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Assessment of heat stress in dairy cows related to physiological responses

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ABSTRACT: Climate change will continue to occur in the years to come and threaten dairy cows. As a result of climate change, various risks can change due to changing ecological conditions in various places on earth. The study aimed to assess heat stress in dairy cows (calf, heifer, lactating, and dry cow). The heat stress assessment method uses the equation presented by the temperature-humidity index (THI). Heart rate, respiratory rate, and rectal temperature are physiological parameters to determine heat stress. The data collection of cattle's temperature, humidity, and physiological parameters was carried out simultaneously. Data analysis used one-way ANOVA, followed by Tukey's further test. The results of the heat stress assessment showed that the THI values reached 82.8 and 78.2 in the afternoon and evening, causing the calves, lactating cow, and dry cow to be exposed to heat stress. The rectal temperature of the calf increased by 39.1^{0}C, the heart rate and respiration rate of lactating cows increased by 66.5-69.2 times/minute and 51.7 times/minute, and the respiration rate of dry cows increased by 49.2 times/minute. Efforts are needed to control heat stress in dairy cows at all age phases so that dairy cows are in comfortable environmental conditions.

Keywords: THI; Climate change; Heart rate; Respiration rate; Rectal temperature

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INTRODUCTION

East Java is the province with the largest dairy cattle population in Indonesia, which is 287,482 heads (Kementerian Pertanian, 2019). The central areas for dairy cattle in East Java are Pasuruan Regency and Malang Regency (BPS of East Java Province, 2017). The development of dairy cows in milk production centers must be continuously pursued.

Heat stress is an animal's non-specific physiological response to the thermal environment when the animal generates more heat than it can give off. The Holstein is the most popular breed of dairy cow in the world. In summer, the breed's ability to dissipate heat through skin evaporation is limited by a relatively low surface area to body weight ratio, underdeveloped sweat glands, and short, dense body surface hair, all of which strain milk production (Liu et al., 2019). Global warming is likely to occur. However, the nature and magnitude of environmental change, both climatic and non-climatic, are challenging to explain. Therefore, a significant focus on the impact of the hot environment on livestock is needed (Lees et al., 2019). Temperature and rainfall can affect animals directly and indirectly. Rising temperature causes heat stress in animals, whereas drought and flooding can affect milk production and quality due to changes in crop and water quality and availability (Misiou et al., 2021). Heat stress in dairy cattle has increased significantly due to changes in the global environment. Heat waves will disrupt livestock production, health, welfare, and reproduction (Noordhuizen & Bonnefoy, 2015). Therefore, the research to identify and control heat stress in dairy cattle needs to be continued.

Livestock management systems and high ambient temperatures during summer statistically affect the daily milk production for high-yielding dairy cows (Trajchev et al., 2016). In Indonesia, not all areas are suitable for dairy farming, so the location for the distribution of dairy cattle is in the medium to highland areas to provide a comfortable environment for FH dairy cattle (Yani dan Purwanto, 2006). During the last ten years, the impact of global warming on dairy farming in Indonesia has caused dairy cattle to experience heat stress in all locations, both in the lowlands (Nugroho et al., 2010) and the highlands (Sudrajad dan Adiarto, 2011; Mariana *et al.* 2016). Heat stress is a challenge for dairy cattle in tropical countries (Renaudeau *et al.*, 2012; Hernández-Castellano *et al.*, 2019), and during the summer (Ghosh et al., 2017) because it has an impact on decreasing milk production and quality in the summer (Rejeb *et al.* 2012; Pragna *et al.* 2017; Mariana *et al.* 2016).

Dairy cattle that smallholder farmers widely cultivate are the Friesian Holstein (PFH) breed, which is the result of a cross between local cattle and Friesian Holstein (FH) dairy cattle. The milk production capacity of PFH dairy cows is lower than that of FH cows. However, PFH cattle can adapt to the tropical climate to be reared and grown in lowland and highland areas. The characteristics of smallholder dairy farmers are the business scale of fewer than ten heads and the diverse structure of the livestock population. Smallholder breeders practice raising heifers in the same way as lactating cows and dry cows. This causes the cow's needs not to be met according to the standard of their physiological status, and it is suspected that it will increase the heat load on dairy cows.

