AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION	A. PRIMARY	Public Health
	B. SECONDARY	Nutrition

2. TITLE AND SUBTITLE
Energy expenditure cutting sugarcane

3. AUTHOR(S)
Spurr,G,B,; Barac-Nieto,M.; Maksud,M.G.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	7p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Department of Physiology, The Medical College of Wisconsin, Milwaukee, Wisconsin 53233

8. SUPPLEMENTARY NOTES (*Sponsoring Organization, Publishers, Availability*)
(In Journal of Applied Psychology, v.39, no.6, p.990-996)

9. ABSTRACT
A report of the methods and results of a study of energy expenditures by sugarcane cutters in a region of Colombia where sugarcane is harvested 12 months a year. This study is part of a larger one dealing with the influence of nutritional repletion on the physical work capactiy of chronically undernourished workers in Colombia. The heart rate, oxygen consumption, and ventilation rate of 61 Colombian sugarcane cutters were measured while they harvested cane and also in the laboratory during a test of maximum oxygen consumption. Productivity and sweat rates were also measured in the field. The subjects had an estimated dietary intake of 2,970 kcal/day, which was lower than the calculated daily energy expenditure. During the work measurements the oxygen consumption was 1.5 1/min, the ventilation 48 1/min, and the heartrate 135 beats/min, with no differences between A.M. and P.M. values. The subjects sustained about 35% of maximum oxygen consumption during the 8-hour workday, but worked at 57% of maximum oxygen consumption during the tests. Measured energy cost was 7.4 $\pm$ 1.5 kcal/min during work. The estimated sustained energy cost was 5 kcal/min during the workday. Sweat rates were higher P.M. than A.M. (5 kg/8 h day). Grouping of the men according to productivity demonstrated that taller, heavier men were better producers and had lower calculated heart rates at oxygen consumption of 1.5 1/min. Efficiency of cane cutting was higher (9%) in the P.M.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-616	

12. DESCRIPTORS		13. PROJECT NUMBER
Activity analysis Colombia Energy Harvesting	Sugarcane	14. CONTRACT NUMBER CSD-2943 Res. 15. TYPE OF DOCUMENT

AID 590-1 (4-74)

JOURNAL OF APPLIED PHYSIOLOGY
Vol. 39, No. 6, December 1975. Printed in U.S.

Energy expenditure cutting sugarcane

G. B. SPURR, M. BARAC-NIETO, AND M. G. MAKSUD
Department of Physiology, The Medical College of Wisconsin, Milwaukee, Wisconsin 53233; Department of Physiological Sciences, Universidad del Valle, Cali, Colombia; Department of Physical Education, University of Wisconsin-Milwaukee, and Research Service, Veterans Administration Center, Wood (Milwaukee), Wisconsin 53193

SPURR, G. B., M. BARAC-NIETO, AND M. G. MAKSUD. *Energy expenditure cutting sugarcane.* J. Appl. Physiol. 39(6): 990–996. 1975. —$\dot{V}O_2$, $\dot{V}E$, and heart rates (f_H) were measured in 61 Colombian sugarcane cutters while harvesting cane in the AM and PM and in the laboratory during a $\dot{V}O_{2\,max}$ test. Productivity and sweat rates were also measured in the field. The subjects had an estimated dietary intake of 2,970 kcal/day, which was lower than calculated daily energy expenditure. During the work measurements the $\dot{V}O_2$ was 1.5 l/min, $\dot{V}E$ 48 l/min, and f_H 135 beats/min; there were no differences between AM and PM values. The subjects sustained about 35% of $\dot{V}O_{2\,max}$ during the 8 h workday, but worked at 57% of $\dot{V}O_{2\,max}$ during the tests. Measured energy cost was 7.4 ± 1.5 kcal/min during work. The estimated sustained energy cost was 5 kcal/min during the workday. Sweat rates were higher PM than AM (5 kg/8 h day). Grouping of the men according to productivity demonstrated that taller, heavier men were better producers and had lower calculated heart rates at $\dot{V}O_2$ 1.5 l/min. Efficiency of cane cutting was higher (9%) PM.

agricultural work; efficiency of work; energy balance; heart rate; heat; nutrition; O_2 cost of work; productivity; prolonged work; sweat rate; work classification

---

THE ENERGY COST of various activities, both in work and leisure, is of interest to physiologists, nutritionists, and physicians, to say nothing of the industrialists' concern with the human energy expenditure involved in the manufacture of their product (2, 12, 21). The effects of undernutrition on the work productivity of their populations is of particular interest to developing countries where the use of heavy manual labor is widespread and balanced against a precarious food supply (4).

We are presently studying the influence of nutritional repletion on the physical work capacity of chronically undernourished patients in Colombia, South America. To relate the laboratory findings to the economic impact of poor nutrition, we have investigated the relationship of work productivity to physical work capacity in sugarcane cutters, who make up a substantial fraction of the agricultural work force in this region. Part of the study involved the determination of energy expenditure while cutting cane. The data obtained form the basis of the present paper.

METHODS

The measurements to be reported were obtained on sugarcane cutters in a region of Colombia where sugarcane is harvested during 12 mo of the year. The men commence work at about 6:30 AM and continue, with only brief breaks for water, until noon. After a hot meal eaten in the field, they return to work at about 1:00 PM and cut until quitting time at 3:30 or 4:00 PM. The pile of cane cut during the day is marked with the worker's identification number for later collection by separate gangs of loaders. It is then weighed and accurate records are kept of the productivity, since the men are paid by the metric ton of cane cut.

