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Heat exposure in sugarcane workers in Costa Rica during the non-harvest season

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This observational pilot study was carried out at three sugarcane companies in Costa Rica. Its main objective was to determine the potential for heat stress conditions for workers in one sugarcane-growing region in Costa Rica during the maintenance (non-harvest) period.

Wet bulb globe temperature (WBGT) variables were measured with a heat stress meter and threshold value limits and the Sweat Rate Indexes were calculated for each workplace. It was determined that workers in this study were in heat stress conditions. Costa Rica is likely to experience warmer temperatures and increased heat waves in the coming decades. It is therefore important to take action to decrease current and future heat-related risks for sugarcane workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics.

Keywords: *sugarcane*; *heat stress*; *productivity*; *climate change*; *wet bulb globe temperature*; *worker*; *Central America*; *Costa Rica*; *occupational health*

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In Costa Rica, the production of sugarcane has increased continually from year-to-year, with some 3,561,378 metric tons produced in 2008 (1), double the production in 1970. Despite the fact that the industry has modernized and has mechanized to a large degree, there is still a striking amount of physical labor required for the planting, maintenance, harvesting, and processing of sugarcane. Although accurate updated data are not available, it is estimated that some 20,000 permanent workers are employed by the industry in Costa Rica (2) and that some 7,890 harvesters were needed for the 2004–2005 harvest (3). Sugarcane workers face an already-documented high number of risks due to their work (2, 4–7).

One of the important risks faced by workers is exposure to extreme heat. Heat stress is a physical risk that can lead to a series of conditions ranging from discomfort and productivity loss to heat stroke and, potentially, death (8). Agricultural workers are among the highest risk groups for heat exposure (9) and Costa Rica is no exception. According to the National Institute for Insurance (INS) in Costa Rica, the agricultural sector has the highest number of reported accidents and the sugarcane industry reports the highest (in severity and incidence) accident levels among all agricultural industries (10). These numbers are likely under-representations due to the fact that much of the manual labor for the industry is carried out by informal sector workers, many of whom are migrant workers from Nicaragua. Accidents in the informal sector or that happen to groups of migrant or subcontracted workers often go unreported (2).

Study area

The cultivation of sugarcane requires a hot climate (around 27°C) with limited rain during growth and dry conditions during the maturation period (7).

This study took place in two sugarcane growing regions in Costa Rica: Turrialba located at latitude: 9°54′00′′ and longitude: 83°41′00′′ and San Carlos,

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located at latitude 10°37′02′′ and longitude 84°30′53′′. Although both regions have tropical climates and have the necessary conditions for growing sugarcane, they are among the coolest regions in Costa Rica where commercial sugarcane production takes place.

Sugarcane seasons and tasks

The sugar cane industry generally operates in two seasons: the harvest (zafra) season, during which sugarcane is not only harvested but also planted when necessary and processed; and the maintenance (no-zafra) period during which fertilizers are applied and general maintenance is given to the fields (such as removing stones, weeding, maintaining irrigation ditches, applying agrochemicals, and upkeep work on machinery). Generally, the working conditions and heat index are least favorable during the harvest season, but conditions during the maintenance season also deserve attention.

Objectives

There is a need for studies documenting current conditions for workers in the sugarcane industry with the aim of improving health and safety condistions for workers (4). It is also necessary to prepare for adaptation since Costa Rica – a tropical country located just north of the equator – is likely to experience warmer average temperatures or higher ‘high’ temperatures and/or an increase in extreme events including heat waves over the next century (11). It is likely that worker populations, particularly worker populations working in outdoor conditions, will be a vulnerable group in light of these changing conditions (12). This study was a pilot project carried out as part of continuing work in Costa Rica to use participatory methods to improve worker health and productivity conditions in the industry. The purpose of this study was to evaluate potential heat stress conditions for workers during the maintenance period of three sugarcane companies in San Carlos and Turrialba.

Methods

This exploratory observational study took place from August to October 2009 in three sugarcane companies, two located in San Carlos (here named Company A and Company B) and one in Turrialba (Company C) (Table 1). Company A is the largest with 2,500 hectares, while Company B has 1,250 hectares (with 550 in production at the time of the study), and Company C has 400 hectares.