Efforts are needed to deal with the adverse effects of climate change on dairy farming in the tropics through improved maintenance management on smallholder farms. The study report on the findings of heat stress in lactating dairy cattle in several topographic regions in Indonesia is practical information on the impact of extreme climate change on dairy farming in Indonesia. This study aims to investigate the heat stress experienced by dairy cows at all stages of growth (calf, heifer, lactating cow, and dry cow) as a preliminary study for adaptation to enter the era of climate change that will occur in the coming years, especially in smallholder livestock management.

MATERIALS AND METHODS

Place and time of research. The research was conducted at the Dairy Farm of Politeknik Pembangunan Pertanian Malang in October 2019.

Research materials and methods. The research material was PFH dairy cows kept in cages consisting of six calves, three heifers, 13 lactating cows, and one dry cow. The equipment used is a digital thermo-hygrometer, clinical thermometer, stethoscope, stopwatch, and THI table. The research method is observation.

Research variables and measurement procedures. The research variables consisted of the weather variable and the physiological response variable of dairy cows. Weather variables are temperature and humidity. The physiological response variables of dairy cows are heart rate, respiration rate, and rectal temperature. Measurements of weather and physiological responses were measured simultaneously according to Du Preez's instructions (2000). Weather data and physiological responses of dairy cows were collected three times a day, namely in the morning (3 am-4 am), afternoon (12 pm-1 pm), and evening (5 pm – 6 pm) for nine days.

Each measurement was repeated three times, and the final measurement result was the average value. Three observers carried out measurements. Measurement of air temperature and relative humidity using a digital thermohygrometer. Furthermore, the weather element data is calculated by calculating the Temperature Humidity Index (THI) with the equation Kibler (1964) as follows:

$$THI = 1{,}8Ta - (1 - RH)(Ta - 14{,}3) + 32$$

Where:

THI = Temperature humidity index
Ta = ambient temperature (^{0}C)
RH = Humidity (%)

THI thresholds for heat stress in cattle: comfort (THI < 68), mild discomfort (68 < THI < 72), discomfort (72 < THI < 75), alert (75 < THI < 79), danger (79 < THI < 84), and emergency (THI > 84).

Heart rate measurement was performed by counting the arterial pulse in the tail and counting the number of pulses for 1 (one) minute directly with a stopwatch and repeated three times for each pulse data collection. Calculate respiration frequency by placing the back of the hand near the nostril (nostril), counting breaths from the expiration process, and repeating three times in each respiration frequency data collection (minutes). Measurement of rectal temperature by inserting a clinical thermometer into the rectal of a cow to a depth of 10 cm for ± 3 minutes.

Data analysis methods and procedures. Analysis of data variance was analyzed using one-way ANOVA, followed by Tukey's further test. The data was using SPSS version 25.

RESULT AND DISCUSSION

Assessment of heat stress using the temperature-humidity index equation (THI)

Reports of studies on heat stress in livestock have focused mainly on temperature and relative humidity because data on the amount of heat radiation received by livestock, wind speed, and rainfall are not publicly available. In contrast, data on temperature and humidity can usually be obtained from the nearest meteorological station. The temperature humidity index (THI) is a simple combination of temperature and humidity and has been designed to measure livestock comfort (Habeeb et al., 2018). THI is a parameter widely used to describe heat load on livestock and is a good indicator of heat stress from climatic conditions.

Table 1. Temperature, humidity, and THI of the farm

	Morning	Afternoon	Evening
Temperature (^{0}C)	22.9±1.83^c	34.4±1.32^a	28.9±2.29^b
Humidity (%)	83.8±5.13^a	42.4±5.06^c	59.4±11.5^b
THE	71.8±2.63^c	82.8±2.22^a	78.2±2.22^b

Description: different superscripts in the same row indicate significant differences at the level of 5% error.

Table 1 shows that the temperature and humidity values in the morning, afternoon, and evening are significantly different. The air temperature ranges from 22.9-34.4^{0}C, while the humidity is lower than Indonesia's general condition, 42.4-83.8%.