The 61 subjects were male employees (18–56 yr of age), of a large sugarcane growing and processing firm. To rule out chronic diseases, only subjects with low absenteeism were chosen. The experience of the men in cutting cane varied from 9 mo to 17 yr, with the majority reporting 2–6 yr.

Measurements in the field. Heart rate (f_H), oxygen consumption ($\dot{V}O_2$), and ventilation ($\dot{V}E$) were determined with subjects in the sitting position after 10 min of rest. During work, collection of data was made between the 5th and 10th min and, between the 20th and 25th min. After the second collection period, the apparatus was removed and the subjects returned to their work. During each period of work testing, the cane cut was carefully collected and weighed on a Detecto Scale Balance.

Heart rates were determined with a Parks Telemetry System. $\dot{V}O_2$ and $\dot{V}E$ were measured with a Kofranyi-Michaelis (K-M) respirometer (Zentralwerkstatt Göttingen) which was calibrated and used as described by Consolazio (7). Immediately following each measurement, 50 ml of mixed expired air were transferred from the collecting balloon to an oiled glass syringe for analysis later the same day at the base laboratory. During the collection periods the three-way respiratory valve (QuinTron Instruments) and mouthpiece were supported by a headpiece and connected to the respirometer by flexible tubing allowing free movements of the subject's arms and shoulders.

Three subjects were measured each day in the field from 7:00 to 10:00 AM. Consequently, the first man had not been working prior to the test, whereas the second and third had been working about 1 and 2 h, respectively, before undergoing the testing procedure. In 58 of 61 subjects, repeat measurements were made in the afternoon of the same day between 1:00 and 4:00 PM.

Ambient air temperatures (T_a) were measured with an unshielded thermometer during each work period and averaged. Humidity was determined with a sling psychrometer. Sweat rates were measured in 20 of the men by obtaining body weights on a Homs Beam Scale accurate to ± 25 g, while clad in shorts, before and immediately after the 25-min period of cutting.

Oxygen debt determinations were made on five men, by collecting 5-min samples continuously for 30 min following the termination of work.

Analysis of gas samples. Oxygen and carbon dioxide concentrations were measured in duplicate by a gas chromatograph (model H-3, QuinTron Instruments). The instrument was calibrated with standard gases, the concentrations of which were established with a Scholander apparatus (8).

Testing in the laboratory. Later in the same week in which the field studies were done, the men were transported to the base laboratory where scapular and triceps skinfold thicknesses were obtained with Lange skinfold calipers (Cambridge Scientific Instruments, Inc.) and body weight (±25 g) and height (±1 mm) measured. Body density was estimated by the formulas of Pascale et al. (20) and body fat by the formula of Brozek et al. (6). In 33 subjects, a 4- to 5-h postabsorptive venous blood sample was taken for serum albumin (19), total proteins (19), hematocrit, and hemoglobin (10) determinations.

The subjects then underwent a maximum oxygen uptake determination in which the speed of the treadmill was held constant at 3 or 3.5 mph and the angle elevated 2.5% every 2 min until the subject was exhausted. The tests were performed at a room temperature of approximately 22°C and relative humidity of 30–40%. Of the 60 subjects tested, 55 gave acceptable $\dot{V}O_{2\ max}$ values (28).

Expired gas samples were taken in oiled glass syringes from a mixing chamber in the expiratory line and analyzed as described above. $\dot{V}E$ was measured by means of a Parkinson-Cowan dry gas meter (model CD4). Heart rates were recorded on a Grass Polygraph, using lead CV_5.

Dietary and activity questionnaires. In 27 of the men, dietary information was obtained by a trained nutritionist utilizing the 24-h recall technique. Activity levels were estimated in 59 of 61 subjects by the procedure described by Saltin and Grimby (25).

Statistics. Statistical comparisons were made on the basis of paired or unpaired Student *t*- and *F* ratio tests as appropriate and, in any case, the null hypothesis was rejected at the 5% level. Except where otherwise indicated, the data are presented as means and standard deviations.

RESULTS

Nutritional status. Table 1 presents the results of the analyses for serum albumin, total proteins, hematocrit, and hemoglobin in 33 of the cutters. The estimated daily dietary intakes of 27 sugarcane cutters are presented in Table 2.

Productivity. The productivity of each cutter was obtained from the company records. The values are daily averages for July, August, and September of 1972 or 1973, when the subjects' energy expenditures were measured. Daily productivity varied from 2.12 to 5.22 tons/day (3.52 ± 0.72 tons/day). The men were divided into three groups based on their productivity. *Group I* consisted of 13 top producers cutting in excess of 4 tons/day (4.48 ± 0.37 tons/day). *Group II* was composed of 28 men cutting 3–4 tons/day (3.62 ± 0.24 tons/day), while *group III* was made up of the 17 lowest producers who cut 2–3 tons/day (2.63 ± 0.29 tons/day). In some of the data to be presented, the results obtained on three men who did not have reliable productivity data were placed in *group II*, on the basis that the field boss judged them to be "average" producers. All data are based on the cutting of unburned cane.