Wet bulb globe temperature (WBGT)

Wet bulb globe temperature (WBGT) variables were measured (dry temperature, globe temperature, wet bulb temperature, air velocity, and percentage of humidity) in all three companies on four different days (a total of 12 different days) and used to calculate the WBGT. The sample size of WBGT measurements was calculated using meteorological data (August–October) from the National Meteorological Institute of Costa Rica (IMN) station located in San Carlos for Companies A and B, and the meteorological station at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) located in Turrialba for Company C. It was determined that 160 measurements were needed for Companies A and B while 85 measurements were needed for Company C. All measurements took place between 9:00 am and 2:00 pm.

Measurements were taken using a heat stress monitor model Quest Temp 36 with a precision of $\pm 0.5°C$. Measurements were taken every 15 min.

Metabolic rate, threshold limit values, and rate sweat index

Standards recommended by the National Institute of Occupational Safety and Health in Spain known as NTP (Notas Técnicas en Prevención/Technical Prevention Notes) based on ISO recommendations were used for this study. Table 2 shows a list of the NTP standards used in this study and the ISO recommendations they are based on. Observation guides were developed and utilized by researchers in order to record the variables (i.e. postures, type of work, and inclination of walking surface and movement of worker) necessary to calculate the metabolic rate using the standard NTP 323 as recommended by the National Institute of Occupational Safety and Hygiene in Spain. One guide was filled out for every worker present on the day observations were made. Variables such as height and weight were obtained by asking workers ($n = 21$, $n = 13$, and $n = 4$ in Companies A, B, and C, respectively), and a metabolic rate was calculated for each individual worker according to the task (for example, applying fertilizer or cutting stalks) he was carrying out in the moment he was observed by the researcher. Individual values were then used to calculate the average metabolic rate for each company (Table 4).

WBGT Reference Values (Threshold Limit Values) for WBGT were determined using the guidelines in the NTP

Table 1. Company descriptions and data sources

Company	Location	Altitude (meters above sea level)	Number of workers per work group	Number of manager interviews
A	San Carlos	225	25	1
B	San Carlos	640	13	1
C	Turrialba	660	4	1

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Table 2. NTP standards recommended by the National Institute of Occupational Health and Safety used in this study and the ISO standards they are based on

Standard/calculation	NTP	Based on ISO
Estimation of heat stress: WBGT index	322	7730
Determination of metabolic rate	323	8996
Heat stress evaluation, Rate Sweating Index	350	7933

322 (based on ISO 7730) according to the calculated metabolic loads.

The Sweat Rate Index was calculated according to the NTP 350 (based on ISO 7933) using climate variables from the least favorable (highest 'high' WBGT) day in order to predict the evaporation, sweat, and humidity conditions necessary to avoid risk. These variables were then used to calculate the maximum time allowed for each job task under the particular weather conditions. For these calculations, a maximum dehydration of 1,500 w/m^2 was used and all of the workers were considered to be fully acclimatized.

Results

General characteristics

Job tasks in each company were carried out by groups of workers each with their respective supervisors. All of the workers and supervisors were men. Workers in all three companies received a fixed salary according to the minimum wage in Costa Rica of 821 colones per hour (approximately US$1.50 per hour depending on the exchange rate) and there is no other incentive payment for the tasks carried out during the non-harvest time.

None of the workers were using personal protective equipment on the days the observation took place. Clothing used was worn at the discretion and cost of each worker. The general description of each workplace can be seen in Table 3. The number of workers per work group varied greatly between the different companies with one group of 4, one group of 11, and one group of 21 workers ranging in age from 18 to 54. The clothing worn by workers in each work group was similar and generally consisted of a hat (baseball or cotton, brimmed hat), handkerchief (tied around the neck or hanging from the back of a hat to cover the back of the neck), long sleeved shirt, long pants, and rubber boots.

Workers carried their own water jugs and none of the three companies had a nearby water source for refilling water during the shift. Most workers brought two water bottles of approximately 4liters each to the workplace.