Heat stress occurs when the ambient temperature exceeds the cattle's thermoneutral zone (comfort zone); high-production dairy cows will experience stress when the temperature exceeds 27^{0}C (Armstrong, 1994). In this research, air temperature in the morning is ideal for dairy cows, but in the afternoon indicates an unsuitable temperature condition for the dairy cow. Indonesia's daily air temperature and humidity values are generally high, ranging between 24–34^{o}C and humidity of 60-90% (Yani & Purwanto, 2006). Nugroho et al. (2010) reported that in the lowlands, the temperature at 6.00 am was 23.00 ± 0.55^{0}C, and the peak at noon was 29.21 ± 0.58^{0}C. The same conditions also occur in the highlands. Mariana et al. (2016) reported that at 6.00 am, the dairy cows in the highlands are still tolerant of environmental temperatures (16.8 ± 0.5^{0}C). An ecological temperature increase starts at 8.00 am and reaches a peak at noon, at 29.6 ± 1.19^{0}C. This condition shows that the environmental temperature of dairy cattle both in the lowlands and in the highlands can cause heat stress, especially during the day and evening. The environment condition in this research site is almost the same as the results of research by Mariana et al. (2016) that the highest air humidity in the Center for Dairy Cattle and Forage Development (BPT-SP HMT) Cikole, Lembang, Bandung at 6.00 am, is 83.26 ± 3.41%. The lowest at 2.00 pm is 42.35 ± 2.19%. This result indicates that in the morning, the dairy cows are comfortable. In contrast, dairy cows can be exposed to heat stress in the afternoon and evening.

This research shows the lowest THI value in the morning while the highest THI value during the day. The THI value in the morning is 71.8, indicating that the dairy cattle are in a state of mild discomfort (68<THI<72), while the THI value in the afternoon is 82.8, indicating that the dairy cow is in a state of danger (79 <THI <84). In addition, the THI value in the evening is day was 78.2, indicating that the dairy cow was alert (75 < THI < 79). Nugroho *et al.* (2010) also reported that dairy cows in Tutor District, Pasuruan Regency (highlands), also experience heat stress day and night. The THI value showed a value of 81.91 ± 1.16 during the day, so the cows experienced stress in the moderate category. At night, the THI value shows 76.13 ± 0.87, so the cow is in the category of mild stress. Armstrong (1994) states that a THI value exceeding 72 causes dairy cows to experience heat stress. Kadzere et al. (2002) noted that a THI value of 70 or less is a comfortable condition for dairy cows. At a THI value of 75-78, cows experience stress conditions. While if a THI value more excellent than 78 causes extreme conditions, lactating cows cannot sustain a thermoregulation mechanism or average body temperature.

Friesian-Holstein cattle have high heat stress at first, second, or third parity in the first stage of lactation and are the most susceptible. Their heat production is twice that of low-yield or dry cows. The respiratory rate of heat-stressed cows increases from 20/minute under normal conditions to 100/minute or more in heat stress conditions. After the ambient temperature has passed 25°C, the cow may have increased up to 50/min. It shows that heifers generate less heat than adult cows due to a relatively larger body surface and a lower metabolic rate. Heifers weighing 600 kg produce more heat than heifers of lower body weight and are therefore more susceptible to heat stress. The heat stress effect's severity depends on the exposure's duration and heat stress severity. For example, heat stress conditions on a single day may not affect because cows can still adapt.

In contrast, heat stress can have a sizeable negative effect for days or weeks, which will be exacerbated by higher humidity levels (Noordhuizen dan Bonnefoy, 2015). The study by Vitali *et al.* (2009) showed a quantitative relationship between the risk of death in dairy cows and THI. The estimated THI values of 80 and 70 are the maximum and minimum THI, respectively, at which mortality rates in dairy farms begin to increase. The maximum and minimum THI values of 87 and 77 are critical THI values where the risk of death of dairy cows is maximum. This study suggests taking emergency measures and mitigation measures that can ensure the survival of dairy cattle and reduce the replacement costs associated with heat stress deaths. Habeeb *et al.* (2018) also stated that when the THI exceeds 72, the cow is likely to start experiencing heat stress, affecting the calf's growth rate.

When THI exceeds 78, it will significantly affect cow's milk production. When the THI is above 82, a very significant milk production loss is likely. The cow shows signs of severe stress and may eventually die.

Relation of heat stress (THI) with a **physiological response of calves, heifers, lactating cows, and dry cows**

The use of THI to measure environmental warmth is the most practical and straightforward index, easy to determine, and relatively reliable for using body temperature and respiratory rate to determine heat stress in cattle and physiological parameters. THI and these physiological parameters should always be used to determine and evaluate heat stress in livestock (Du Preez, 2000). Measuring THI and physiological parameters of cattle were carried out simultaneously (Liu et al., 2019).

