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Chronobiological Indicators of Heat Stress in *Bos indicus* Cattle in the Tropics

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Abstract: In the tropical western part of Paraguay, the Chaco Boreal, general acticity and grazing behavior in Bos indicus cattle were measured continuosly during the hot rainy season. The objective of this study was to determine in which way the time rhythms of these behavioral patterns were influenced by the environmental cycles (light and ambient temperature) under the conditions of various tree densities and how heat stress could be reduced by shade. 24 Nellore steers were split up in four paddocks of 4 ha size each. Three paddocks differed in tree density (10 trees ha^{-1}, 20 trees ha^{-1}, bush-tree stripes) and the control, was completely cleared of bush and trees. A precondition for the analysis of the circadian time structures of "general activity" and "grazing" was the long term uninterrupted measurement with the help of data logger-collars. The bio-rhythmic research on the behavioral patterns based on the time-series studies was carried out with the autocorrelation and power spectral analysis. This procedure is recognized as a very sensitive indicator of environmental stress-causing stimuli affecting the animals. It shows in which ways and to what degrees the animals' biorhythms react to alternating environmental rhythms ("Zeitgeber") such as light or ambient temperatures. In addition to that the rectal temperature of the cattle as well as their body weights were measured every week. The general activity of the cattle from the three shaded paddocks was primarily grazing motivated. Rhythms typical of cattle can be ascertained respecting the two mean curves of general activity and grazing. In this case, there were temporal well-ordered conditions which allow behavior typical of cattle. The power spectrum exhibited, extremely strong harmonic oscillations, thus, favorable performance-promoting animal-environment relations. On the paddock without trees or shade, the mean curve of general activity contrasted sharply to the grazing curve. That signifies that the general activity of the unshaded cattle was not grazing-motivated. Instead, they sought shade. From noon until sunset, their grazing activity was at a very low level. The power spectrum for grazing showed definitive disorders in the time spectrum typical for cattle. This resulted in poor daily weight gains and significantly higher body temperatures ($p < 0.05$).

Key words: *Bos indicus* cattle, heat stress, behavior, shade

Introduction

Cattle husbandry has increased enormously in the tropical regions of South America. This has resulted in radical and extensive clearing of the natural forest vegetation. In the western sections of Paraguay, the Chaco Boreal, the cattle population has doubled and in Central Chaco even quadrupled in the last decade, and this caused a dramatically increased demand for grazinglands. Not only the supply of nutrition necessary for humans and animals must be taken into consideration, but also the negative effects of the excessive clearing of trees on the climate and soil. An ecological compromise aiming at less consumption of forests, on the one hand, and pasture use, on the other, will have to be found. This is urgently required to avoid irreparable damage to the environment resulting from forests and bushland being transformed into steppes.

The climatic conditions in this region, where extreme ambient temperatures of more than 45°C are registered, consequently require a reduction in animal heat load for reasons of health, welfare and productivity (Arnold and Dudzinski, 1978; Blackshaw and Blackshaw, 1994).

Thus tropical cattle husbandry must guarantee a minimum number of shade trees per unit of area to meet the vital needs of the animals and to avoid severe soil erosion.

Materials and Methods

The research was carried out during the hot, rainy season at the GTZ (Gesellschaft für technische Zusammenarbeit) station "Estaciõn Experimental Chaco Central," located in the Central Chaco Boreal of West Paraguay.

Four paddocks, each four hectares in size and differing in numbers of trees and/or clearing grade (Fig.1), were tested at the same time with respect to their impact on cattle behavior, physiology, and productivity. The first paddock (A) was completely cleared of bush and trees, the second (B) only in stripes. On the third paddock, 20 trees ha^{-1} (C) were left standing, and on the fourth 10 trees ha^{-1} (D).

The size of the paddocks, the grass species (*Panicum maximum*) as well as the number and breed of cattle (Nellore) per paddock were standardized.

Altogether 24 three-year-old Nellore steers with similar initial weights were used and randomly split up into four groups of six each per paddock. The experiment started at the end of the dry season, and took place mainly during the very hot rainy season, which continued, into the following year (August to February). Thus it was possible to measure in particular the heat stress resulting from the ambient temperatures and the

possibility of relieving it by supplying shade, as well as to evaluate it with respect to ethological aspects.

