ENERGY EXPENDITURE AND ECONOMY OF MOVEMENT OF SUGARCANE CUTTERS IN BURNT AND GREEN CANE

M DE L SMIT, MF COETSEE AND SEH DAVIES

Department of Human Movement Science, University of Zululand, KwaDlangezwa, South Africa

Abstract

The purpose of this study was to investigate differences in the energy expenditure and economy of movement of sugarcane cutters with regard to burnt and green cane *in situ*. The primary objective was to investigate the differences in physiological responses, namely oxygen consumption (VO_2), heart rate (HR) and energy expenditure (EE) and the economy of movement with regard to burnt and green sugarcane during a normal working day. The secondary study was to investigate the effect of the long and the short handled curved blade knives on the cutter's energy expenditure and economy of movement. The average relative VO_2 for cutting burnt cane and the calculated relative EE were both significantly lower than those for green cane. The average HR during work was not significantly different for burnt or green cane, neither was the maximal HR. Rate of productivity for burnt cane was significantly higher than that for green cane. Energy per kilogram required for burnt cut cane was significantly lower than that for green cane. The amount of cane cut per litre of oxygen consumed for burnt cane was significantly higher than that for green cane. The number of cane cutting strokes per minute for green cane was significantly lower than that for burnt cane. The number of stalks cut per stroke of green cane was significantly higher than that for burnt cane. The secondary study produced no significant differences in any of the measured variables for the comparison between the long handled knife and the short handled knife, except for the cane cutter's perceived exertion (RPE). Results showed that cutting burnt cane surpassed all aspects of harvesting with regard to physiological parameters and economy of movement compared with green cane. The choice of knives depended on the preference of the cane cutter.

Introduction

Manual labour is still common in many industries in various parts of the world, in spite of the trend towards mechanisation. Sugarcane harvesting in South Africa is no exception. Much research has been done on the energy expended in manual cane harvesting and improved cane harvesting methods (Lambert *et al*., 1994; Immink *et al*., 1987; Collins *et al*., 1976; Spurr *et al*., 1975; Morrison and Blake, 1974; Davies, 1973). However, many of these studies have used indirect methods of predicting energy expenditure. Also, little is known about the physiological demands and energy cost of cane cutting using different cutting implements when harvesting green and burnt cane. Scientific research is of vital importance in identifying potential improvements in productivity. Thus a sound knowledge of the various factors influencing the labourers' performance and their relative importance is necessary.

The Zululand region has the largest number of growers in KwaZulu-Natal and the fourth highest percentage of the total population of growers in South Africa. The productivity of a typical cutter/stacker in Zululand is 4.37 tons per day and 874 tons per season, while for the cut only category it is 6.26 tons per day and 1304 tons per season. In Zululand 85% of the cane harvested is burnt (SA Cane Growers Labour Utilisation and Cost Survey, 1999/00).

Until now, research in the field, of sugarcane cutters in South Africa, has been restricted to indirect measurement of oxygen uptake and therefore energy expenditure. McArdle *et al* (1991) states that although the technique for using heart rate to estimate energy expenditure is practical, it is of limited use for research purposes because its validity has yet to be adequately established. Evidence shows that heart rate-oxygen uptake during an actual activity differs from measurements in the laboratory at equal workloads. Environmental temperature, emotions, previous food intake and the muscle groups exercised, can influence the heart rate response. With this in mind, oxygen uptake and energy expenditure was measured directly, by the most advanced portable metabolic analyser available, namely the MetaMax Ergospirometry system.

Metabolic measurements

Cane cutting involves repetitive movements for prolonged periods of time. On this basis it may be termed as a continuous loading activity, whereby the workload is matched by the metabolic cost. The predominant energy-releasing reactions in the body ultimately depend on the utilisation of oxygen. Energy expenditure is a work physiology parameter, which can be measured indirectly by oxygen uptake, since 1 litre of oxygen has an energy equivalent to approximately 4.82 kcal or 20.186 kJ (McArdle *et al*., 1991). Energy expenditure can be expressed as an absolute or a relative value. The absolute energy expenditure ($kJ \cdot min^{-1}$) was therefore normalised to body mass ($kJ \cdot kg^{-1} \cdot min^{-1}$) and to cane cutting performance in order to obtain a normalised or relative energy cost. By calculating the relative energy expenditure, the effects of both body size and of individual variation in performance of the task can be minimised.

