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Changes in Livestock Weather Security Index (Temperature Humidity Index, THI) During the Period 1917-2016 in Veracruz, Mexico

Belisario Domínguez-Mancera[1]*, Antonio Hernández-Beltrán[2], Araceli Rodríguez-Andrade[3], Patricia Cervantes-Acosta[4], Manuel Barrientos-Morales[5] and Juan Manuel Pinos-Rodriguez[6]

[1]Laboratory of Cell Biology, School of Veterinary Medicine and Animal Science, University of Veracruzana, Veracruz, MEXICO
[2]Laboratory of Functional Alterations, School of Veterinary Medicine and Animal Science, University of Veracruzana, Veracruz, MEXICO
[3]Department of Chemistry and Biochemistry, Veracruz Institute of Technology, MEXICO
[4]Laboratory of Molecular Biology, School of Veterinary Medicine and Animal Science, University of Veracruzana, Veracruz, MEXICO
[5]Laboratory of Animal Reproduction Biology, School of Veterinary Medicine and Animal Science, University of Veracruzana, Veracruz, MEXICO
[6]Laboratory of Animal Nutrition, School of Veterinary Medicine and Animal Science, University of Veracruzana, Veracruz, MEXICO

**Corresponding author: B Domínguez-Mancera; Email: beldominguez@uv.mx*

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ABSTRACT

In Veracruz, raising livestock takes place in an environment that offers little comfort, and this condition has worsened since 1990. Projections of climate change scenarios for Veracruz, Mexico, show increases in temperature; central Veracruz will be the most affected. Analysis of daily temperatures (ºC) and relative humidity (%) for the period 1917-2016 was carried out to obtain the Livestock Weather Security Index (LWSI) using the Temperature and Humidity Index (THI) provided by the forecast center of the Gulf of Mexico and to determine changes in THI. Cattle comfort was obtained with the equation: $THI = 1.8 \times T + 32 - (0.55 - 0.55 \times HR) \times (1.8 \times T - 26)$; Where "T" is temperature (°C) and "RH" relative humidity (%). THI values were interpreted as ≤ 74 Comfort, 75-78 Alert, 79-83 Dangerous and ≥ 84 Emergency. Periods of 30 years known as Normal I: (1917-1930), II: (1931-1960), III: (1961-1990), IV: (1991-2016) were made. THI means in the time periods were (I) 75.15 ± 0.061, (II) 75.80 ± 0.041, (III) 75.55 ± 0.044, and (IV) 76.62 ± 0.049 ($p < 0.05$). Percentage (%) of days for THI categories in each Normal was (I) 34.15, 46.69, 19.14, 0.0; (II) 30.84, 42.13, 27.01, 0.0; (III) 32.53, 39.67, 27.78, 0.009; (IV) 27.54, 34.10, 38.17, 0.17 for Comfort, Alert, Dangerous and Emergency ($p < 0.05$). Comfort has been reduced in recent years; increases in the percentage of days with THI > 79 are expected.

Keywords: livestock comfort index, heat stress, climate change

Changes in different agricultural production systems in the world will be driven by climate change. How it happens will depend on timeliness of mitigation and adaptation activities that consider the interests of the producers and their productive capacity, as well as their articulation with public policies concerning the abiotic and biotic environment in which these activities are developed (Schönhart *et al*., 2016). However, opportunities for adaptation will be limited by the severity of climate change. Moderate climate change will likely benefit some agricultural production systems, but severe climate change is unlikely to bring benefits (Howden *et al*., 2017).

In the region of Veracruz, Mexico, livestock raising takes place in a climate that offers little comfort to the animals, and this condition has become notably more acute in recent years, since 1990, the year in which, according to experts, the effects of climatic change began. In addition, according to projections of climate change scenarios in some municipalities in the state of Veracruz, further increases in temperature are expected by 2020, especially in the summer, with the central region being the most affected, followed by the southern region (Hernández *et al*., 2011).