Table 2. Heart rate, respiration rate, and rectal temperature in calves

Physiological response	Morning (THI = 71.8±2.63)	Afternoon (THI = 82.8±2.22)	Evening (THI = 78.2±±2.22)
Heart rate (times / minute)	68.2±4.79^{ns}	69.1±5.17^{ns}	66.3±6.95^{ns}
Respiration rate (times / minute)	38.7±5.90^{b}	44.7±4.09^{a}	42.1±4.70^{a}
Rectal temperature (^{0}C)	38.5±0.62^{b}	39.1±0.30^{a}	38.9±0.40^{a}

Description: - different superscripts in the same row indicate significant differences at the level of 5% error;
- The superscript ns shows an insignificant difference at the 5% error rate.

The data in Table 2 shows that the calf heart rate in the morning, afternoon, and evening is not significantly different. In contrast, the values of the calves' respiration rate and rectal temperature are very different in the morning and afternoon. Calves experience heat stress during the day and evening, as indicated by an increased response to rectal temperature. Liu et al. (2019) explained that the THI value and rectal temperature positively correlate where the temperature increase is more significant when the THI value is greater than 72.

The respiration Rate and heart rate of the calf are normal because The ranges of heart rate, and respiration rate, for dry dairy cows were 52.8-70.2 times/minute and 18.9-36.6 times/minute (Suprayogi et al., 2019). The ambient temperature at the research location during the day and evening indicated that the environment was at a critical temperature condition for dairy cows. Sherman et al. (2013b) reported an air temperature of 26^oC with an air humidity of 86% in Bogor and an air temperature of 26^oC with an air humidity of 88% in Jakarta, and dairy cows began to experience critical temperatures with heat stress indicators at rectal temperatures.

Heart rate, respiration rate, and rectal temperature for heifers in the morning, afternoon, and evening are significantly different, as presented in Table 3.

Table 3. Heart rate, respiration rate, and rectal temperature in heifers

Physiological response	Morning (THI = 71.8±2.63)	Afternoon (THI = 82.8±2.22)	Evening (THI = 78.2±2.22)
Heart rate (times / minute)	50.5±11.39^b	59.0±11.31^a	60.1±8.62^a
Respiration rate (times / minute)	31.8±3.26^b	45.5±8.47^a	44.7±4.55^a
Rectal temperature (^0C)	37.1±1.26^b	37.8±1.36^{ab}	38.2±0.56^a

Description: different superscripts in the same row indicate significant differences at the level of 5% error.

Armstrong (1994) states that heat stress occurs due to a combination of environments that causes the effective temperature of the background to be higher than the animal's thermoneutral zone. Kumar et al. (2011) stated that heat stress occurs in animals when there is an imbalance between heat production in the body and its disposal. The heart rate values, respiration rate, and rectal temperature of heifers are in the normal range. These show that heifers do not experience heat stress either in the morning, afternoon, or evening. The results showed different results from Suherman et al. (2013a) that FH heifers' respiratory frequency was more sensitive to stress due to temperature and humidity changes compared to heart rate in two locations, namely Bogor and Jakarta. FH heifers experienced a critical temperature of 24.5°C and humidity of 78% in Bogor, namely a heart rate of 67-84 beats/minute.

Meanwhile, in Jakarta, FH heifers experienced a critical temperature of 23.5°C and a humidity of 88%, namely a heart rate of 72-88 beats/minute. Heifers experienced a critical temperature of 22.5°C and a humidity of 78% in Bogor, namely the respiration rate of 27-38 times/minute, while in Jakarta, the critical temperature of heifers was 23.5°C and 78% humidity, namely the respiration rate of 26-46 times/minute. Respiratory rate is influenced by body size, animal age, physical activity, restlessness, ambient temperature, pregnancy, digestive system disorders, health conditions, and animal position (Suprayogi et al., 2019) and increased respiratory rate situations of stress, work, fever, and pain. There can also be a decrease in the frequency of breathing in the respiratory center sensitivity to depression in cases such as increased pressure in the brain, loss of consciousness, uremia, and increased oxygen pressure.