Heart rate

Heart rate (HR) is recognised as an indicator of bodily effort or stress involved in the performance of physical work. This is an indirect measure of human energy expenditure, given the relatively linear relationship between heart rate and the volume of oxygen consumed per minute (VO_2). However, HR is influenced by a number of factors, e.g. size of muscle mass involved, type of muscular contraction, environmental conditions, psychologi-

cal factors, the physical training state, age and gender of the individual (McArdle *et al*., 1991).

Measurement of economy of work

The subject's work economy was expressed as a ratio between the energy expended against the workload performed. Work output was measured by means of accurately collecting and weighing the amount of cane cut for the recording period of 30 minutes. Through incorporating this ratio, alternative ways of performing the same task with different cane cutting implements were compared as well as the demands of the work placed on the physiological system when harvesting green or burnt sugarcane. Economy of movement was expressed in terms of:

1. amount of cane cut per minute (work output) ($kg \cdot min^{-1}$)
2. energy expended per kilogram of cane cut ($kJ \cdot kg^{-1}$)
3. amount of cane cut per litre of oxygen consumed ($kg \cdot LO_2^{-1}$)
4. number of strokes for cutting cane ($strokes \cdot min^{-1}$)
5. number of stalks cut per stroke.

Subjective ratings

Ratings of perceived exertion (RPE) have been found a valuable and reliable indicator when monitoring an individual's exercise tolerance (Borg, 1982). It provides a perceptual and cognitive complement to physiological responses to exercise. The RPE can thus be described as a subjective self-report of energy expenditure using a validated scale for quantification.

Subjects were shown the Universal RPE Scale (Scott, 1990) which is a revised and simplified scale using diagrams, better understood by the subject, and thereby providing the tester with more valid information. The subjects were familiarised with the principle that the numbers from 6-20 are descriptive terms, which represent their perception of work intensity. Thus, '6' equals very, very light and '20' equals very, very hard.

Manual harvesting of green and burnt cane

Cane is either cut green as it stands, called trashing, or it is burned before it is cut. The advantage of burnt cane is that it does not require stripping of the leaves from the stalks at harvest, which is more effective in terms of cost and time. On the other hand, trashing cane requires stripping. Usually, when unburnt cane is cut, a short handled straight or curved blade knife is used. This type of knife is used for cutting, stripping and topping. With burnt cane the selection of a cane knife depends on the topography and state of the cane. Usually the short handled curved blade will be used if cane grows on a steep slope. For straight or badly lodged cane either the long or short handled curved blade knife is used (SASEX Training Manual, n.d.).

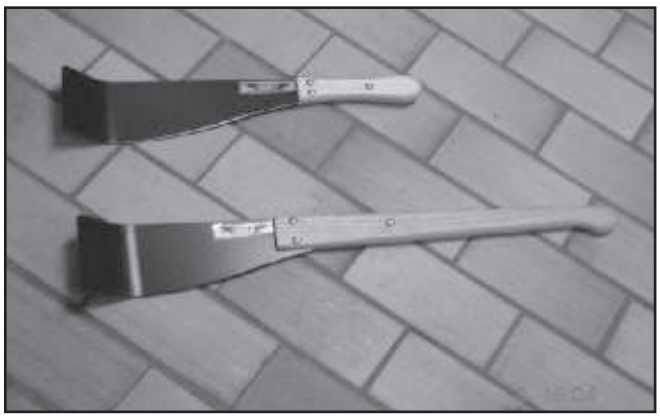

FIGURE 1. Short handled curved blade and the long handled curved blade sugarcane knives.