TABLE 1. *Blood and serum values in 33 sugarcane cutters 4–5 h postabsorptively*

	Mean ± SD	Range
Total proteins, g/100 ml	7.55 ± 0.28	7.00–8.20
Serum albumin, g/100 ml	4.21 ± 0.27	3.70–4.70
Blood hemoglobin, g/100 ml	14.1 ± 1.3	12.0–16.5
Hematocrit, %	44.9 ± 3.8	38.0–53.0

TABLE 2. *Estimated daily dietary intake of 27 sugarcane cutters*

	Mean ± SD	Range
Protein		
g	73 ± 11	50–83
g/kg*	1.22 ± 0.21	0.84–1.61
Total kcal, %	10.2 ± 1.5	6.9–14.1
Animal, %	36 ± 8	14–58
Vegetable, %	64 ± 8	42–86
Fat		
g	45 ± 12	25–75
g/kg*	0.76 ± 0.22	0.44–1.36
Total kcal, %	14.4 ± 4.3	8.7–27.4
Carbohydrate		
g	546 ± 129	313–948
g/kg*	9.19 ± 2.19	5.36–11.16
Total kcal, %	75.3 ± 5.5	59.8–83.2
Calories		
kcal	2,970 ± 564	1,855–4,676

* Per kilogram body wt.

Anthropometric data. The physical characteristics of the subjects are presented in Table 3. There were no statistically significant differences among groups in age, weight/height ratios, or lean body mass/m of height. The men in *group I* were significantly taller ($P < 0.01$) than those in *groups II* and *III*, although the latter were not different from each other. The same tendency is seen in body weight and lean body mass expressed in kg (Table 3).

Ventilation, oxygen consumption, and heart rates. The results of the measurements of $\dot{V}E$, $\dot{V}O_2$, and f_H are presented in Table 4, together with the oxygen pulse and ventilation equivalent. There were no statistically significant differences among the groups and, with the exception of resting f_H ($P < 0.05$), there were no differences between AM and PM measurements. This was also the case when $\dot{V}O_2$ was expressed in terms of body weight (ml/kg·min^{-1}).

Utilizing the resting and the 5- and 20-min values for f_H and $\dot{V}O_2$, a least-squares regression line was calculated for each subject AM and PM. A heart rate at $\dot{V}O_2$ = 1.5 l/min (the approximate average level of work) was calculated using the equations obtained. The results of this analysis are presented in Fig. 1. The slopes of these lines were significantly less and the intercepts greater PM compared to AM (left insert, Fig. 1) with the intercepts showing no differences among the three groups of subjects. However, the slopes exhibited a progressive increase, both AM and PM, as the average productivity decreased from *group I* to *group III* (right insert, Fig. 1), giving rise to the group differences in calculated heart rates (presented to the right of Fig. 1). There were no statistically significant differences between

AM and PM values, but heart rates were significantly lower ($P < 0.03$) in the good cutters at this work level and became progressively higher as the group productivity decreased. The average estimated heart rates were 123 ± 9, 133 ± 7, and 141 ± 20/min AM and 125 ± 11, 137 ± 16, and 140 ± 14 PM for *groups I, II,* and *III*, respectively.

TABLE 3. *Physical characteristics of sugarcane cutters*

Age, yr	Ht, cm	Wt, kg	Wt/Ht, kg/m*	Body Fat		Lean Body Mass	
				%	kg/m*	kg	kg/m*
Group I (n = 13)							
32.5	168.8	62.5	36.6	10.2	3.8	55.9	32.6
8.2	6.5	6.9	3.5	1.6	0.9	5.9	2.8
Group II (n = 29)							
29.3	162.9†	58.0†	35.5	9.9	3.5	52.3	32.0
6.4	5.5	5.3	2.6	1.1	0.6	4.5	2.2
Group III (n = 17)							
28.6	159.8†	56.7†	35.4	11.2‡	4.0	50.3	31.4
6.1	6.4	7.4	3.6	2.1	1.2	5.7	2.6
Total (n = 59)							
29.8	163.3	58.6	35.7	10.3	3.7	52.5	32.0
6.7	6.7	6.5	3.1	1.6	0.9	5.4	2.4

Values are means ± SD. * Height in meters. † $P \leq 0.05$ compared to *group I.* ‡ $P < 0.05$ compared to *group II.*

The oxygen debts for the five men in whom they were measured were 1.09 ± 0.34 liters AM and 0.70 ± 0.35 liters PM ($P < 0.20$). For the 25-min work periods these values amounted, on the average, to only 44 and 28 ml/min, respectively, or less than 3% of the aerobic $\dot{V}O_2$ determinations.

Energy expenditure. The energy expenditure of 61 men cutting cane was calculated from the $\dot{V}O_2$ (5.047 kcal/l). There were no significant differences among the four measurements AM and PM, nor among the three groups of subjects. The four values for each man were then averaged. The mean and standard deviation for all 61 men were 7.4 ± 1.5 kcal/min (range 4.5–12.4 kcal/min).

The weight of the cane collected during each measurement in the field was expressed as kilograms of cane cut per h (Fig. 2). Since there were no statistically significant differences among the three groups, the data were averaged and showed that the rate of cane cutting increased significantly from 686 ± 181 kg/h AM to 762 ± 191 kg/h PM ($P < 0.001$).

