Estimation of Heat Dissipated During Mounding Operation in Farming

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Abstract

Most of the heat produced in the body is generated in the deep organs, especially in the liver, brain, heart and the skeletal muscles during physical work like mounding operation in farming. This heat is transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings through conduction, convection and radiation. The main aim of this study was to determine the amount of heat dissipated during mounding operation. Seven men and five women were randomly selected among farmers in two villages in Abeokuta, Ogun State. The subjects' body core temperatures and the environmental temperatures were obtained. The heat dissipated by the farmers was determined from the conduction, convection and radiation models in thermodynamics. Some of the values used in the application of the models were obtained from the literature. The maximum heat dissipated during the mounding operation was determined as 416.21 W. It was concluded that mounding operations may not result in heat stress and could be due to the methods employed by the farmers.

Keywords

Heat Dissipation; Mounds; Manual Work; Heat Stress; Thermodynamics; Farmers

Introduction

Agricultural work is carried out during various weather conditions as crops must be planted and harvested, livestock must be tended, and every daily farm routine completed. Farmers in the tropical region are habitually exposed to extremely hot environment and high severity of work and are therefore prone to heat stress and other health hazards [1, 2]. As noted by Yisa [3], peasant farmers cultivate 80 percent of the food consumed by Nigerians. Similarly, Oyedemi and Olajide [4] estimated that 86 percent of the land cultivation in Nigeria is done using hoes, cutlasses and similar tools. The import of these findings is that farmers using hoes, cutlasses and similar tools cultivated the majority of the foods being consumed by Nigerians. Mounds are made using hoes after weeding of farmlands and not long before planting. To form mounds, furrows are cut in the farmlands at a distance of 60–70 cm from one another and usually 16–20 cm high and 20–25 cm wide.

The use of these tools results in multiple risk factors for musculoskeletal discomfort and injuries [5, 6]. If discomfort and injuries are combined with heat stress, Nigerian farmers may be subjected to their combined effects that may be disastrous, lead to reduction in work efficiency and productivity and even threaten survival [7]. Heat is has been regarded as environmental and occupational hazards [8]. Ergonomists define "heat stress" as the exposure to high heat, while "heat strain" is the physiological impact of heat stress and "heat stroke" is a combination of serious symptoms possibly leading to unconsciousness and death [9, 10]. Heat exposure and heat stress will affect a person’s physical activity [10] with workers in heavy work most affected as heat is generated in the body. The body can be cooled down by sweating or other cooling mechanism to avoid adverse impact of heat stress or to work slowly or reduce work output [11]. Strenuous physical activities under high air temperatures and high humidity have a high potential for inducing heat stress to workers engaged in such operations [12].

Three parameters were defined by Fanger [13] for a person to be in thermal comfort and these are the body is in heat balance, sweat rate is within comfort limits and mean skin temperature is within comfort limits. Heat stress results from imbalance between the demands imposed on the worker by the task and the environment, and the worker's capacity to eliminate the heat load as modified by clothing [14].

From physiology, performing more demanding physical work would make the body's muscles require more oxygen. The heart responds to this increased demand with a proportional increase in heart rate (HR). The increase in work also leads to an increase in metabolic heat production. As heat is produced, it is either stored internally, causing a rise in the body core temperature, or is lost to the surrounding environment. The body core temperature is naturally regulated by the human body, and may tolerate a temperature difference of usually to within 3 to 4 degrees Celsius. As work continues, and heat is stored, the body will attempt to lose heat to the environment by shunting warm blood to the skin, where it is cooled by convection or evaporative mechanisms. As the need for cooling increases, blood flow to the skin increases. Increased blood flow to the skin leads to an increase in HR beyond that needed to supply tissues with oxygen for work [15].

Most of the heat produced in the body is generated in the deep organs, especially in the liver, brain, heart and the skeletal muscles during physical work. This heat is transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings through conduction, convection and radiation. Therefore, the rate at which heat is lost is determined mainly by two factors: how rapidly heat can be conducted from where it is produced in the body core to the skin and how rapidly heat can then be transferred from the skin to the surroundings. Heat could be radiated from (if the body temperature if greater than that of the surrounding) or to the body (if the body temperature is less than that of the surrounding) depending on the body temperature.