Sugarcane knives

The two cane knives investigated were the short handled curved blade and the long handled curved blade (Allrounder curved blade), shown in Figure 1. The curved blade and the cutting grip position of the handle enables the cane cutter to cut the stalk at ground level, leaving almost no stubble. The curved blade also cuts a larger volume of cane than a straight blade. In addition to the improved productivity when using the curved blade, the cane is cut more economically as the straight blade cuts the cane at an angle, thereby leaving behind some stalk near the base, which contains the highest concentration of sucrose. The harvested cane can easily be picked up using the curvature of the blade, thereby minimising forward flexion of the cane cutter's trunk and reducing strain being placed on the musculo-skeletal system (Voss, 2000).

The lighter weight of the short handled knife makes it a popular choice with cane cutters. Its use also has agronomic advantages. According to Meemeduma and Dhamrawardene (1994) and Morrison and Blake (1974), the short handled curved blade knife cuts the stalks almost horizontally, eliminating the need to stubble shave and enabling even germination of the following ratoon. However, the relatively shorter length of the handle produces a shorter lever arm, which necessitates an increased number of strokes and greater force application to achieve the same standard of production possible with the long handled knife. In addition, it is necessary for the cutter to bend further to make a cut, clear the base and pick up the stalks, which depletes his energy level sooner than would be the case were he using a long handled knife.

The long handled curved blade knife cuts in a manner similar to the short handled curved blade knife. There is, however, an increase in the length of the stalk from the bottom-most part of the stalk, which contains the highest concentration of sucrose, thereby increasing the weight, sugar content and the quality of the stalk. The length of the handle adds to the lever arm length, producing an increased momentum and force, while at the same time reducing the number of strokes. Furthermore, it does not require bending forward to such an extent as with the short handled knife in cutting, clearing the base and picking up the stalks. This reduction in forward bending leads to less fatigue and an increase in productivity. It has taken a long time to convince cane cutters of the advantages of using the long or medium handled knife, as they were accustomed to the short handled straight blade cane knife, but it provides considerable benefits to the cutter, the farmer and the miller.

Methods and materials

The present study was carried out on Dover-Logoza Estate in the Umhlatuzi Valley Sugar Company in Zululand. Here,

sugarcane is harvested nine months of the year, from April to December. A group of 15 professional male cane cutters was randomly selected and participated with written informed consent in this study. The subjects' average age was 34.13 ± 7.5 years and their average length of experience in sugarcane cutting was 12.18 ± 7.32 years.

Implement familiarisation

To ensure that all subjects were familiar with both the short and long handled curved knife, they were questioned concerning the use of the specific cane knives, work experience in terms of cutting cane and their preference for either the long or short handled cane knife. Mchunu (1999) recommended additional training sessions for at least one week (40 hours) for those who required it, until improved skill was demonstrated with a specific knife.

The activity recording was conducted on three consecutive occasions, to guard against the characteristics of one knife confounding those of the other. Test periods of 30 minutes each, using the long and short handled cane knives on burnt cane were allocated to each subject. On a separate occasion, a test period of 30 minutes was allocated to the subjects to harvest the green and burnt cane with a short handled knife. This led to a total of 90 recordings. Four subjects were measured each day between 05h00 am and 09h00. The amount of cane cut for the specific period of work testing was carefully collected and calculated.

Metabolic measures

The VO_2 was measured with the MetaMax Ergospirometry System (CORTEX Biophysik GmbH, Leipzig, Germany) as seen in Figure 2. The MetaMax was placed into a backpack and mounted firmly onto the subject. The subject commenced cutting for a continuous period of 30 minutes.

Heart rate measures

HR was measured telemetrically by means of a Polar Pacer Heart Rate Monitor (FIN-90440, KEMPELE, Finland). The Polar Pacer Transmitter with its strap is adjusted to fit snugly and comfortably around the subject's chest. This device transmits impulses parallel to the cardiac frequency of the receiver of the MetaMax base unit. After collection, the heart rate data were downloaded via a Polar Interface Plus with Training Advisor Software onto a computer, where they were analysed.

FIGURE 2. Sugarcane cutter wearing the MetaMax Ergospirometry system for oxygen consumption measurement.