Body temperature and feed intake for dairy cows are influenced by the increase in temperature and humidity, affecting milk production and reproduction. Although THI integrates ambient temperature and humidity information to assess heat stress, there are still many research deficiencies to date. First, the accuracy of THI monitoring is not sufficient. Many studies use seasonal averages, monitoring only a few working days. Also, only specific time (for example, morning, afternoon, and evening) is used to monitor the workday. As a result, monitoring results are intermittent, do not record daily THI changes, and cannot timely and accurately reflect cows' heat stress status. Second, it is not sufficient for all regions and farms to determine the heat stress state according to whether the THI exceeds 68 or 72. Instead, we must analyze more concretely.

Third, heat stress is a particular cow's physiological reaction to its thermal environment and is affected by THI and varies between breeds, individuals, farms, and management practices. The magnitude of heat stress should be more accurately reflected using a comprehensive assessment of environmental indices and physiological parameters. With the rapid development of mechanical and electrical sensing technology, automatic monitoring equipment for body temperature and cow activity has been gradually improved. This technique will be important in the scientific evaluation of heat stress in cows by combining THI, body temperature, and other indices to make dairy cow management better and even individually forecast heat effectively (Liu et al., 2019).

Table 4. Heart rate, respiration rate, and rectal temperature in lactating cows

Physiological response	Morning (THI = 71.8±2.63)	Afternoon (THI = 82.8±2.22)	Evening (THI = 78.2±2.22)
Heart rate (times/minute)	$63.2±12.88^{b}$	$66.5±14.72^{ab}$	$69.2±10.48^{a}$
Respiration rate (times / minute)	$37.4±9.34^{c}$	$51.7±11.67^{a}$	$47.3±8.72^{b}$
Rectal temperature (^{0}C)	$37.6±2.12^{a}$	$37.7±0.53^{a}$	$37.6±0.84^{a}$

Description: different superscripts in the same row indicate significant differences at the level of 5% error.

The data in Table 4 shows that the heart rate and respiration rate values of lactating dairy cows in the morning, afternoon, and evening are significantly different. The value of rectal temperature based on the difference in observation time is not very different. During the day, there is an increase in heart rate. This condition indicates that lactating dairy cows experience heat stress day and evening. Increased heart rate and respiratory frequency are the adaptations of dairy cows to hot environments to maintain homeostasis (Rejeb et al., 2012). Respiration rate is the first physiological measure that increases when animals experience heat stress (Mcmanus et al., 2014).

Furthermore, Mcmanus et al. (2014) reported that in Brazil, under heat stress conditions, the respiration rate and rectal temperature in purebred *Bos taurus* were significantly higher when compared to the Holstein-Zebu cross. These show that crossed dairy cows can adapt well to stressful conditions. Sudrajad & Adiarto (2011) reported that lactating dairy cows in BPTU Baturraden, a plateau, are also indicated to experience stress based on the respiration rate value, which reaches 50.71 times/minute. Mariana et al. (2016) also reported that lactating dairy cows raised in the highlands during the long dry season experience mild stress, marked by an increase in heart rate of 79.74 ± 6.19 beats/minute. The result shows that lactating dairy cows raised in Indonesia's lowlands and highlands are experiencing heat stress. Summer heat stress negatively impacts the performance of dairy cows in most areas of the world. This severe heat stress problem will become severe as global warming continues and genetic selection for milk production continues (Bernabucci et al., 2010).

Exposure to livestock, incredibly high dairy cows, and heat stress conditions significantly change their organisms' physiological and biochemical parameters. Preliminary estimates of the risk of heat stress limit the negative impact on welfare and livestock productivity. Therefore, based on a reliable environmental index and animal response studies. To eliminate, or at least reduce, the adverse effects of heat stress, there is reason to improve the genetic composition of dairy cows. Therefore, it is necessary to search for information on genetic differences in livestock tolerance to heat stress. One of these methods is cow performance modeling as a function of sustainable THI, leading to the identification of highly productive dairy cows with low sensitivity to THI variations (Herbut et al., 2019).

