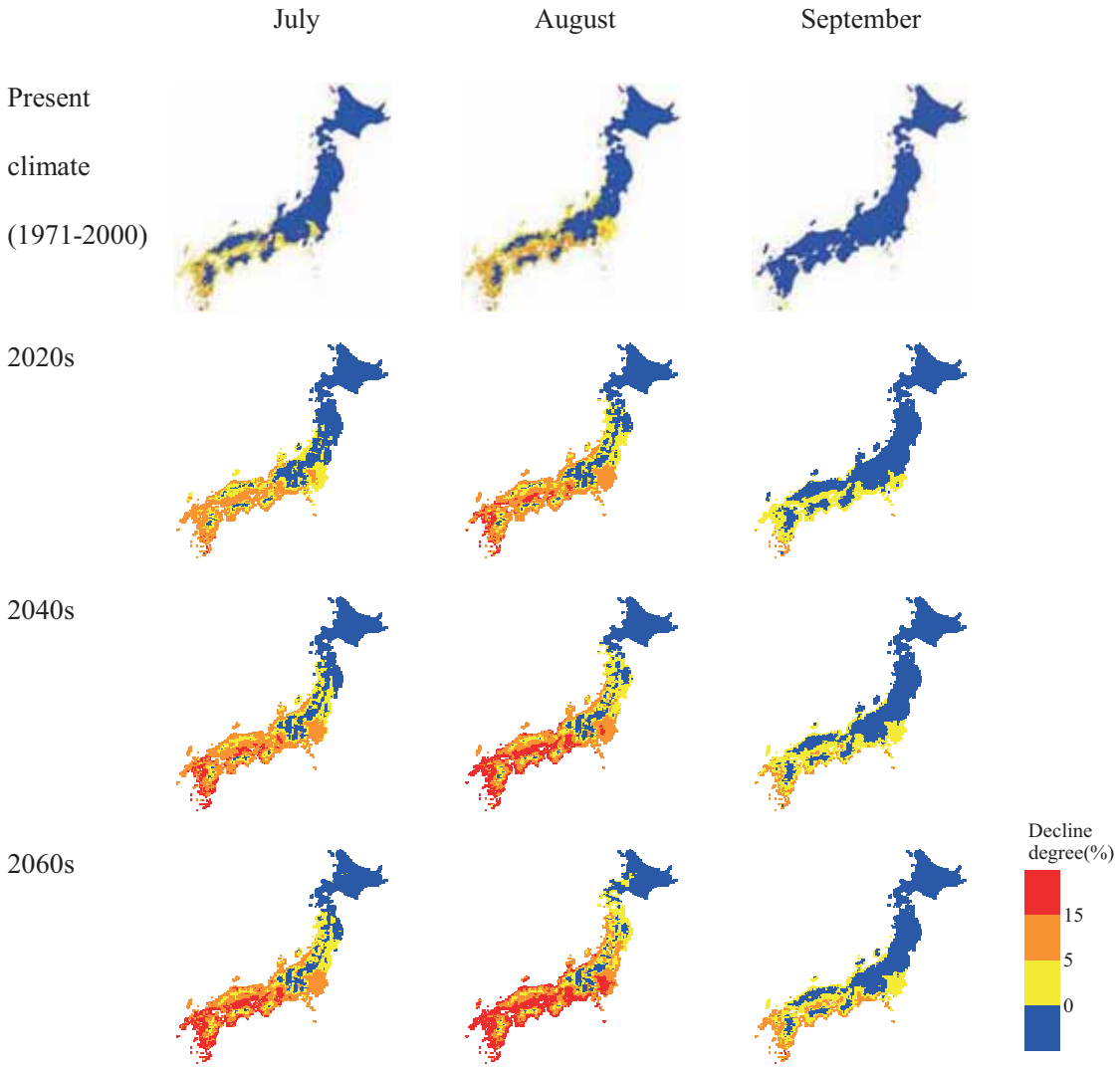

Fig. 3. Spatial distribution of the degree of decline in daily weight gain of Holstein heifers in the present and the 2020s, 2040s and 2060s (Nonaka et al., 2010)

University of Tokyo and the National Institute for Environmental Studies. The average value of four models was calculated as the predicted value. The global warming prediction of these models is that the temperature will rise 0.37°C in a decade. The mesh relevant to the given temperature zone was extracted by the predicted value and indicated on the map using the program by Sugiura and Yokozawa[23] for analysis. The current climate is shown by the monthly average temperature of "Mesh climate data 2000" of the Meteorological Agency issued in 2002[9]. The summer (July, August and September) data were analyzed with a program illustrating the temperature range and area on the map.

Over the last three decades of the 20th century to the 2020s, 2040s and 2060s, the areas of declining body weight gain will expand to include western Hokkaido, and the rate of decline will accelerate over time, especially in July and August (Fig. 3).

High humidity with hot temperatures adversely affects animal production[4], so we attempted to gauge the effects of high temperature and humidity on heifer growth based on the results of Experiments 1 and 2. The index of temperature – humidity[4] was used, as follows: dry-bulb × 0.35 + wet-bulb × 0.65 and the relational expression between the temperature – humidity index and daily weight gain was calculated[17]. The assessment of heifer weight gain in August was estimated for the areas of southern Kyushu and northeastern Hokkaido. If the relative humidity were the same as the current relative humidity, the body weight gain in the 2060s would decrease by 21% in the southern Kyushu area; however, the body weight gain in the 2060s will remain constant in the northeastern Hokkaido area. High humidity and hot temperatures will significantly affect heifer growth in Japan.

Predictions of the effect of global warming on broilers[29] and growing pigs[25] have been made by the same model as was used for heifers, so we compared the effects of global warming on broilers, growing pigs and heifers. Growing pigs are considered less tolerant of heat stress than broilers and heifers. In heifers, it was found that at 26.4 and 28.8°C, the predicted daily weight gain decreased by 5 and 15%, respectively, compared to changes at 20.0°C and RH60%. On the other hand, when growing pigs were exposed to 24.5 and 27.3°C, their daily weight gain was found to decrease by 5 and 15%, respectively. Broilers are more tolerant of hot environments than pigs and heifers (at 27.2 and 30.0°C their daily weight gain decreased by 5 and 15%, respectively). However, broilers experience the greatest direct impact from heat stress when marketed during or after summer, because the number of days until market age for broilers is the shortest among broilers, pigs and heifers, while heifers can recover in autumn what they lost in summer. In domestic animals, it is predicted that the animal production in summer will further decline as global warming progresses and the temperature rises, and the affected area in Japan will expand.

Conclusion and future prospects

Heifers with elevated body temperature exhibit lower DMI, daily gain and energy retention as protein. When we examined the potential impact of global warming on heifer growth performance in Japan, we concluded that the areas of declining body weight gain will expand to western Hokkaido, and that the rate of decline will accelerate over time during summers.

A metabolism trial of energy and protein is an important method to study animal nutrition and the nutritive values of feed. In addition to the present study, we are researching rumen microbes and fermentation in a hot environment[3, 24]. Methane gas is one of the greenhouse gases, hence the importance of measuring the amount of methane gas from ruminants[22]. Our research institute is collaborating with Thailand[10, 19], Indonesia[20] and Inner Mongolia[28] to measure respirational gases using a face mask technique system, ventilated hood-type system and SF_6 technique.

If the hot environment in summer intensifies over time, animals will face an increasingly serious situation. We have to develop methods for nutritional management and feeding strategies for increasing nutrient intakes, and improve livestock barn environment management, for example, by using cooling systems to decrease heat stress.

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