Economy of movement

The economy of movement was estimated from the amount of cane cut per minute ($kg \cdot min^{-1}$), the amount of energy expended to cut 1 kg of cane ($kJ \cdot kg^{-1}$), the amount of cane cut for 1 litre of oxygen consumed ($kg \cdot LO_2^{-1}$), the number of cane cutting strokes per minute, and the number of stalks cut per stroke.

Subjective ratings

Ratings of perceived exertion (RPE) were recorded every 10 minutes, presenting a clearly readable Universal RPE Scale. The subject pointed out and verbalised the appropriate diagram on the Universal RPE Scale that most accurately reflected his perception of strain at that point in time.

Statistical analysis

The analysis of co-variance (ANCOVA) was used to compare variables. The significance level for all tests was established at $p < 0.05$, unless otherwise mentioned.

Results and discussion

Physiological parameters

All physiological parameters are summarised in Table 1. The average relative oxygen consumption (rel VO_2) for cutting burnt cane and the calculated relative energy expenditure (rel EE) were both significantly lower than those for green cane. There was a significant difference in relative VO_2 of 10.7%, and a significant difference in relative EE of 10%, in regard to cutting burnt and green cane.

The average absolute VO_2 for cutting burnt cane was significantly lower than that for green cane. The figures for oxygen consumption ($L \cdot min^{-1}$) were comparable with those of other researchers: 1.62 ± 0.32 (Collins *et al*, 1976); 1.5 (Spurr *et al.*, 1975); 1.69 ± 0.34 and 1.90 ± 0.44 for burnt and 1.42 ± 0.15 for green cane (Morrison and Blake, 1974).

Average HR during work was not significantly different for burnt or green cane, neither was the maximal HR. This implies that cutting burnt or green cane produces similar peak and mean levels of exertion, as indicated by the heart rate response. Previous studies of heart rate during cane cutting, correlated well with the findings in this study, with the following average heart rates ($beats \cdot min^{-1}$) reported: 103 ± 3 (Lambert *et al*., 1994), 135 ± 20; 132 ± 16 (Collins *et al*., 1976); 137 ± 20 (Spurr *et al*., 1975), and 118 (Davies, 1973).

The average maximal heart rates during cutting burnt cane and green cane, were 131.13 and 135.87 $beats \cdot min^{-1}$, respectively. The most common method for calculating maximal heart rate is 220 minus age, from which it can be deduced that cutters whose average age was 34.13 years, had exerted themselves at 70.6%

TABLE 1. Summary of means and standard deviations for relative VO_2 (ml · kg · min^{-1}), relative EE (kJ · kg^{-1} · min^{-1}), average HR and maximal HR (beats · min^{-1}) for burnt and green sugarcane and percentage differences (Δ %).

Physiological parameter	Burnt	Green	* = p < 0.05	Δ %
Rel VO_2	29.85 ± 7.88	33.42 ± 5.74	*	10.7%
Rel EE	0.63 ± 0.17	0.70 ± 0.12	*	10%
Mean HR	119.8 ± 18.61	123.67 ± 13.23		
Max HR	131.13 ± 19.16	135.93 ± 14.32		

and 73.1% of their maximal heart rate, respectively. Bearing this in mind, these HR measures can be classified as very heavy work (Åstrand and Rodahl, 1986).

Economy of movement

Economy of movement was ascertained by the measurement of four parameters: rate of productivity (kg · min^{-1}), energy required for cutting 1 kilogram of cane (kJ · kg^{-1}), amount of cane cut per 1 litre of oxygen consumed (kg · LO_2^{-1}), number of cutting strokes per minute (strokes · min^{-1}) and number of stalks cut per stroke (stalks · $stroke^{-1}$).

The rate of productivity for burnt cane was significantly higher than that for green cane. From this it was apparent that the rate of productivity for burnt cane was 24.2% higher than that for green cane.