The energy expenditure (kcal) per kilogram of sugarcane cut was calculated from the $\dot{V}O_2$ and the cane weight as an expression of efficiency and is presented in Fig. 3. The mean PM values were less in all three groups ($P < 0.001$ in *group*

TABLE 4. *Physiological responses while cutting sugarcane*

	AM ($\bar{T}_a$ = 24.6°C)			PM ($\bar{T}_a$ = 30.2°C)		
	Rest	Cutting Cane* 5 min	20 min	Rest	Cutting Cane* 5 min	20 min
Cardiac frequency (f_H), beats/min						
n	59	57	48	56	52	40
Mean	72	131	135	80	133	137
± SD	10	16	20	10	17	20
Range	55–97	103–165	101–172	59–110	96–172	96–179
Oxygen consumption ($\dot{V}O_2$), l/min STPD‡						
n	58	57	52	55	55	49
Mean	0.25	1.50	1.46	0.25	1.51	1.44
± SD	0.09	0.34	0.34	0.07	0.34	0.31
Range	0.15–0.61	0.85–2.74	0.85–2.52	0.11–0.46	0.93–2.68	0.94–2.42
Oxygen consumption ($\dot{V}O_2$), ml/kg·min⁻¹ STPD‡						
n	58	57	52	55	55	49
Mean	4.3	25.8	25.2	4.2	25.8	24.9
± SD	1.5	5.5	5.6	1.0	0.8	4.8
Range	2.7–12.0	17.0–48.1	13.8–44.2	1.9–8.1	18.2–40.5	16.9–39.1
Oxygen pulse ($\dot{V}O_2/f_H$), (ml/min)/beat						
n	58	55	46	54	50	38
Mean	3.53	11.45	10.70	3.11	11.27	10.59
± SD	1.27	2.26	2.34	0.81	2.07	1.79
Range	1.85–8.73	8.11–17.70	7.08–19.21	1.50–5.81	7.75–16.42	6.98–14.54
Pulmonary ventilation ($\dot{V}_E$), l/min BTPS§						
n	59	58	54	57	57	50
Mean	11.12	48.35	48.66	11.31	48.42	48.77
± SD	3.58	9.70	10.28	2.36	9.12	10.02
Range	7.02–32.33	27.33–70.23	28.03–70.40	6.33–18.66	30.53–68.66	27.89–70.73
Ventilation equivalent ($\dot{V}_E$/100 ml $\dot{V}O_2$)						
n	58	57	51	54	54	48
Mean	4.60	3.28	3.41	4.71	3.27	3.50
± SD	0.84	0.39	0.45	1.04	0.35	0.43
Range	2.46–6.22	2.23–4.02	2.27–4.14	2.66–7.30	2.17–4.02	2.71–5.03

$\bar{T}_a$ = mean air temperature. * All values while cutting cane are significantly different from values at rest; $P < 0.05$. † Significantly different from comparable AM value; $P < 0.001$. ‡ Standard temperature and pressure, dry. § Body temperature, ambient pressure, saturated

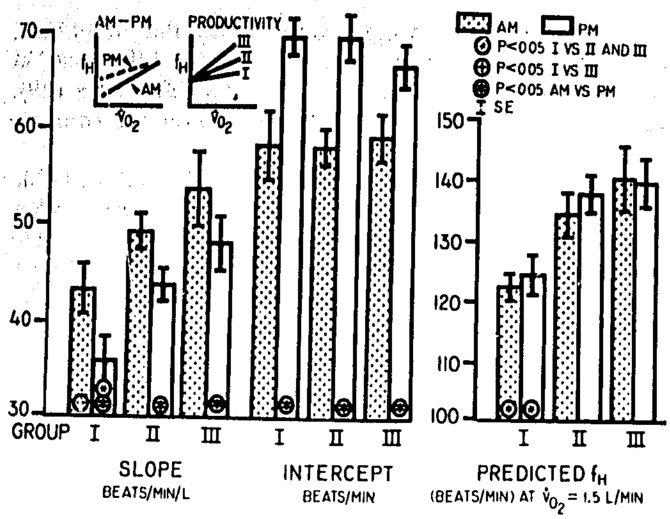

FIG. 1. Slopes and intercepts of the regression of heart rate (f_H) on $\dot{V}o_2$ during sugarcane cutting in good, average, and poor producers (*groups I, II*, and *III*, respectively). Predicted f_H at $\dot{V}o_2$ = 1.5 l/min calculated from regression lines.

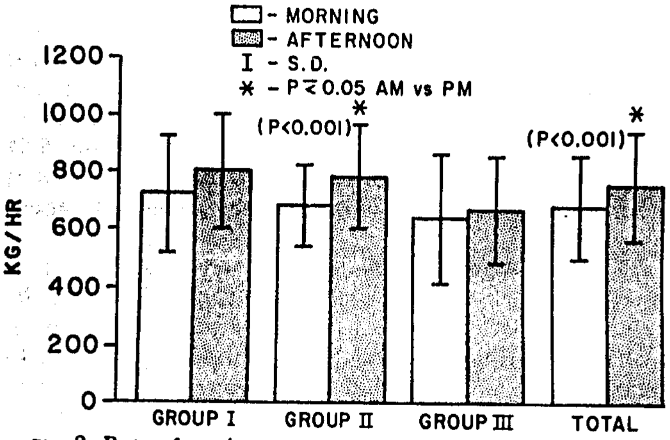

FIG. 2. Rate of cutting sugarcane AM and PM of good, average, and poor producers (*groups I, II*, and *III*, respectively). No statistically significant differences exist among groups.