Likewise, scenarios have been developed to evaluate the Livestock Weather Security Index (LWSI), through the Temperature and Humidity Index (THI), which uses the ambient temperature and relative humidity. These indexes indicate whether the environmental conditions in which the animals are located are appropriate for their welfare and comfort. It is predicted that in the next decade, during the warm months (May-August), the conditions will not be appropriate and it is expected that livestock will be in serious danger from heat stress (Hernández *et al*., 2011; Alonso-Spilsbury *et al*., 2012).

In the case of cattle, being warm-blooded animals, they maintain their body temperature constant despite changes in environmental temperature, which allows them to live in very different places (Ravagnolo *et al*., 2000). Animals can lose heat in several ways. Evaporation through sweating and panting is the most important, occurring as ambient temperature increases and approaches body temperature. This is the only way to lose heat (Hoffmann, 2010). Periods of heat stress have negative effects on animal proficiency. Heat stress reduces milk production, food intake, physical activity and growth (West, 2003). Reproduction also decreases as prolonged heat stress is the main factor responsible for low fertility (De Rensis and Scaramuzzi, 2003). In addition, in cows more miscarriages and embryonic deaths occur during and after the warm months in most countries, resulting in significant economic losses (Ealy *et al*., 1993).

International recognition of change in present and future climate, as well as the demonstration of the susceptibility of cattle in tropical conditions (dairy and meat cattle), requires further study to identify and characterize the changes in climatology in the next years and with they, identify animals capable of adapting to these new conditions, while preserving their productive qualities, and to seek their welfare.

MATERIALS AND METHODS

Climatic data from 1917 to 2016 provided by the Gulf of Mexico forecast center of the National Meteorological Service (station 309-692) located in the city of Veracruz were used. The livestock weather security index (Valtorta *et al*., 2000) was established by the following equation:

$$ITH = 1.8 \times T + 32 - (0.55\text{-}0.55 \times RH) \times (1.8 \times T - 26);$$

Where:

"T" is the average daily temperature in °C

"RH" is the relative humidity in %

The LWSI by Hahn *et al*. (2000) considers four categories of the THI to evaluate the impact of thermal environmental conditions associated with respirations per minute. Nienaber *et al*. (2007) consider increase in respiratory frequency a proportional compensatory response to heat stress. Values of ITH ≤ 74 were considered Comfort, 75-78 were considered Alert, 79-83 were considered Dangerous and ≥ 84 were considered Emergency.

The entire time span was divided into periods known as Normal (periods of 30 years): Normal I (1917-1930), Normal II (1931-1960), Normal III (1961-1990), Normal IV (1991-2016).

Data were analyzed with a factorial ANOVA and Simple Linear Regression using STATISTICA V10.0 software (StatSoft, 2011); multiple comparisons were made with Tukey ($\alpha = 0.05$), and figures were constructed with Sigma Plot v11 software (Sigma Plot for windows, 1999).

RESULTS AND DISCUSSION

The averages ± standard errors of the mean, minimum and maximum temperatures; as well as the mean, minimum and maximum the ITH (Livestock Weather Security Index) in each Normal are shown in Table 1.

We analyzed the maximum, average and minimum temperatures through the different periods (Fig. 1. A, B and C), known as normal, and over the years (Fig 1. D) and determining variability.

Proceeding with the climatological analysis, we analyzed changes in relative humidity through the years of studies and for periods (Normals). Fig. 2, shows a significant reduction ($p < 0.05$) over time in relative humidity.