The animals' behaviors "general activity" and "grazing" were measured simultaneously on the four paddocks by using data-logger-collars (IMF Frankfurt/O., Germany). All of the movements the animals made were registered as "general activity," while those specific activities which involved head down movements were recorded as "grazing" (Scheibe *et al.*, 1997). These two behavioral patterns were measured per second, and in this special case, a 5-minute mean interval was calculated automatically. The logger data correlated with continuous visual observations (300 hours) of general activity with $r = 0.84$ ($P < .05$), and grazing with $r = 0.72$ ($P < .05$).

Based on the mean day curves of both behaviors (grazing and general activity), the specific objective was to find out in which way the course and level of the amplitudes showing general activity were influenced or determined by those of grazing, which were measured simultaneously (Figs. 2-5).

The bio-rhythmic research on the behavioral patterns based on the time-series studies was carried out employing autocorrelation and power spectral analysis (Sinz and Scheibe, 1976). By using these methods, one is able to analyze the biorhythmic time structures of ethological parameters such as general activity and grazing. This procedure is recognized as a very sensitive indicator of environmental stress-causing stimuli affecting the animals (Alados *et al.*, 1996). It shows in which ways and to what degrees the animals' biorhythms react to environmental rhythms ("Zeitgeber") such as light or ambient temperatures. By measuring and analyzing the behavior in this manner, it is possible to evaluate the animals' stress status as well as the environmental quality (Scheibe *et al.*, 1995).

The biorhythms of behavioral patterns can be separated into those that are periodical and others which are non-periodical. The latter are stochastic and, therefore, filtered out of the spectrum by using the autocorrelation analysis. The periodic oscillations show the correlation between the animal's biorhythms and the external Zeitgeber-rhythms. A power spectrum shows the level of the amplitudes of these periodical oscillations, i.e., animal activity highly related to the light and dark cycles of the environment can be seen in the high percentage of periodical oscillations within the power spectrum. The more oscillations of behavioral patterns are in an integer relation with the external 24 h day (Zeitgeber light and temperature), the better the adaptation of the animal to its environment. These biorhythm-components of 24-, 12-, 8-, 6-, 4-, 3-, or 2 hour duration are called "harmonic". In contrast, the non-harmonic sections of the periodical spectrum show a status of desynchronisation between animal and environment and are not in this integer relation to the 24 hrs day.

The "degree of functional couplings (DFC)" is calculated as a quotient of the harmonic among all registered periodical oscillations. It expressed the correlation between external (environmental) and animal internal processes and low values characterize stressful situations (Scheibe *et al.*, 1995). .

A digital thermometer was used twice a week to measure the rectal temperature, and the 24 Nellore cattle were weighed every second week over a period of 28 weeks. Rectal temperature and average daily gain data were analyzed, using Proc GLM in SAS (Statistical Analysis Systems Institute Inc.,1988).

Results and Discussion

Circadian Behavioral Rhythms: On the paddock without trees or shade (A), the mean curve of general activity contrasted sharply ($r = -0.41$, $P < 0.05$) with the grazing curve (Fig. 2). That signifies that the general activity of the cattle was not grazing-motivated. Instead, they sought shade. From noon until sunset, the grazing activity was at a very low level. This certainly had a negative effect on daily weight gain in the animals belonging to this group.

The cattle on the treeless paddock used larger volumes of energy for the obligatory thermic metabolism requirements. That is to say, the biological costs arising from the heat stress are extremely high and are aggravated by the decreased average daily gains. The treeless paddock offered the best nutritional basis, but it could not adequately be utilized from an ethological standpoint and, in particular, with respect to the motivation of needs hierarchy: the animals' ethological need to regulate the heat was greater than the impulse to graze.

Due to poor pasture conditions the animals on paddock (B) mainly browsed and fed on trees and bushes, but this was not measured by the data-loggers. Therefore the grazing curve appeared to be lower than that of the animals from the other paddocks (Fig. 3) and the correlation between both parameters was relatively low ($r = 0.71$, $P < 0.05$).