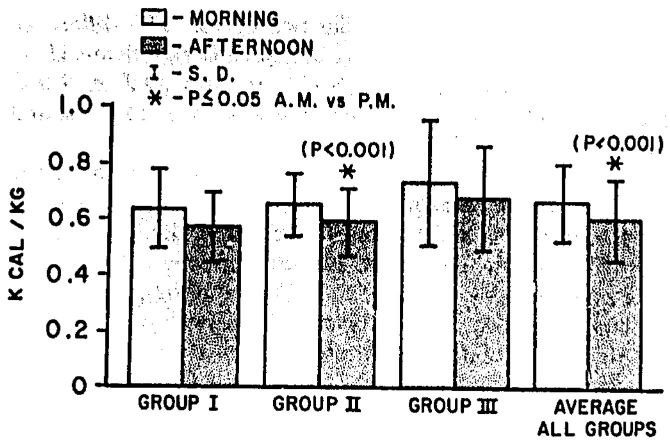

FIG. 3. Efficiency expressed in terms of kcal/kg of cane cut AM and PM by good, average, and poor producers (*groups I, II*, and *III*, respectively). No statistically significant differences exist among groups.

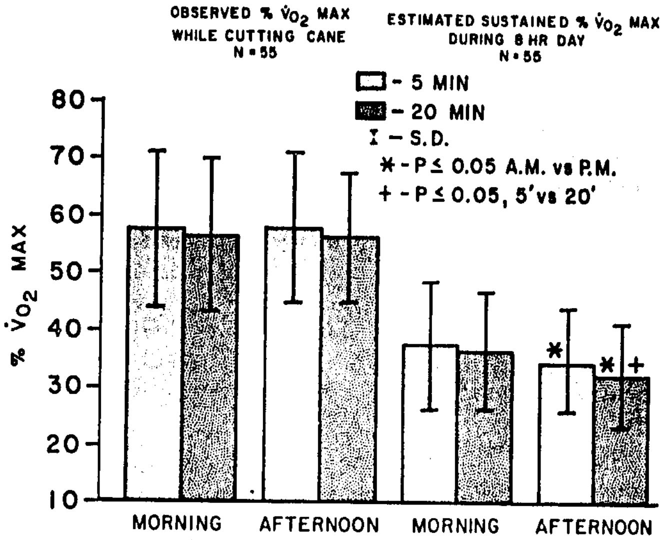

FIG. 4. Percent $\dot{V}o_{2\,max}$ observed in 55 sugarcane cutters in the field and estimated percent $\dot{V}o_{2\,max}$ which can be sustained for 8 h, calculated from the energy cost/kg of cane cut (Fig. 3) and productivity of each subject for the 5- and 20-min measurements AM and PM.

II). Since there were no statistically significant differences among the groups, the data were averaged and demonstrated a significant decrease in caloric expenditure per kilogram of cane from 0.676 ± 0.159 kcal/kg AM to 0.616 ± 0.147 kcal/kg PM ($P < 0.001$), an increase in efficiency of about 9%. Using the daily productivity for each man and the average of his AM and PM values for efficiency (kcal/kg of cane cut), it was possible to estimate the 8-h daily caloric expenditure while cutting sugarcane to be 2,254 ± 562 kcal/8 h.

The percent $\dot{V}o_{2\,max}$ which the men were utilizing during the four measurement periods was calculated from the $\dot{V}o_2$ determined in the field and the $\dot{V}o_{2\,max}$ measured in the laboratory (2.63 ± 0.37 l/min, 45.2 ± 5.2 ml/kg·min^{-1}). The results for 55 cutters are shown on the left in Fig. 4. The values were 57.4 ± 13.6% and 56.3 ± 13.4% during the 5- and 20-min measurements AM and 57.7 ± 12.9 and 56.2 ± 11.2 during the same periods PM. There were no significant differences between AM and PM measurements. These values are considered higher than can be sustained for an 8-h workday (1, 16). Furthermore, it can be calculated from the rates of cane cutting (Fig. 2) that, if the men had sustained these rates for 8 h, their daily productivities would be much higher than they were. Knowing the average daily productivity and the $\dot{V}o_2$ per kilogram of cane cut, the oxygen cost of the daily productivity of each worker can be calculated and expressed as estimated percent $\dot{V}o_{2\,max}$ that would have to be sustained during an 8-h workday. These results are presented on the right in Fig. 4. Using the $\dot{V}o_2$ values observed during the the four measurement periods, the values obtained were 37.4 ± 11.0% and 36.4 ± 10.1% during the 5- and 20-min determinations AM, respectively, and 34.5 ± 9.4% and 32.3 ± 8.9% during the same measurements PM. These values are in agreement with those reported by Michael, Hutton, and Horvath (16) for laboratory subjects. The differences between AM and PM measurements were statistically significant ($P < 0.05$), indicating a slightly decreased effort as the day progressed.