Table 1: Analysis of the Temperature and Temperature Humidity Index (THI) in each Normal period

	Normals			
	(1917-1930)	**(1931-1960)**	**(1961-1990)**	**(1990-2012)**
Temperature	**I**	**II**	**III**	**IV**
Minimum	22.12 ± 0.038^{a}	21.97 ± 0.026^{b}	21.54 ± 0.029^{c}	22.19 ± 0.032^{d}
Maximum	26.97 ± 0.042^{a}	28.38 ± 0.027^{b}	29.12 ± 0.031^{c}	29.84 ± 0.032^{d}
Mean	24.54 ± 0.037^{a}	25.18 ± 0.025^{b}	25.15 ± 0.027^{c}	25.87 ± 0.031^{d}
THI	**I**	**II**	**III**	**IV**
Minimum	71.07 ± 0.064^{a}	70.52 ± 0.043^{b}	69.71 ± 0.048^{c}	70.67 ± 0.052^{d}
Maximum	79.23 ± 0.066^{a}	81.09 ± 0.043^{b}	82.01 ± 0.048^{c}	83.07 ± 0.052^{d}
Mean	75.15 ± 0.061^{a}	75.80 ± 0.041^{b}	75.55 ± 0.044^{c}	76.62 ± 0.049^{d}

^{a,b,c,d}; Different literals between columns of the same row are significant statistically ($p < 0.05$)