The mean curves of the two parameters general activity and grazing on the paddock with 20 trees ha^{-1} ($r = 0.87$, $P < 0.05$) and with 10 trees ha^{-1} ($r = 0.92$, $P < 0.05$) ran strictly parallel to each other (Fig. 4 and 5) which signifies that the cattle were motivated to graze. This parallelism differed in accordance with the varying habitat-typical density of the trees. On the paddock with 10 trees per hectare (C), the time and amplitude of the two parameters demonstrated the greatest convergence. The general activity was in this case primarily grazing motivated. They rested in the shade of the trees and moved primarily in order to graze. The activity peaks are highly light related (sunrise and sunset). This macroscopic status analysis showed that rhythms typical of cattle can be ascertained.

Biorhythmical Analysis: Cattle biorhythms were established on the basis of a power spectrum analysis

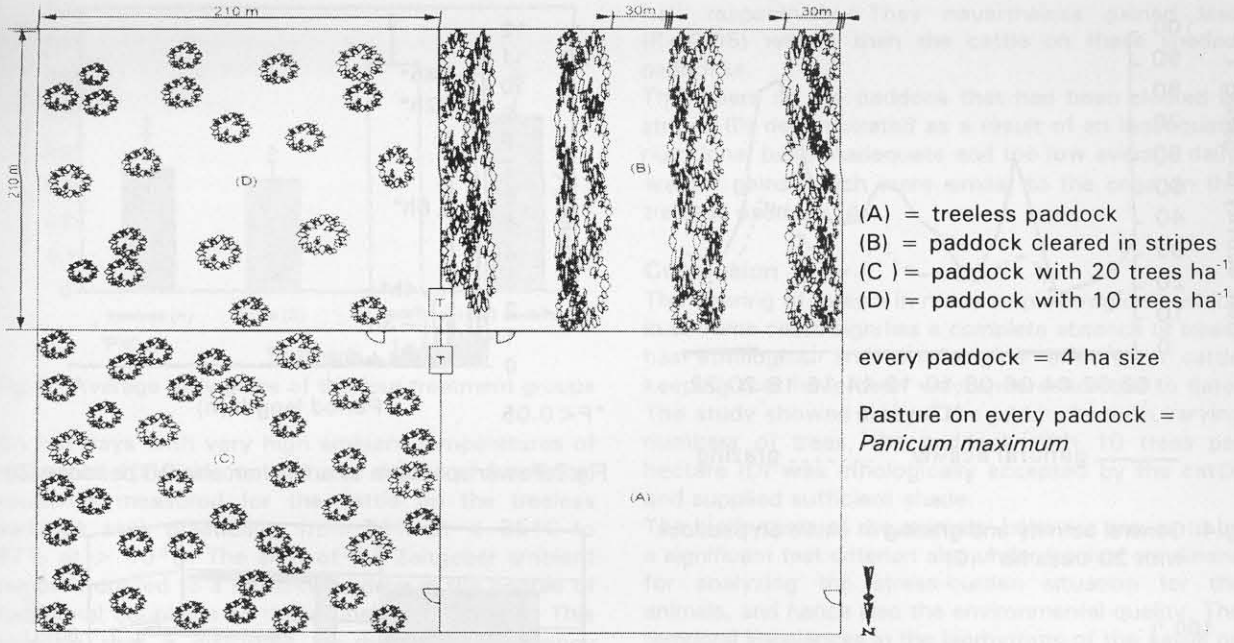

Fig.1: Schematic presentation of the research location in the central Chaco Boreal, Paraguay