Sweat rates. The sweat rates for the 20 individuals in whom they were measured during 25 min of work averaged 0.80 ± 0.34 kg/h (15.18 ± 6.24 g/kg per h) AM and 1.26 ±

0.50 kg/h (22.25 ± 8.20 g/kg per h) PM. The difference between AM and PM values was statistically significant ($P < 0.01$). T_a averaged 24.6 ± 3.4°C AM and 30.2 ± 2.9°C PM ($P < 0.001$). Relative humidity was 76 ± 14% AM and 47 ± 14% PM ($P < 0.001$).

Since it was evident that the men worked at a higher rate during the measurement periods than they sustained all day, it follows that the sweat rates were higher. Utilizing the ratio of the estimated sustained percent $\dot{V}O_{2\,max}$ to measured percent $\dot{V}O_{2max}$ (35.2/56.9 = 0.62), utilized in cutting cane (Fig. 4) and the measured sweat losses, it was possible to calculate an estimated sustained rate of sweating during the AM and PM work periods and from this to estimate an 8-h sweat loss. The AM sweat rate, corrected in this manner, was 0.57 ± 0.22 kg/h (10.4 ± 4.2 g/kg per h) and 0.77 ± 0.28 kg/h (13.8 ± 4.6 g/kg per h) PM. This amounted to about 5 kg/8-h workday in the 18 men for whom values were available.

No measurements of water intake were made. However, body weights prior to beginning the field tests were available on 25 of the men. These averaged 56.86 ± 5.82 kg AM and 56.74 ± 5.79 PM ($P > 0.05$). Therefore, water replacement was adequate. No observations were made on salt intake and there were no reported incidences of muscle cramps in our subjects during the period of study. The incidence of muscle cramps amounted to less than 1% in the population of sugarcane cutters studied by Leithead et al. (15).

Activity levels. Using an activity level classifying system (25), the men were categorized into one of 4 groups, based on their leisure-time activity; 40 were in *group I* (almost completely inactive), 18 in *group II* (some physical activity at least 4 h/wk), and one in *Group III* (regular activity). There was no relation between leisure-time activity and productivity.

DISCUSSION

Nutritional status and energy balance. The results of the blood analyses in 33 of the subjects showed that total proteins, serum albumin, hematocrit and hemoglobin values were comparable to those reported for the Colombian civilian population (14). None of the subjects were in the "deficient" range; 15 were in the "low" range for hemoglobin (12.0–13.9 g/100 ml), and five were low for hematocrit (36–41%). All were in the "high" range for total proteins (14). The relatively high protein intake (1.2 g/kg per day, Table 2), as compared to that recommended (0.8 g/kg per day) for the United States population (13), may account for the latter.

Viteri (29) reported anthropometric data on several groups of adult male Guatemalan subjects who were classified according to their socioeconomic status, nutritional background and intake, and by work activity. The value of 32.0 ± 2.4 kg/m for lean body mass measured in the cane cutters (Table 3) is very close to those reported by Viteri (29) for the subjects he considered as having a good nutritional intake during his studies and higher than those he classified as having only an adequate or poor intake (29). On the other hand, the body fat content of the cutters (Table 3) is significantly lower than the values for all of Viteri's (29) groups, except those having "poor" nutritional intake. Our values were significantly higher than the latter. The differences in fat content may reflect differences in work activity levels, as well as nutritional differences (29). More active populations tend to have lower fat contents (22).

The average total caloric intake of 2,970 kcal/day (Table 3) may be a low estimate. If one assumes that each worker obtained 8 h of sleep at 1 kcal/h per kg and that 8 h were spent at a very low level of activity at approximately 1.5 kcal/h per kg and using the mean body weight of 58.6 kg (Table 3), the estimated caloric expenditure for the nonworking hours would be 1,172 kcal. The calculated energy cost of 8 h of work was 2,254 kcal for a total of 3,426 kcal/24 h. Part of the discrepancy between daily caloric intake and expenditure may be explained by two unmeasured sources of calories. Company policy discourages consumption of sugarcane during work, although it is common to see workers chewing on cane in the field. Its consumption may not have been reported accurately to the nutritionist. Second, the workers bring plastic jugs of sugar water from home for consumption during working hours. Subsequent fillings are made from a water tank in the field, which does not contain sugar. The 3-kg weight of the K-M meter might be suspected of contributing to the discrepancy between intake and output. Consolazio (7) quoted a report of an energy expenditure of 5.51 kcal/min without and 5.54 kcal/min with the K-M meter while walking for 10 min at 3.5 mph on a treadmill. This difference amounts to about 15 kcal/8 h.

The body weights of five subjects were measured 1 yr apart under the same laboratory conditions. In 1972, the mean weight was 62.87 ± 5.27 kg; in 1973, it was 63.84 ± 5.61 kg. The difference was not statistically significant. In general, it would seem that the subjects studied were in adequate nutritional condition and that their caloric intake approximated the energy expended in 24 h.

Productivity. The average productivity of 3.52 ± 0.72 tons/day of our Colombian cutters is comparable to that reported by Morrison and Blake (17) for 200 Rhodesian cane cutters (3 tons/day) and by Davies (11) for 78 cane cutters (3 tons/day) in Tanzania, East Africa, all of whom were cutting unburned cane. In the latter case, the author also divided his subjects into high, medium, and low producers with daily averages of 3.51, 3.04, and 2.60 tons/day, respectively.