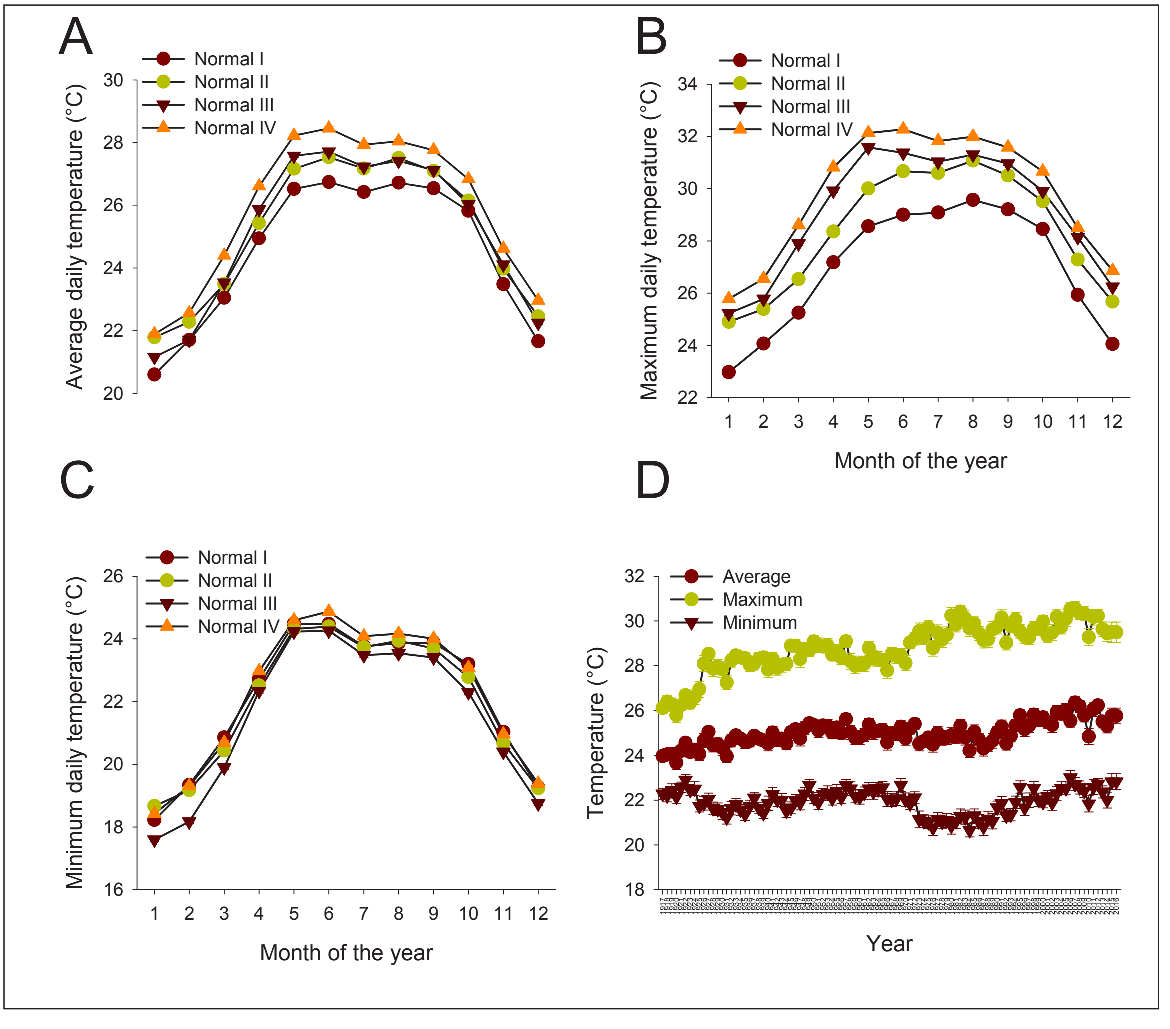

Fig. 1: Monthly temperatures in the different periods (Normals) average (A), maximum (B) and minimum (C); Annual temperatures (D)

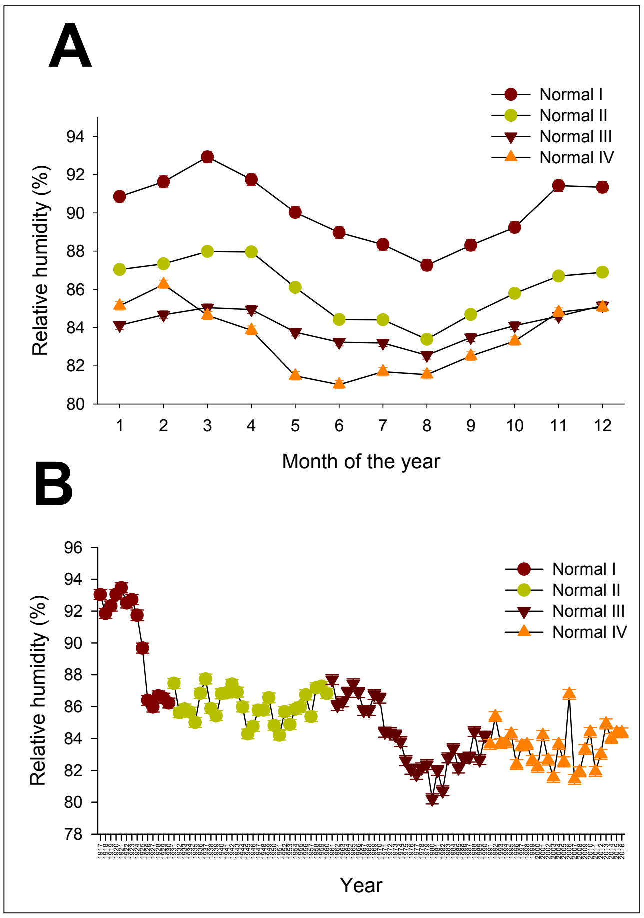

Fig. 2: Analysis of relative humidity through the months in different normal periods (A) and through the different years (B)

The two weather variables (Temperature and Humidity) were analyzed as a whole, and with this, the THI (Livestock Weather Security Index) was obtained; the results can be seen in Fig. 3.

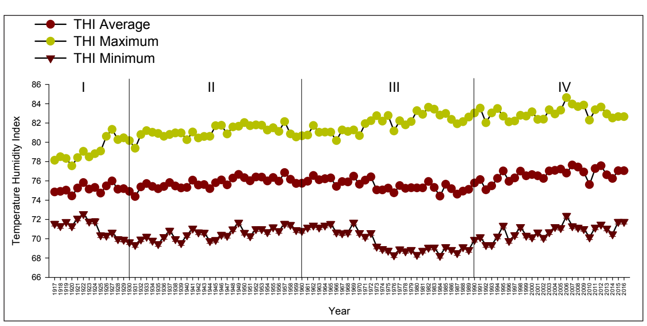

Fig. 3: Analysis of the livestock weather security index through the temperature humidity index (THI) by year (1917-2016)

The Fig. 3, shows significant increases ($p < 0.05$) over the years in the average and maximum THI obtained from average and maximum temperatures. No significant changes ($p > 0.05$) were observed in the THI obtained with the minimum temperature.