Heat dissipated during physical activities can be measured directly (direct calorimetry) or the amount of oxygen consumed (indirect calorimetry) to indicate the caloric expenditure by the body. However, both have limited practical application because they interfere with work.

The aim of this work is to estimate the heat dissipated by the body of farmers while preparing mounds for planting of crops.

Material and Method

If the body is to remain at approximately a constant temperature then, on average, the heat outputs from the body must be equivalent to heat inputs to the body. This is known as heat balance and a usual starting point for derivation is the heat balance as stated in Eq.1 [16].

$$M - W = E + R + C + K + S \quad (1)$$

here M is the energy produced by the metabolic processes of the body and W is the energy required for physical work; C is the heat loss by convection; R is the heat loss by radiation; K is the heat loss by conduction; E is the heat loss by evaporation; and S is the heat stored.

If no heat is stored in the body, the heat dissipated could be estimated by adding Eq. 2 for heat transferred by conduction through the hand to hoe and foot to the ground; Eq. 3 for heat transferred by convection; and Eq. 4 for heat transferred by radiation resulting to Eq. 5. ISO7933 gave the maximum allowed amount of dehydration for manual workers as D_{max} = 3900 g to prevent dehydration and thermal fatigue [17] which is equivalent to sweating heat release of 1.5 kWh/m^2 [18] for a working day (6-8 hours). Therefore, we used heat transferred through evaporation, E = 1.5 kWh/8h = 187.5 W/m^2.

$$Q_c = \frac{kA_{pf}(T_{core} - T_{environment})}{t} \quad (2)$$

here k = thermal conductivity of the skin, A_{pf} = area of the palm and foot, T_{core} = body core temperature, $T_{environment}$ = ambient temperature, t = thickness of the skin at the palm and foot, Q_c= heat dissipated by conduction through the palms (since they in contact with the hoe) and foot (since they in contact with the ground)

$$Q_{convection} = h_c A(T_{core} - T_{environment}) \quad (3)$$

h_c = specific heat capacity of the skin; $Q_{convection}$ = heat dissipated by convection which takes place through the entire surface of the human body; A = total surface area of the human body

$$Q_r = e\sigma A(T_{core}{}^4 - T_{environment}{}^4) \quad (4)$$

e = Emissivity of the skin, σ = Stefan-Boltzman constant = 5.6703 x 10^{-8} Watt/m^2 k^4

$$\begin{aligned} Q_{Total} &= \frac{kA_{pf}(T_{core} - T_{environment})}{t} + h_c A(T_{core} - T_{environment}) + e\sigma A(T_{core}{}^4 - T_{environment}{}^4) \\ &= (T_{core} - T_{environment})\{A_{pf}\frac{k}{t} + Ah_c + e\sigma A(T_{core}{}^3 - T_{environment}{}^3)\} \end{aligned} \quad (5)$$

Seven (7) men with a mean age of 47.3 years, standard deviation, SD of ± 10.33 years and 5 women with a mean age of 33 years, standard deviation, SD of ± 6 years participated in the study.

The protocols for the study were explained to the participants and their consent obtained. The field experiment was conducted in the month of December 2011 on farms in Abule Ojere and Onikolobo area of Abeokuta South in Ogun State. During the experiment, various parameters namely weight, height, body and environmental temperatures were recorded. Three replications of the measurements were taken to ensure correctness, however, no changes were observed.