The physical characteristics of the subjects presented in Table 2 indicate that the lower producers weighed less and were shorter than the good cutters in *group I*. A similar tendency is seen in the data reported by Davies (11).

Heart rates. The resting f_H of the subjects in all three groups were higher PM than AM, probably as a result of previous work and the noon meal (27). The lower calculated f_H in the high producers at a given work load (Fig. 1) indicate that they are in better physical condition than the poorer producers (2).

The lack of difference in f_H during work AM and PM may be due to the average T_a encountered. Nielson (18) has shown that, while body temperature was regulated to a higher level during work and was dependent on the work load, it was independent of T_a in the range 5–30°C. Oxygen pulse, an indicator of stroke volume (2), was no different

AM or PM (Table 4) while cutting cane, suggesting no difference in cardiac output. A lack of difference in cardiac output during work in comfortable and hot environments was found by Williams et al. (30).

Energy expenditure and efficiency. When the average energy expenditure of 7.4 kcal/min is expressed in terms of a standard 65-kg man (12), utilizing the mean body weight of 58.6 kg (Table 3), one obtains a value of 8.2 kcal/min per 65 kg for the energy expenditure. This is within the range of energy expenditures described as "heavy" by Durnin and Passmore (12). This value is higher than is sustained during the day (Fig. 4). Using the ratio of estimated sustained percent $\dot{V}O_{2\,max}$ to observed percent $\dot{V}O_{2\,max}$ it is possible to estimate that this value would be about 5.1 kcal/min per 65 kg, which would place it in the "moderate" category of industrial work presented by Durnin and Passmore (12, 21). This is in very close agreement with the value of 5 kcal/min suggested by Passmore and Durnin (21) as the probable upper limit which can be sustained during an 8-h day in heavy industry. This raises a question about classification systems, based on relatively short-term measurements which are influenced by subject stimulation so familiar in the psychological literature (3). For example, if the value of 7.4 kcal/min obtained in the present study had been used to estimate daily caloric expenditure in cutting sugarcane, we would have obtained about 3,570 kcal/8 h instead of 2,254 ± 562 kcal/8 h. Some other measure(s) of energy expenditure, like productivity and energy expenditure/unit of product, is needed to improve accuracy of estimates.

Morrison and Blake (17) reported a value of 1.42 ± 0.15 l/min for $\dot{V}O_2$ in 200 Rhodesian cane cutters while harvesting unburned cane at a rate of 9.0 ± 1.6 kg/min (540 kg/h). This amounts to 7.2 kcal/min, which is comparable to the energy expenditure found in the present study. These authors state that their Rhodesian cutters were also working at a higher rate than usual during the tests (17). However, when related to the rate of cutting, the efficiency of the Rhodesians is lower than that of the Colombians. It can be calculated that the former were expending 0.8 kcal/kg of cane cut as compared to values of 0.676 and 0.616 kcal/kg found in the latter. The Rhodesians utilized a somewhat different cutting technique than that employed by the Colombian cutters (11).

The improved efficiencies observed PM (Fig. 3) were the result of an increased rate of cutting sugarcane (Fig. 2) and an unchanged $\dot{V}O_2$ (Table 4). Williams et al. (30) and Brouha and collaborators (5) reported a similar finding in that the $\dot{V}O_2$ of their subjects was lower in the heat at the same work loads. Rowell et al. (24) found no thermally induced change in $\dot{V}O_2$ in their experiments, while Robinson (23) and Consolazio et al. (9) reported higher $\dot{V}O_2$ during submaximal work in the heat. These differences are no doubt due to a variety of variables such as degree of heat acclimatization, physical condition of the subjects, as well as laboratory and field conditions under which the experiments were done. Another factor which might contribute is that the second time the subjects performed the test (always PM) may have been easier for them than the first (AM) test. The results of the O_2 debt measurements indicate that the increased efficiency was not the result of increased utilization of anaerobic sources of energy PM.

Exercise results in an increase in muscle temperature above changes produced in the rectal or esophageal temperatures (26). If this muscle temperature rise is higher PM than AM, it could explain the increased efficiency (Fig. 3) observed in the present experiments through a direct effect of temperature on cellular enzyme systems (30).

In summary, our data suggest that manual sugarcane cutting represents a work level that approaches the highest values that can be sustained for an 8-h day. The data also indicate a positive relationship between body size and physical condition and the productivity of sugarcane cutters.

The authors express their appreciation to Central Castilla, Ltda., Colombia, for the very generous cooperation extended by them during the conduct of this study. The helpful assistance of Dr. Guillermo Ayalde and the willing participation of the cutters is especially acknowledged. We are grateful to the technical staffs of the Metabolic Unit and Exercise Laboratory, Universidad del Valle and Research Service, Wood Veterans Administration Center for their many contributions.

This work was supported in part by Contract AID/CSD 2943 with the Office of Nutrition, Agency for International Development.

Received for publication 14 April 1975.