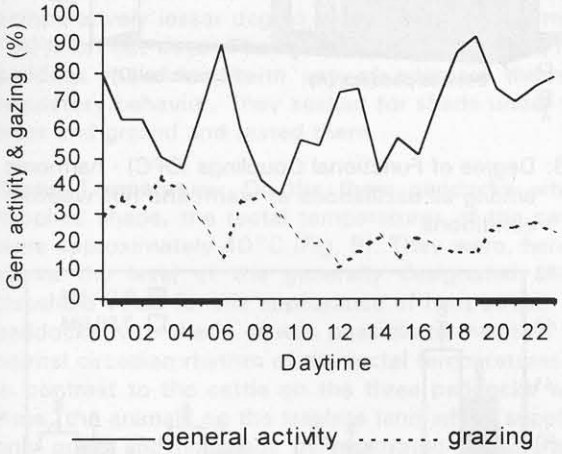

Fig.2: General activity and grazing in cattle on the treeless paddock (A)

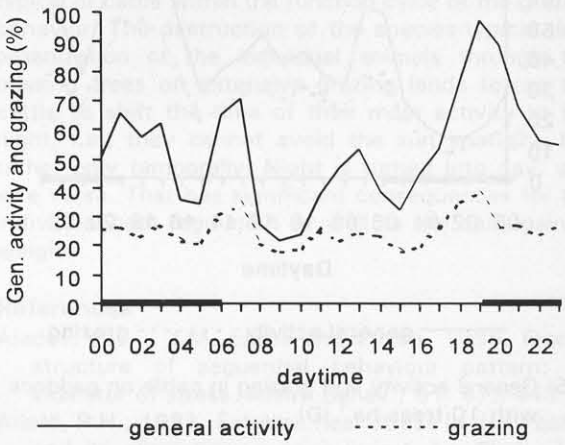

Fig.3: General activity and grazing in cattle on the paddock cleared in stripes (B)

employing the data-logger data for the two parameters "general activity" and "grazing activity". On the cleared paddock (A), the power spectrum for grazing showed definitive disorders (4.43 h rhythm, Fig. 6) in the time system typical for the behavior of cattle. A harmonic oscillation was demonstrated for only the 6 h rhythm. The high degree of discomfort from which the animals continually suffer under these environmental conditions is reflected here. In contrast to the treeless paddock, the animals on the paddock with 10 trees per hectare (D) displayed extremely strong harmonic oscillations (which are in an integer relation to the 24 hrs cycle of the environment), like 24-, 12-, 6-, and 4 h (Fig. 7).

In this case, there are temporal- and thus spatial-temporal-well-ordered conditions, which are appropriate for the species and allow behavior typical of cattle. The power spectrum exhibited favorable performance-promoting animal-environment relations (Veissier *et al.*, 1989).

The degree of functional couplings is considered to be the measure of animal-internal biorhythm synchronization (Aschoff *et al.*, 1967), and it describes the percentage of cyclic behavior components in the sample, which is synchronized with the circadian environmental rhythm (Langbein and Nichelmann, 1993). On the treeless paddock (A), the cattle showed at cloudy, and thus less hot days (< 35 °C),

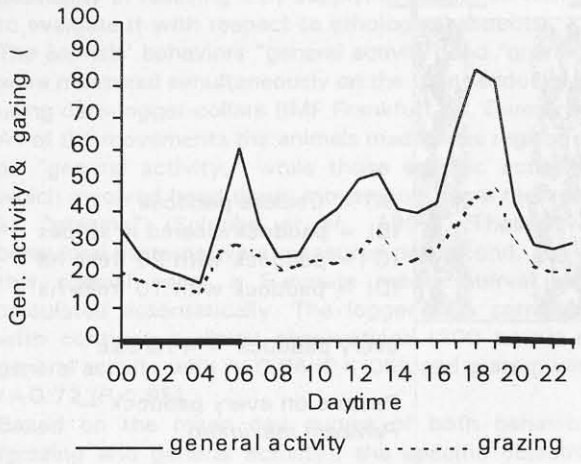

Fig.4: General activity and grazing in cattle on paddock with 20 trees ha^{-1} (C)