Calculation of metabolic rate

According to the NTP guideline 323 and using direct observation and interviews with managers and workers, a metabolic rate was calculated first for individual workers and then for the work group on average (Table 4). The following variables were taken into account: posture (sitting, crouching, kneeling, or standing), type of work (work with two arms, trunk, or one arm), movement (not including lifting), and clothing used. Basal metabolisms for individual workers were calculated based on interviews with each person and then averaged for the group. The highest basal metabolism was at Company A, where sugarcane stalks were being cut for planting (73.43 Kcal/h), corresponding to the highest total metabolic load of 425.63 Kcal/h. The workers carried out the same task during all 4 days of observation, which required being in a standing position, or a standing inclined position, and with intense movement from both arms for cutting and moving the stalks. The field where this group was working was completely flat so that there was no calculation for walking on an inclined slope. In Companies B and C, there were different tasks carried out during the different days of observation, so an average metabolism was calculated for the 4 days. The lowest average basal metabolism was 67.25 Kcal/h at Company C where herbicides were being applied and general maintenance (weeding) was carried out, corresponding to a calculated total metabolic rate of 346.5 Kcal/h. The workers in Company B were applying fertilizer and doing general field maintenance (weeding). This corresponded to a basal rate of 68.6 Kcal/h and a total metabolic rate of 397.3 Kcal/h.

Table 3. General work description of each company

Company	Number of workers per work group	Hours worked per day (shift)	Age range of workers (years)
A	21[a]	9 (6:00–15:00)	21–50
B	11	9 (6:00–15:00)	18–54
C	4	7 (6:00–13:00)	23–49

[a]Although 25 workers were part of the work group, 21 were working on the day interviews were conducted.

Table 4. Calculation of basal metabolism, total metabolism, and threshold limit values

Company	Number of workers	Basal metabolism (Kcal/hr)	Total metabolic rate (Kcal/hr)	Range of total metabolic rate in individuals (Kcal/hr)	Tasks completed	Classification of work	TLV determined (°C WBGT)
A	25	73.43	425.63	171.9–450.5	Cutting cane for planting	Crouched position, intense labor with both arms, flat surface	26
B	13	68.6	397.3	164.1–406.3	Applying dry fertilizer (with hands), weeding	Crouched position, moderate effort with both arms, flat surface	27
C	4	67.25	346.5	164.1–429.7	Applying herbicides, weeding	Crouched position, moderate effort with both arms, flat surface	27

Wet bulb globe temperature (WBGT) reference values

Following the guidelines in the NTP 323, the WBGT reference values (Threshold Limit Values; TLV) calculated for Company A was 26°C (WBGT) while for Companies B and C, where the metabolic rate was slightly lower, the TLV was calculated at 27°C (Table 4).

Sweat Rate Index

Calculations regarding the Required Sweat Rate Index (Table 5) show a risk for an excessive increase in internal body temperature in all three companies. According to this method, however, a significant risk for dehydration did not exist.

Wet bulb globe temperature (WBGT) measurements

The climate variables measured are reported in Table 6 with their respective minimum, median, and percentile values by company and day. Average climate variables and WBGT are reported in Table 7. Average WBGT values were higher in Company A (29.7–31.2°C), but daily WBGT averages of at least 29.5°C were seen in Company B (day 3) and C (day 2 and day 4) as well. The maximum WBGT was seen in Company C on day 4 (32.9°C) and a similarly high value was attained on day 3 in Company A (32.8°C). The largest range of WBGT was seen on day 1 in Company B where, although the average was only 26.4°C, there was a 7.2°C between the high and low values (24.8–32.0°C). The smallest range of WBGT values was seen in the same company just 2 days later where the average value was 29.8°C and the range only 2.2°C (28.7–30.9°C). The lowest WBGT (day 3, Company C) was followed by the day with the highest WBGT measurement of any of the three companies (32.9°C, day 4, Company C).