REFERENCES

1. ÅSTRAND, I. Aerobic work capacity in men and women with special reference to age. *Acta Physiol. Scand.* 49:Suppl. 169: 1–92, 1960.
2. ÅSTRAND, P.-O., AND K. RODAHL. *Textbook of Work Physiology.* New York: McGraw, 1970.
3. BADIA, P., A. HABER, AND R. P. RUNYAN. *Research Problems in Psychology.* Reading, Mass.: Addison-Wesley, 1970.
4. BERG, A. *The Nutrition Factor.* Washington D.C.: Brookings Institution, 1973.
5. BROUHA, L., P. E. SMITH, R. DELANNE, AND M. E. MAXFIELD. Physiological reactions of men and women during muscular activity and recovery in various environments. *J. Appl. Physiol.* 16: 133–140, 1960.
6. BROZEK, J., F. GRANDE, J. T. ANDERSON, AND A. KEYS. Densitometric analysis of body composition: revision of some quantitative assumptions. *Ann. N.Y. Acad. Sci.* 110: 113–140, 1963.
7. CONSOLAZIO, C. F. Energy expenditure studies in military populations using Kofranyi-Michaelis respirometers. *Am. J. Clin. Nutr.* 24: 1431–1437, 1971.
8. CONSOLAZIO, C. F., R. E. JOHNSON, AND L. J. PECORA. *Physiological Measurements of Metabolic Functions in Man.* New York: McGraw, 1963.
9. CONSOLAZIO, C. F., L. O. MATOUSH, R. A. NELSON, J. B. TORRES, AND G. J. ISAAC. Environmental temperatures and energy expenditures. *J. Appl. Physiol.* 18: 65–68, 1963.
10. CROSBY, W. H., J. I. MUNN, AND F. W. FURTH. Standardizing a method for clinical hemoglobinometry. *US Armed Forces Med. J.* 5: 693–703, 1954.
11. DAVIES, C. T. M. Relationship of maximum aerobic power output to productivity and absenteeism of East African sugar cane workers. *Brit. J. Ind. Med.* 30: 146–154, 1973.
12. DURNIN, J. V. G. A., AND R. PASSMORE. *Energy, Work and Leisure.* London: Heinemann, 1967.
13. Food and Nutrition Board, National Research Council. *Recommended Dietary Allowances.* Washington, D.C.: Natl. Acad. Sci., 1974.
14. Interdepartmental Committee on Nutrition for National Defense. *Nutrition Survey.* Colombia, May–Aug, 1960.
15. LEITHEAD, C. S., E. R. GUNN, AND C. C. CHUNG. *Muscle Cramps*

in Cane Cutters in British Guiana. Liverpool School of Trop. Med. Rept., 1961.

16. Michael, E. D., K. E. Hutton, and S. M. Horvath. Cardiorespiratory responses during prolonged exercise. *J. Appl. Physiol.* 16: 997–1000, 1961.
17. Morrison, J. F., and G. T. W. Blake. Physiological observations on cane cutters. *European J. Appl. Physiol.* 33: 247–254, 1974.
18. Nielsen, M. Die Regulation der Körpertemperatur bei Muskelarbeit. *Scand. Arch. Physiol.* 79: 193–230, 1938.
19. Oser, B. L. (Editor). *Hawk's Physiological Chemistry* (14th ed.). New York: McGraw, 1965, p. 1082–1085.
20. Pascale, E. R., M. I. Grossman, H. S. Sloane, and T. Frankel. Correlation between thickness of skinfolds and body density in 88 soldiers. *Human Biol.* 28: 165–175, 1956.
21. Passmore, R., and J. V. G. A. Durnin. Human energy expenditure. *Physiol. Rev.* 35: 801–840, 1955.
22. Pollack, M. L., T. K. Cureton, and L. Greninger. Effects of frequency of training on working capacity, cardiovascular function and body composition of adult men. *Med. Sci. Sports* 1: 70–74, 1969.
23. Robinson, S. Physiological adjustments to heat. In: *Physiology of Temperature Regulation and the Science of Clothing*, edited by L. H. Newburgh. Philadelphia, Pa.: Saunders, 1949, p. 193–231.
24. Rowell, L. B., J. R. Blackmon, R. H. Martin, J. A. Mazzarella, and R. A. Bruce. Hepatic clearance of indocyanine green in man under thermal and exercise stresses. *J. Appl. Physiol.* 20: 384–394, 1965.
25. Saltin, B., and G. Grimby. Physiologic analysis of middle aged and old former athletes. Comparison with still active athletes of the same ages. *Circulation* 38: 1104–1115, 1968.
26. Saltin, B., and L. Hermansen. Esophageal, rectal, and muscle temperature during exercise. *J. Appl. Physiol.* 21: 1757–1762, 1966.
27. Schneider, E. C., and D. Truesdell. Daily variations in cardiovascular conditions and a physical efficiency rating. *Am. J. Physiol.* 67: 193–202, 1923.
28. Taylor, H. L., H. R. Buskirk, and A. Henschel. Maximum oxygen intake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8: 73–80, 1958.
29. Viteri, F. E. Considerations on the effect of nutrition on the body composition and physical working capacity of young Guatemalan adults. In: *Amino Acid Fortification of Protein Foods*, edited by M. S. Scrimshaw and A. M. Altschull. Cambridge, Mass.: MIT, 1971, p. 350–375.
30. Williams, C. G., G. A. G. Bredell, C. H. Wyndham, N. B. Strydom, J. F. Morrison, J. Peter, P. W. Fleming, and J. S. Ward. Circulatory and metabolic reactions to work in heat. *J. Appl. Physiol.* 17: 625–638, 1962.