The following values were used in the application of the model:

(i) Thermal conductivity of human skin, k = 0.21W/m-K [19]

(ii) Thickness of human skin, t = 0.0046 m [20]

(iii) Area of palm = 1% of BSA [21, 22]

(iv) Area of foot = 0.0591 m^2 [23]

(v) Specific heat capacity of human skin, h_c = 3.4 W/m^2 per K [24]

(vi) Emissivity of human skin, e = 0.98 [25]

(vii) Stefan-Boltzman constant, σ = 5.6703 x 10^{-8} Watt/m^2 K^4

(viii) Body surface area (BSA), A = 71.3989 x $H^{(.7437)}$ x $W^{(.4040)}$ [26]

(ix) Area of palm and foot, A_{pf} = 1% of BSA + 0.0591 m^2

Table 1. Anthropometric data of the participant

Percentiles	Age (years)	Weight (kg)	Height (m)	T_{core} (°C)	$T_{environment}$ (°C)	Resting Time(min)	Working Time(min)	Body Surface Area (m^2)	A_{pf}
5^{th}	29.2	52.9	1.55	36.2	31.9	50	201.5	1.56	0.15
50^{th}	38	58.9	1.71	36.4	32.7	61	298.5	1.70	0.15
95^{th}	56.3	73.3	1.92	36.9	35.2	95.4	330	1.98	0.15

Results and Discussion

Table 1 show that the mean age of the farmers was 38 years, mean weight of 58.9 kg and mean height of 1.71m. The farmers had a mean BMI of 20.1 kg/m^2 and about 5 percent of them were underweight with a BMI of 17.9 kg/m^2. They worked for an average of 298.5 minutes and had rest for an average of 61 minutes. The average surface area of their skin was

1.70 m^2 and that of the palm and feet were 0.15 m^2. The farmers lost a maximum heat of 416.21 W to the atmosphere while performing the mounding operations.

Table 2. Heat energy dissipated by the participants

Percentiles	Heat due to evaporation	Heat due to Conduction	Heat due to convection	Heat due to radiation	Total Heat
5^{th}	295.41	9.22	15.35	0.04	333.06
50^{th}	318.75	17.91	29.65	0.08	361.43
95^{th}	363.19	20.58	34.52	0.09	416.21

The mean working time for mounding operation of 298.5 minutes obtained in the current study compared favourably with 274 minutes obtained by Dada and Abiola [27] for ridging operation. Similarly, the mean resting time for mounding operation of 61 minutes obtained from the current study compared favourably with 68.5 minutes obtained by [27] ridging operation. The mean body core temperature of 36.4°C is not up to the 38°C limit set by the American Conference of Governmental Industrial Hygienists (ACGIH) in 1992 to prevent heat stroke. It is also less than the tolerance limit of 39 to 40°C when working in hot environment, in view of the critical thermal maximum as proposed by Pandolf and Goldman [28] and Mairiaux and Malchaire [29]. This may be due to the fact that the farmers observed some minutes of rest in between work which allow them to let out some heat before resuming the mounding operations. In addition, the farmers started work early in the morning (6 a.m) and stopped working at 1 p.m. The circulatory function is affected by the hot environment [30] as while working in the hot environment, the skin vessels dilate to increase blood flow in the skin raising the skin temperature and increasing the heat radiation from the skin. This dilation of skin vessels simultaneously leads to the decrease of blood pressures. Normal body function will be maintained if the deep body temperature is within a very narrow limit of ± 1°C around the acceptable resting body core temperature of 37°C.

To maintain the body temperature equilibrium, a constant exchange of heat between the body and the environment is necessary. This exchange is governed by the fundamental laws of thermodynamics [31], which the current study confirmed. The type and level of activity performed by people exposed to hot environments will determine the energy used for the activity and therefore the heat produced by the body. Since heat stress occurs when the body takes in and/or produces more heat than it gives off, thus raising the core body temperature [32] and the core body temperature is within the normal, the mounding operation in this study would not lead to heat stress for the farmers. Miller and Bates [33] had observed that Thermal Work Limit (TWL) of more than 220 W/m^2 in an unrestricted environment like working outdoor by workers performing continuous manual labour while fully exposed to the sun would not lead to heat stress. This value using the maximum body surface area is 435.6W.

Conclusions

It may be concluded from this work that the heat dissipated during mounding operation in farming was 416.21 W and may not lead to heat stress. This may be because the farmers did not work beyond 1 P.M and also observed rests in between work. In addition, the study confirmed the application of some thermodynamics models in the determination of heat dissipated from the body during the mounding operation. This study is however limited due to the number of participants as few people now reside in the villages.

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