The most significant variable in determining the differences in WBGT across days and companies was the dry temperature in which daily averages ranged from 26.8°C (day 1, Company B) to 31.7°C (day 1 and day 4, Company A) and reached a maximum of 34.0°C (day 3, Company A). Both the highest (4.06 m/s) and lowest (0.72 m/s) air speeds were seen in Company A (day 1 and day 4 respectively). The average humidity was above 50% on all days in all three companies and reached a high of 83.0% (day 2, Company C) and above 75% humidity was seen at least once in all three companies.

Threshold limit values (TLVs) and heat stress

With the TLVs calculated at 27°C WBGT (Companies B and C) and 26°C WBGT (Company A), it is possible to see that there was a risk of heat stress for all three companies during each day of the study with the exception of day 3 in Company C (Fig. 1). On this day, there were cloudy skies and light drizzle, resulting in cooler conditions for the duration of the sampling time. During the other days in all

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Table 5. Results of sweat index analysis

Company	Values	Evaporation	Humidity	Sweat	Maximum time (min)
A	Required	272.12	3.39	−57.23	15.63
	Observed	80.00	1.00	160.35	
B	Required	245.25	9.06	−6.13	13.00
	Observed	27.08	1.00	54.17	
C	Required	222.57	2.33	−129.65	23.61
	Observed	95.48	1.00	190.97	

three companies, there were clear skies or partly cloudy skies. With the exception of day 3 in Company C, the average WBGT was above the TLV on all days in all three companies, there were only 2 days in which any of the values recorded were below the calculated TLV (day 1 and day 4, Company B).

Discussion

Wet bulb globe temperature (WBGT)

In general, WBGT in Company A was higher than in Companies B and C, a difference that is likely attributable largely to altitude since Company A is located at 225 meters above sea level (m.a.s.l.), whereas Companies B and C are located at 640 and 660 m.a.s.l., respectively (Table 1). Nonetheless, the highest WBGT measured (32.9°C) was from Company C (day 4) and it followed the day with the lowest WBGT (22.9°C, day 3, Company C). This difference of 10°C WBGT in 24 h demonstrates the variability possible from one day to the next and the need for employers and workers to be prepared for rapidly changing climate conditions. All three companies had at least 2 days in which the WBGT reached at least 30.0°C.

Measurements at all three locations demonstrated generally high humidity and relatively low wind speed, factors that contributed to the high WBGTs registered. High humidity and low wind speed reduce the effectiveness of sweating by decreasing the amount of evaporation that can take place while thereby decreasing possibilities for workers to lose excess heat. This may be further exasperated by clothing worn by workers. Clothing was worn and purchased at the discretion of the workers. Decisions about what clothing and boots to wear are likely made based on economic possibilities rather than effectiveness in combating heat exposure. This may be one area for future study with the potential to reduce heat stress in sugarcane workers.

Metabolic load, threshold limit values (TLVs), and Sweat Rate Index

Importantly, when compared to the threshold limit value calculated, there were only 2 days (day 1 and day 4, Company B) of the 12 total in which *any* of the measurements were below the threshold limit value. Workers in this study started their shift at 6:00 am when WBGTs were likely lower but were not measured. Even if the WBGT was considerably lower, the majority of the work day (6 h out of 9-h shifts for Companies A and B) and 4 h out of 7-h shifts for Company C) were included in the study.

One of the most common and practical ways for avoiding heat stress in the workplace – working during the coolest (usually early morning) hours – has limited viability for these workplaces since the shift already starts shortly after sunrise. This means that employers and researchers need to be creative in creating work systems that allow for workers to be protected. Examples of possible strategies include programmed breaks in the shade, work rotation, and continual rehydration either with water or hydration drinks. Hydration in sugarcane fields is particularly challenging (4, 13) for multiple reasons including: rapid heating of drinking water that

Table 6. WBGT maximum, minimum, median, and percentile values by company and day (measurements taken every 15 min)