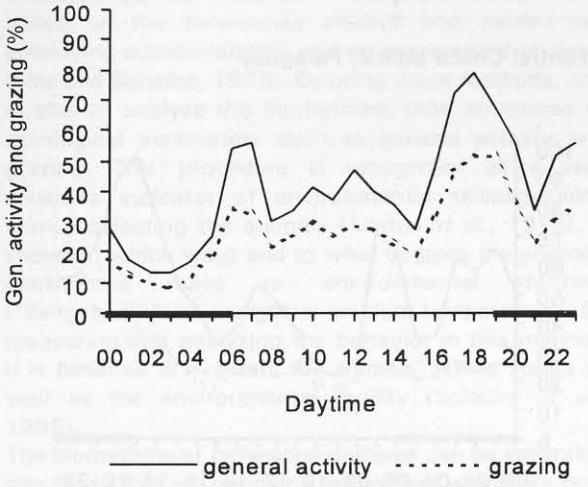

Fig.5: General activity and grazing in cattle on paddock with 10 trees ha^{-1} (D)

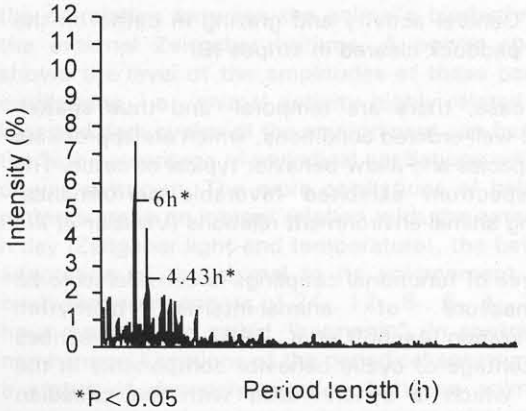

Fig.6: Power spectrum of an (stressed) animal on the treeless paddock (A)

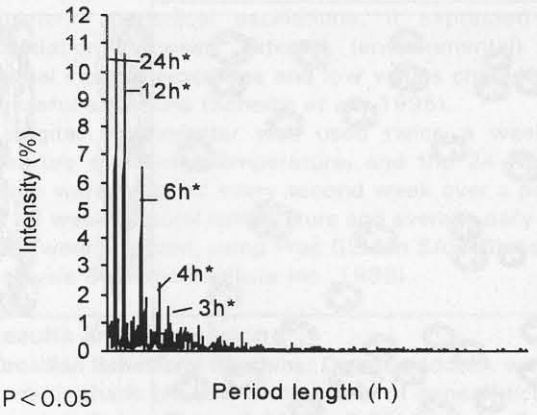

Fig.7:Power spectrum of animal on shaded paddock (D)

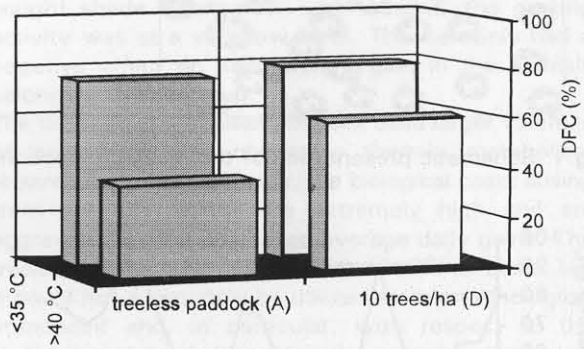

Fig.8: Degree of Functional Couplings (DFC) - harmonic among all oscillations at warm and hot weather conditions

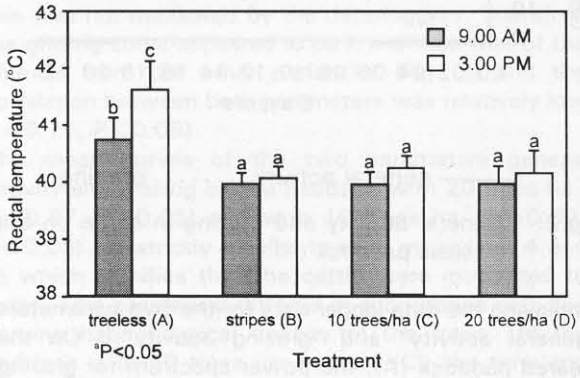

Fig.9:Rectal temperatures of the four treatment groups

approximately the same DFC-values as the ones on the 10 trees ha^{-1} paddock (Fig. 8). The shade cast by the clouds resulted in a higher DFC in the case of the animals on the treeless paddock, i.e., the disadvantages of the totally cleared paddock (A) were negated on cloudy days in comparison to paddock (D), the paddock with 10 trees ha^{-1}.