Energy per kilogram required for cutting burnt cane was significantly lower than that for green cane, with a difference of 29.1% in favour of burnt cane. The amount of cane cut per 1 litre of oxygen consumed for burnt cane was significantly greater than that for green cane. When a cutter consumed 1 litre of oxygen, there was a difference of 35.4% with regard to the amount of sugarcane being cut, compared with trashing. Economy of movement indicated much more efficient and economic outcomes when cutting burnt cane than when cutting green cane.

Interestingly enough, the number of cane cutting strokes per minute for green cane were significantly lower than those for burnt cane. However, number of stalks cut per stroke for green cane was significantly higher than those for burnt cane. Despite the higher values in favour of green cane, the total highest productivity rate remained with the burnt cane. The number of cutting strokes in the Lambert *et al*. (1994) study was 35 strokes · min^{-1}, and 1-2 stalks per stroke were cut in the study of Morrison and Blake (1975). Refer to Table 2 for parameters of economy of movement.

The secondary study produced no significant differences in any of the measured variables for the comparison of the long handled knife and the short handled knife. The economy of movement was ascertained by taking identical measurements for the four parameters for the long and short handled knives.

The only significant difference between the long and short handled knives was the subject's perceived exertion scores (RPE). The difference between the short and long handled cane knives was 9.6%, in favour of the long knife. It can therefore be concluded that neither the use of the long nor the short handled knife had any effect on overall energy expenditure or economy of movement. The use of the different types of knives appears to depend largely on the preference for a certain knife by the cane cutter.

Conclusion

The data collected during this study were obtained via a portable metabolic analyser and, at the time, only two of these devices were available in South Africa. The data collected are therefore exceptionally valid and reliable due to the direct measurement of VO_2 and EE, compared with indirect methods.

The physiological responses of sugarcane cutters to cutting burnt and green cane differed significantly ($p<0.05$) for the following variables: relative and absolute oxygen consumption (VO_2), and relative (kJ · kg^{-1} · min^{-1}) and absolute energy expenditure (kJ · min^{-1}). Significant differences ($p<0.05$) occurred between RPEs for burnt and green sugarcane.

TABLE 2. Economy of movement is expressed in terms of productivity rate (kg · min^{-1}), energy required for 1 kg of cane cut (kJ · kg^{-1}) (Econ kJ), amount of cane cut per 1 litre of oxygen consumed (kg · LO_2^{-1}) (Econ kg), the number of cutting strokes per minute (strokes · min^{-1}), the number of stalks cut per stroke (stalks · $stroke^{-1}$) and percentage differences (Δ%).

Parameter	Burnt	Green	* = p < 0.05 ** = p < 0.01	Δ %
Productivity rate	30.3 ± 11.52	22.98 ± 5.86	**	24.2%
Econ kJ	1.51 ± 0.58	2.13 ± 0.61	*	29.1%
Econ kg	16.43 ± 8.61	10.62 ± 2.79	**	35.4%
Strokes	34.42 ± 6.87	25.45 ± 3.3	*	29%
Stalks	2.45 ± 0.37	2.55 ± 0.49	*	3.9%

In terms of economy there was a significant difference ($p < 0.05$) between cutting burnt and green sugarcane for the measured variables: rate of productivity, energy per kilogram required for cane cut, the amount of cane cut per 1 litre of oxygen consumed, the number of cutting strokes per minute and the number of stalks cut per stroke.

The results of this research project can be summarised as follows:

- With regard to physiological variables and economy of movement, cutting burnt cane surpassed all aspects of harvesting compared with cutting green cane. The energy expenditure required for cutting burnt cane was 10% lower than that required when cutting green cane.
- A higher rate of productivity was observed for cutting burnt cane than for green cane, although the number of strokes was less than that for cutting green cane which is contrary to other findings (Morrison and Blake, 1974), while the number of stalks cut per stroke was greater for green cane. This may be due to the fact that the green cane stalks were generally straight whereas some of the field measurements were done on lodged burnt cane, which would naturally lead to a lower number of stalks being cut per stroke. The number of cane cutting strokes per minute was calculated by taking into account only the strokes needed to cut the stalks, and not the strokes required to strip the leaves of green cane.
- Caution is necessary in regard to previous heart rate extrapolated findings, because of the unknown demands of cane cutting on the cutter.
- The choice of knives depends on the preference of the cane cutter, as there were no significant differences measured in physiological and economy of movement parameters.