Company	A				B				C			
Day	1	2	3	4	1	2	3	4	1	2	3	4
Maximum WBGT	31.5	31.6	32.8	32.6	32.0	29.8	30.9	30.4	30.6	28.6	28.5	32.9
75th percentile WBGT	30.6	31.0	32.1	31.4	28.9	28.8	30.5	28.3	30.2	28.1	26.2	31.9
Median WBGT	30.0	30.4	31.2	29.7	26.4	28.4	29.8	27.4	29.5	27.7	24.4	30.1
25th percentile WBGT	28.7	29.9	30.7	28.9	26.1	27.6	29.2	26.2	28.6	27.1	23.8	29.3
Minimum WBGT	27.1	28.5	29.2	28.2	24.8	26.1	28.7	25.3	28.2	26.4	22.9	27.1

Table 7. Climate variables and WBGT by company and day

Variable		Company A				Company B				Company C			
		D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
Dry temperature (°C)	Average	30.0	31.7	30.1	31.7	26.8	28.0	30.0	27.9	30.0	27.8	25.2	30.7
	SD	1.12	0.73	1.72	0.97	1.91	1.32	1.20	1.55	0.59	0.73	1.29	1.68
	Max	31.3	32.8	34.0	33.8	30.3	30.2	32.1	30.6	30.9	29.6	27.7	33.4
Globe temperature (°C)	Average	38.1	41.9	40.2	39.4	34.8	39.3	43.8	34.3	43.7	39.4	31.2	43.5
	DE	0.72	3.03	3.22	3.49	4.98	2.91	2.12	4.26	2.77	1.66	4.54	3.78
	Max	42.7	45.7	47.2	44.8	43.3	44.6	46.8	44.3	47.5	43.2	41.8	52.0
Wet bulb globe temperature, (°C)	Average	27.1	27.1	26.7	27.2	25.4	24.8	26.0	25.4	25.2	24.1	23.2	26.3
	DE	0.72	0.55	0.50	1.02	1.01	0.60	0.37	0.65	0.47	0.55	0.89	0.95
	Max	28.4	28.4	28.8	30.3	27.8	25.7	26.8	26.6	25.9	25.3	25.0	27.5
Air velocity (m/s)	Average	0.72	3.33	3.06	4.06	1.50	2.73	2.33	2.10	1.30	2.77	1.52	1.18
	DE	0.85	1.57	1.19	1.60	0.71	5.20	1.17	0.79	0.47	2.47	1.05	0.92
	Max	3.80	8.20	5.00	7.80	3.10	6.80	5.10	3.40	2.10	5.20	4.00	3.00
WBGT(°C)	Average	30.0	30.4	31.2	29.7	26.4	28.4	29.8	27.4	29.5	27.7	24.4	30.1
	DE	1.26	0.89	1.05	1.31	2.02	1.07	0.67	1.39	0.83	0.58	1.61	1.57
	Max	31.5	31.6	32.8	32.6	32.0	29.8	30.9	30.4	30.6	28.6	28.5	32.9
Relative humidity (%)	Average	59.1	47.8	56.4	53.4	63.3	58.7	48.4	67.7	47.2	51.1	69.7	42.6
	DE	7.46	4.15	6.64	3.61	11.4	5.20	5.15	9.49	4.44	2.47	8.91	8.10
	Max	78.0	56.0	71.0	59.0	81.0	68.0	58.0	82.0	53.0	72.0	83.0	71.0

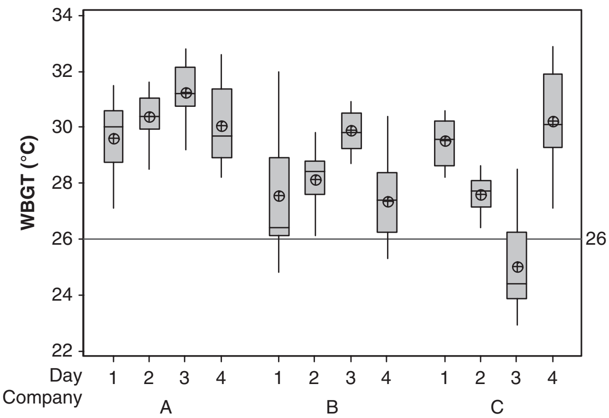

Fig. 1. WBGT measurements by day and company and threshold value limit (26°C for Company A and 27°C for Companies B and C).

workers bring to the field, the amount of liquid workers are culturally (workplace culture) accustomed to drinking, doubt about water quality, the impossibility of carrying bottles and cutting cane at the same time (thereby forcing workers to walk back to fetch their water bottles at their last stopping point), and distance from filling stations (when present).