When the days of the year in which the animals were in the different THI categories (comfort, alert, dangerous and emergency) were quantified and plotted during the study period (Fig. 4), the number of days in which the animals are in the comfort range has significantly decreased ($p < 0.05$). From 1990 on, animals are seen to be in an emergency (Fig. 4A). The percentage of days in comfort has decreased over the years, and days in alert and dangerous categories are increasing ($p < 0.05$) (Fig. 4B).

Linear adjustment was performed with the average temperatures (Fig. 4C) and the THI obtained with average temperature (Fig. 4C). A significant increase of 0.01 °C was found ($p < 0.05$) for almost all the 100 years of analysis, as well as a significant increase ($p < 0.05$) in the average THI.

When adjusting the THI data (Fig. 5) and changing from average temperature to maximum daily temperatures, severe changes in the number of days are observed (Fig. 5A), as well as changes in the percentage of days in the year (Fig. 5B) in which the animals are found in the comfort range.

Finally, we decided to analyze rainfall in the years of study to determine whether there have been significant changes in the number of days with rain, millimeters accumulated per year, as well as precipitation per day. The results are shown in Fig. 6.

As can be seen in Fig. 6, there are significant variations in the number of rainy days per year, but there is no trend toward a reduction or increase in the number of days or in accumulated rain per year. In section B of Fig. 6, it is shown that average rainfall per day has not changed significantly ($p > 0.05$) although a variation between the years 1977-1980 occurred; the same variation has not been repeated in the course of the years.

Problems associated with the global environmental crisis are different for each country and region of the planet, as are the processes of deterioration of natural resources that are occurring. Today, climate change is defined as a set of altered environmental factors that occur over a given