Mcmanus et al. (2014) explained that heat stress impact based on the livestock production level. Dairy cows crossed with European cows (*Bos taurus*) produce more milk than zebu cows (*Bos Indicus*), although crossbred cows are more sensitive to heat and solar radiation. Livestock management systems and high environmental temperatures during the summer have a statistically significant effect on daily milk production to be anticipated for high-yielding dairy cows (Trajchev et al., 2016). The milking frequency at the research location was carried out two times/day at 03.30 am and at 01.00 pm, applicable to dairy cows in all lactation periods. The average milk production during the observation was 9.9 liters/head/day. The result differs from the research by Nugroho et al. (2010) that dairy cows' milk production in lowlands experiencing heat stress reaches 10.17 ± 2.57 recliners. The average PFH dairy cow milk production has been reported by Utami et al. (2011) at 10.7 liters/head.

This result shows that PFH cows are not very sensitive to heat stress, so they do not experience a sharp decrease in milk production like the FH breed. Under the statements Kadzere et al. (2002) and Pragna et al. (2017), the condition is that cows with high production of milk are more susceptible to heat stress than low production cows. Mariana et al., 2019) reported that FH cattle reared at different altitudes were exposed to heat stress during the dry season. However, FH cattle showed physiological adaptability and could cope with the condition. Production of FH cattle in the highlands, medium, and low, respectively, is 13.1 ± 3.52 kg, 11.3 ± 4.73 kg, and 7.0 ± 3.36 kg. Rejeb et al. (2012) reported that increasing the THI value from 65 to 83 decreased milk production by 6.19 kg/day. THI increased during the day and evening in this study, from 71.8 to 82.8 and 78.2. Allen & Anderson (2013) reported that in heat stress conditions, namely a THI of more than 68, the cow's standing time is longer than the resting time to remove heat from all over its body surface. This condition will reduce milk production. Pragna et al. (2017) also explained that increased temperature and humidity harm feed intake, which harms reproductive potential and reduces milk production due to heat stress and could raise body temperature, affecting fat synthesis in the mammary glands.

The rectal temperature for dry dairy cows is average. According to Suprayogi et al. (2019), the average temperature of dairy cows is between 37,6ºC to 38,6ºC, but there is no significant difference in measurements in the morning, afternoon, and evening. Meanwhile, the heart rate and respiration rate of dry dairy cows were significantly different in size in the morning, afternoon, and evening as presented in Table 5.

Table 5. Heart rate, respiration rate, and rectal temperature of dry cows

Physiological response	Morning (THI = 71.8±2.63)	Afternoon (THI = 82.8±2.22)	Evening (THI = 78.2±2.22)
Heart rate (times / minute)	79.0±2.85^{a}	78.0±7.68^{a}	70.7±2.36^{a}
Respiration rate (times / minute)	31.0±1.45^{b}	49.2±5.74^{a}	47.8±4.82^{a}
Rectal temperature (^{0}C)	37.9±0.58^{a}	38.4±0.78^{a}	38.2±0.62^{a}

Description: different superscripts in the same row indicate significant differences at the level of 5% error.

Table 5 informs that dry dairy cows are exposed to heat stress during the afternoon and evening, indicating an increase in the respiration rate, namely 49.2 times/minute and 47.8 times/minute. Suprayogi et al. (2019) reported that the physiological value of dry dairy cows reared in the highlands is standard not to be exposed to heat stress. The heart rate, respiration, and body temperature ranges for dry dairy cows were 52.8-70.2 times/minute, 18.9-36.6 times/minute, and

37.6-38.6°C, respectively. Climate change can change the thermal environment of livestock production, which may harm welfare and productivity. The thermal environment influences the welfare and productivity of cattle. Regardless of climate change and predictable changes to the thermal environment, hot weather will continue to trigger heat load responses in livestock worldwide. Therefore, livestock production systems must identify and utilize efficient and effective mitigation strategies to reduce heat loads. In the coming years, integrated approaches to adopting and managing mitigation opportunities will become increasingly essential to support livestock production systems' sustainability (Lees et al., 2019).

CONCLUSIONS

The study concluded that dairy cows (calf, lactating cow, and dry cows) were exposed to heat stress during the day (morning and evening), while heifers did not experience heat stress. Stress in calves is known from an increase in rectal temperature. In lactating cows, it is known from an increase in heart rate and respiration rate. In dry cows, it is known for an increase in respiration rate. The environmental conditions at the research site are not yet ideal for dairy cows, so it is necessary to improve management to control heat stress.

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