Recommendations

The present study appears to have been largely successful in presenting an informed understanding of those factors having an influence on the cane cutting industry. The following recommendations should be considered for future research:

1. Observations should be carried out using the same variety of cane and all cane should be straight, whether burnt or green, to minimise variables.
2. The period for collecting data on energy expenditure in regard to different knives should be increased, to ensure more accurate measurements. It was observed that the cutting rate in the early morning (05h00) was higher than that during mid-morning (10h00), which could lead to significant differences in the use of different implements.
3. A more comprehensive study in which labour productivity could be compared with the quality of the sugarcane in terms of the Cane Testing Services (CTS) analysis, i.e., sucrose content, percentage ash and percentage fibre, should be undertaken.

Acknowledgements

The authors gratefully recognise the contribution throughout this study made by the South African Sugar Experiment Station (SASEX), Okapi Cane Knives and the University of Zululand. The authors wish to thank Eddie Meyer of SASEX, Mick Furby and the sugarcane cutters on Dover-Logoza Estate and Renate Voss (Okapi) for their generous co-operation in the data collection process.

REFERENCES

Åstrand PO and Rodahl K (1986). *Textbook of work physiology: Physiological bases of exercise.* Third edition. Singapore: McGraw-Hill.

Borg GA (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, 5(2): 377-381.

Collins KJ, Brotherhood RJ, Davies CTM, Doré C, Hackett AJ, Imms FJ, Musgrove J, Weiner JS, Amin MA, El Karim M, Ishmail HM, Omer AHS and Sukkar MY (1976). Physiological performance and work capacity of Sudanese cane cutters with *Schistosoma mansoni* infection. *The American Journal of Tropical Medicine and Hygiene*, 25(3): 410-421.

Davies CTM (1973). Relationship of maximum aerobic power output to productivity and absenteeism of East African sugar cane workers. *British Journal for Industrial Medicine*, 30: 146-154.

Immink MDC, Flores CR, Viteri FE and Sibrian R (1987). Body composition of Guatemalan sugarcane cutters, worker productivity and different work settings and conditions. *Human Biology*, 59(5): 827-836.

Lambert MI, Cheevers EJ and Coopoo Y (1994). Relationship between energy expenditure and productivity of sugar cane cutters and stackers. *Occupational Medicine*, 44: 190-194.

McArdle WD, Katch FI and Katch VL (1991). *Exercise Physiology: Energy, Nutrition, and Human Performance*. Third edition. Philadelphia: Lea & Febiger.

Mchunu SW (1999). Personal interview with the Trainer from the Training Department, Experiment Station, 20 August 1999, Mount Edgecombe: South African Sugar Association.

Meemeduma D and Dhamrawardene N (1994). An improved green cane harvesting knife. Paper presented at ISSCT Agricultural Engineering Workshop on Green Cane Harvesting and Trash Management held in Mauritius and Reunion, 5-14 October 1994.

Morrison JF and Blake GTW (1974). Physiological observations on cane cutters. *European Journal of Applied Physiology*, 33: 247-254.

SA Cane Growers Labour Utilization and Cost Survey (1999-2000). SA Cane Growers Association, 170 Flanders Drive, Mount Edgecombe 4300 KwaZulu-Natal, South Africa.

SASEX Training Manual (n.d.). Training Department, South African Sugar Association Experiment Station, Mount Edgecombe 4300 KwaZulu-Natal, South Africa.

Scott PA (1990). The development of a psychophysical scale for evaluating self-perceived strain. Ph.D. (Human Movement Science) Dissertation. Stellenbosch: University of Stellenbosch.

Spurr GB, Barac-Nieto M and Maksud MG (1975). Energy expenditure cutting sugarcane. *Journal of Applied Physiology*, 39(6): 990-996.

Voss R (2000). Personal interview with the Export Manager, 7 August 2000, Mandini: Okapi Cane Knife Manufacturers.