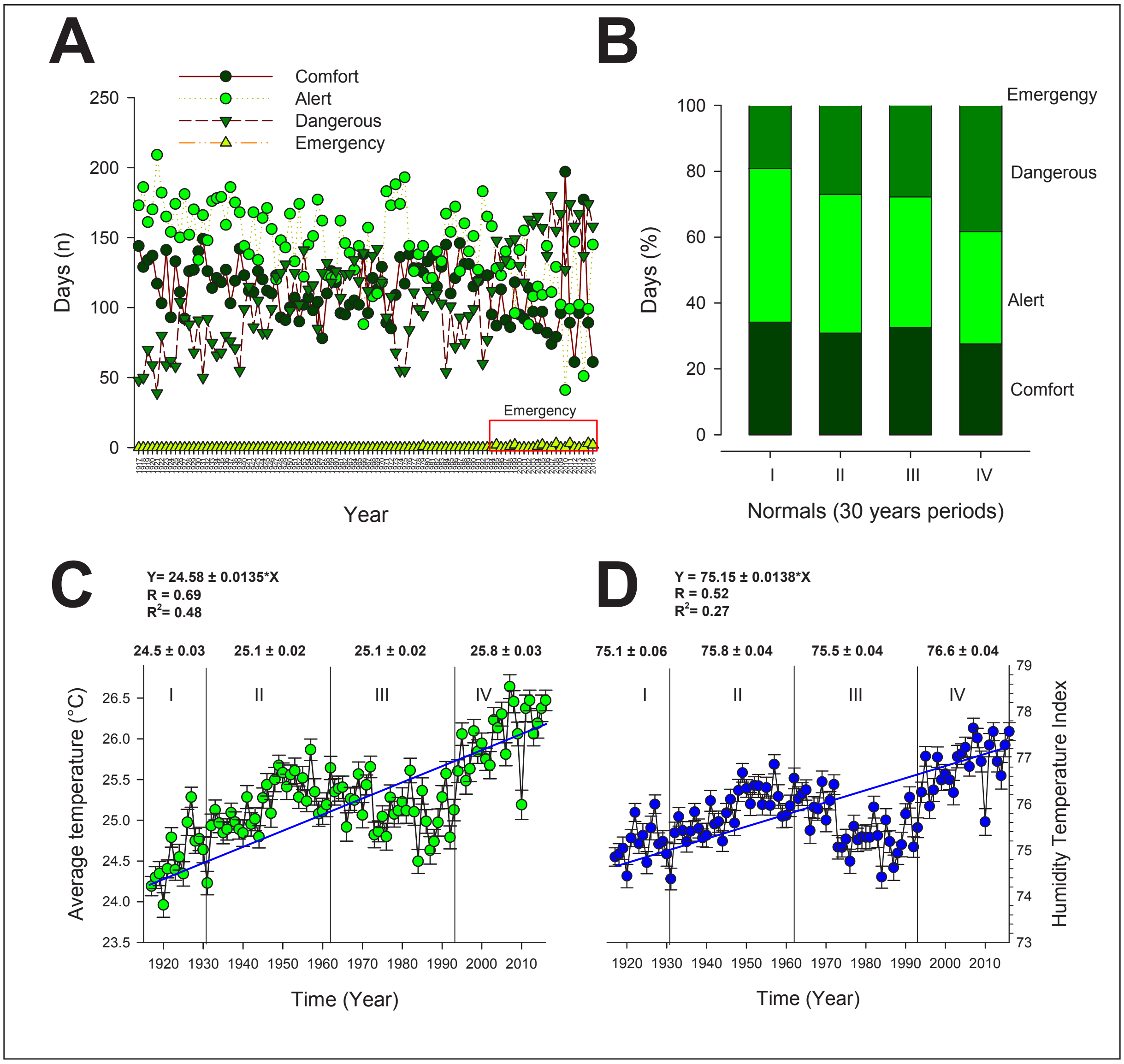

Fig. 4: Temperature Humidity Index (THI) analysis during 1917-2016. A. Percentage of days in THI category within the year divided into Normal I, II, III and IV. B. Percentage of days in THI category with average temperature within each Normal. C. Average annual temperature in °C for each Normal period. D. Annual average THI in each Normal period. In C and D values of the linear adjustment of the temperature and the Temperature Humidity Index, as well as R and R^2 values are shown

period attributed to direct or indirect human activity. One of the most important effects of climate change is the increase in the minimum and maximum temperatures over the planet. Climate change strongly affects the agricultural sector, both crop and livestock production (Morton and de Haan, 2006), although the nature of the biophysical factors brought about by such change and the human responses to them is complex and uncertain (Arias *et al*., 2008). Livestock is directly affected by changes in climatic factors, such as temperature, rainfall, humidity, and the frequency and severity of certain extreme events, such as droughts, floods and wind (Hoffmann, 2010). An increase has been observed in the mean temperature of the surface of the earth has increased since 1861; during the 20th century, the increase is reported to be between 0.2 and 0.6 °C (IPCC, 2013), similar increments temperature