The Required Sweat Rate Index as applied in this study demonstrated conditions of concern since, according to this system, workers should only be allowed to work approximately 15 min, 13 min, or 24 min of every hour in Companies A, B, and C, respectively, on the days with the highest WBGTs registered. This option is clearly not attractive to employers nor is it practical for workers. Both the Sweat Rate Index and the WBGT standards have been criticized as being overprotective of acclimatized workers in tropical climates (14) and in conditions where mean radiant temperature exceeds dry air temperature (15). The need for 'tropicalized' guidelines regarding workplace heat exposure (14) has already been called for by other authors. The present study demonstrates deficiencies in the Sweat Rate Index (specifically that it recommends restrictions that are impractical or impossible to implement) that could be improved through modifications of the index or implementation of new methodologies. Although the WBGT index was a helpful tool in this study, it does require the use of sophisticate and expensive equipment as well as advanced knowledge of the technique, thereby making implementation difficult in many workplace settings. Procedures and guidelines that are easier to understand and implement would be helpful in the sugarcane industry and other sectors in the tropics.

Despite running the risk of being overprotective or recommending limits that are impractical, the results of this study clearly demonstrate heat stress conditions that must be improved for workers. This is particularly true since the climate in the regions where the study took place is among the least harsh (non-harvest season in the coolest sugarcane-growing regions of the country) experienced by workers.

Heat and climate change

Both regions where this study took place are expected to see an increase in temperature (dry bulb temperature) over the next century. Using the worst case scenario, these changes are expected to be quite big (4–5°C increase in maximum temperature, 2–4°C increase in minimum temperature in Turrialba; 4–5°C increase in maximum temperature, 2–3°C increase in minimum temperature in San Carlos) (11). Although a decrease in precipitation is predicted for most of the country (therefore likely to decrease humidity), San Carlos is expected to have no significant change in precipitation over the next century outside of normal variance (11). Therefore, the high humidity seen in this study is likely to remain a problem for workers near San Carlos.

The changes in temperature, and to some degree humidity levels, are likely to be important to working populations in the rest of Central America and elsewhere in the tropics since many are already working at the limits of temperature extreme. Regardless of psychological motivation or economic incentive, increased WBGT will affect workers' productivity and likely their health as well (8).

This study demonstrates the need to work toward strategies to protect workers from the negative health and productivity effects of heat exposure under current conditions. The non-harvest season is generally considered the less intensive for workers and the companies where this study took place have some of the most favorable (coolest) climatic conditions compared to other sugarcane growing areas in the country. If, as predicted, temperatures rise in Costa Rica and elsewhere in the tropics, there is a pressing need to get strategies in place before conditions, which are already dangerous for workers, become worse.

It is of note that the sugarcane industry and the Costa Rican government have invested in studies of climate change to adjust to current changes/variability in climate and to avoid productivity loss in the face of future changes (16). The research and measures that are being taken, however, are focused on crop production and pest reduction. Up until now there have been few, if any, efforts to address climate as it affects the health and productivity of workers. One company in the northern Guanacaste region of Costa Rica is showing leadership in this area by joining university researchers from the National University and the Costa Rican Technical Institute in a project to study and improve the heat-related health and productivity of sugarcane cutters. The findings of the study reported here and future work in the sugarcane industry can lead to improvements for the workers of this sector, and will also be applicable to other labor-intensive job sectors in the tropics.

Conclusions

This study demonstrated a clear risk of heat stress for workers in non-harvest season tasks in three companies in Costa Rica. The non-harvest season is generally considered the least intensive of the two seasons for workers. Likewise, the two companies where this study took place have some of the most favorable (coolest) climate conditions compared to other sugarcane growing areas in the country. Costa Rica is likely to experience warmer temperatures and increased heat waves in the coming decades. It is therefore important to take action to decrease current and future heat-related risks faced by sugarcane workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics.

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