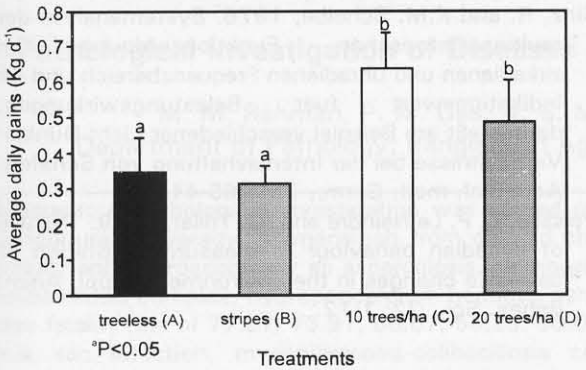

Fig.10:Average daily gains of the four treatment groups

On hot days with very high ambient temperatures of more than 40°C, in contrast, the degree of functional couplings measured for the cattle on the treeless paddock sank drastically: from 76% at < 35°C to 37% at > 40°C. The shift of the Zeitgeber ambient temperature led to a remarkable drop in the degree of functional couplings of these unshaded animals. This signifies that a disturbed bio-rhythmical frequency harmonization took place.

The degree of functional coupling of the cattle group on the paddock with 10 trees ha^{-1} (D) sank to a comparatively lesser degree, from ~80% on warm to ~60% on hot days. The animals on the 10-trees ha^{-1} paddock make long-term use of adaptive thermal-regulatory behavior. They seeked for shade under the trees and grazed and rested there.

Rectal Temperature: On the three paddocks which supplied shade, the rectal temperatures of the cattle were approximately 40°C (Fig. 9). They were, hence, above the level of the generally designated 39°C threshold value for the appearance of heat stress. On paddocks with shade, it was possible to maintain the normal circadian rhythm of the rectal temperatures.

In contrast to the cattle on the three paddocks with trees, the animals on the treeless land which supplied only grass and no shade demonstrated considerably increased rectal temperatures as well at 9 AM ($P<0.05$) as at 3 PM ($P<0.05$), even in the lethal range of more than 42°C in some cases (Ansell, 1981). A reason for the high rectal temperatures might be the excessive night grazing activity, which is atypical for cattle. The high degree of activity drastically reduces the period of rest. Thus the heat dissipating function of conduction by the cooling ground at night is extremely limited due to behavioral abnormalities.

Average Daily Gain: The average daily gains of the Nellore cattle (Fig. 10) corresponded only partially to the degree of grass coverage on the individual paddocks. The animals on the treeless paddock had 30% more *Panicum maximum* grass available than those on the paddocks with 10 trees ha^{-1} or 20 trees ha^{-1} respectively. They nevertheless gained less ($P<0.05$) weight than the cattle on these shaded paddocks.

The steers on the paddock that had been cleared in stripes (B) demonstrated as a result of an inadequate nutritional basis inadequate and too low average daily weight gains which were similar to the ones on the treeless paddock (A).

Conclusion

The clearing of forests in many tropical regions, which in extreme cases signifies a complete absence of trees, has ethological and physiological effects on cattle keeping that have been way underestimated to date. The study showed that of the paddocks with varying numbers of trees, the paddock with 10 trees per hectare (D) was ethologically accepted by the cattle and supplied sufficient shade.

The biorhythms of the animals' behavior proves to be a significant test criterion also under tropical conditions for analyzing the stress-burden situation for the animals, and hence also the environmental quality. The temporal imbalances in the biorhythms of the cattle on the treeless paddocks led to economic losses in production. Shade supplied by trees in connection with tree density secures the utility of the circadian rhythm typical of cattle within the function cycle of the grazing behavior. The destruction of the species-typical time organization of the individual animals through the missing trees on extensive grazing lands forces the cattle to shift the time of their main activity to the night, i.e., they cannot avoid the sun spatially, but rather only temporally. Night is turned into day, and vice versa. That has significant consequences for the individual heat regulation as well as the daily gain in weight.

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