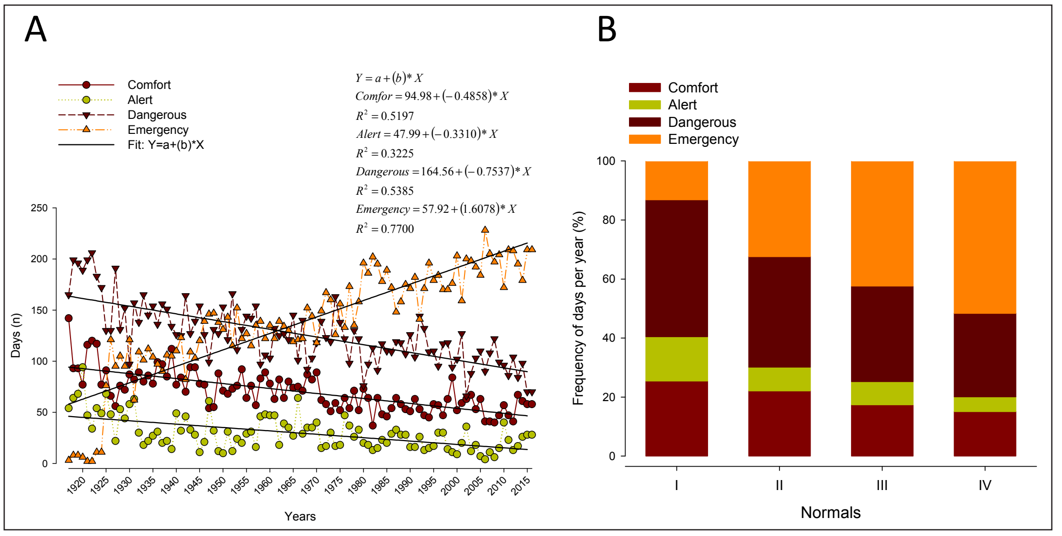

Fig. 5: A. Temperature Humidity Index, through the years 1917-2016. Obtained from maximum temperatures. B. Percentage of days in different categories of livestock climate comfort index (THI) in periods of 30 years (normal), obtained from the maximum temperatures

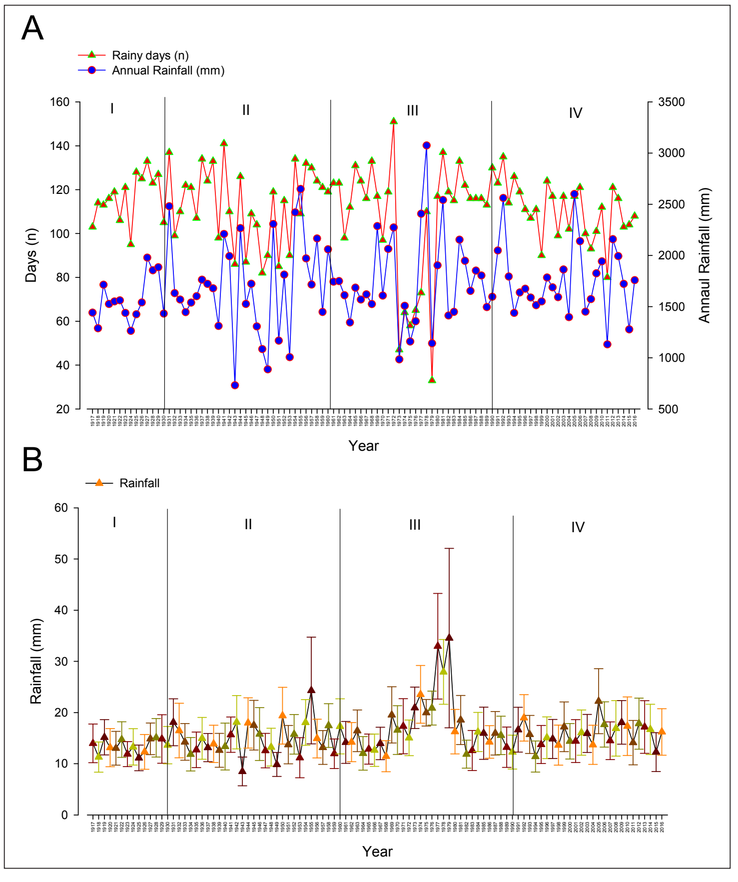

Fig. 6: Analysis of rainfall in the central Veracruz. A. Number of days with rain and annual cumulative rainfall. B. Average precipitation on rainy days. The line represents the separation into normal periods

are reported in the present manuscript. Interpretations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Observations of temperature and other variables on a world scale began to take place in the instrumental era of the mid-nineteenth century. As of 1950, more complete sets of observations are available. Paleoclimatic reconstructions provide records that date back centuries or millions of years. Together they provide an overview of long-term variability and change (IPCC, 2013; IPCC, 2014a). Since 1950, there have been changes in many extreme weather and climate events, it is very likely that the number of cold days and nights has decreased and that the number of warm days and nights has increased; as can be seen in the results of the analysis of the THI. Understanding recent changes in the climate system is the result of a combination of observations, feedback studies, and model simulations (IPCC, 2014a). Assessment of the capacity of climate simulation adjustments to project recent changes requires the analysis of all components of the climate system. Due to the greater extent and detail of observations and the improvement of climate models today, it is possible to estimate future changes in the climate system that may affect agriculture and livestock, although other variables must be included in the analysis, such as emissions of the greenhouse gases methane and carbon dioxide (IPCC, 2014a; IPCC, 2014b).

Ramírez Sánchez *et al*. (2016) analyzed the average and maximum temperatures of regional models belonging to 208 stations distributed in the state of Jalisco in western Mexico, during the period 1971 to 2000. They reported higher intensity and frequency of warming with a decrease in cold events from 76 to 35%, and an increasing tendency to warming events from 39 to 64%. In warm and humid climates, animals have trouble losing heat since evaporative cooling is not effective (De Rensis and Scaramuzzi, 2003).

It is recognized that bovines are more adaptable to cold and are more sensitive to high temperatures. Studies have shown that environmental factors such as solar radiation, wind speed, air temperature and water vapor content, condition bovine comfort. The combination of these climatic factors determines an effective temperature that, when it exceeds the animal's comfort zone, causes stress that negatively impacts their productive behavior (Bouraouia *et al*., 2002). The livestock weather security index through the temperature and humidity index (THI) is the most used indicator to monitor environmental conditions that are stressful for cattle and allows evaluating the degree of heat stress. In this same sense, the environmental temperature range of comfort that has been estimated for European breeds is 15 to 25 °C with relative humidity not exceeding 60% (Kadzere *et al*., 2002).

Heat stress negatively affects animal productivity, reproductive fitness and health in production cows. This situation generates a decrease in voluntary intake of 10 - 20% (Silanikove, 2000), which implies a decrease in dairy production and lower calf weight at weaning (Kuczynski *et al*., 2011). In addition, heat stress decreases in fertility of cows and reduces pregnancy rates due to embryonic death. Lower weight and decreased viability of calves has also been reported (De Rensis and Scaramuzzi, 2003).

Management must consider local circumstances to effectively address the negative effects of climate change. According to Monterroso *et al.* (2014), Veracruz is highly and very highly vulnerable; many of its localities, including the present study site, already have a degree of affectation due to environmentally negative anthropogenic practices. Although the climatic exposure of the site is considered average, this same report indicates that the vulnerability to climate of the livestock sector in the entire state presents the following percentages: 6, 60 and 34%, for low, medium and high vulnerability.

The increase in the number of days with ITH in danger and emergency values observed in the present study, will effect voluntary intake and the daily weight gain of feedlot cattle (Renaudeau *et al*., 2012; Lalrengpuii and Ramendra, 2016). Renaudeau *et al.* (2012) propose three effective strategies to mitigate the high temperatures that affect livestock under animal production systems in tropical regions of the world: increasing feed intake, increasing intake of feed that decreases production of metabolic heat that leads to improvement of heat loss capacities in stressed individuals, and actions that involve genetic selection for heat tolerance. Studies have shown that there is an inverse relationship between resistance to heat stress and milk production (Hernandez *et al*., 2011). Breeding programs have sought to improve heat tolerance of high-yield dairy breeds (such as Holstein) by crossing with locally adapted breeds (*Bos Indicus*), which has had few benefits, reducing the ability to produce milk, relative to high-yield breeds (Jordan, 2003). As animals continue to be selected for dairy production, they will continue to be more sensitive to heat stress.

CONCLUSION

Livestock comfort has been reduced in recent years: the percentage of days with THI> 79 are expected to increase. It is recommended that actions be undertaken to mitigate the effects of heat stress in cattle and thus reduce losses in productivity and possible deaths.

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