PRODUCTIVITY AND PHYSICAL WORKLOAD OF CUTTING CREWS IN SAO HILL SOFTWOOD PLANTATIONS

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO.

ABSTRACT

Physical workload and cutting productivity of two-man raker and peg toothed saws were compared when clearfelling a *Pinus elliottii* compartment in Sao Hill forest plantation. Three logging crews working with the two types of saw were studied between July and October 1990. Heart rate data was collected after every 30 seconds using a SPORT TESTER while maximum aerobic power was estimated using sub-maximal tests on a cycle ergometer respectively.

A total of 1271 trees with an average Dbh of 25 cm were felled and bucked into logs. Analysis of the data revealed that:

(a) Effective cutting time when using raker and peg toothed saws were 8.8 and 9.6 min/tree respectively. For a 7 hour workday only about 4.7 hours were spent for productive work.

(b) Raker-toothed saws had higher cutting production rates than peg-toothed saws. Production rates for raker and peg- toothed saws ranged from 3.25 - 3.6 and 2.98 - 3.16 m^3/crew - h respectively.

(c) The heart rates of the workers during effective cutting time were 112 - 117 and 115 - 118 beats/min

when using raker and peg-toothed saws respectively. Maximum aerobic power of the workers averaged 2.54 l/min ranging from 2.37 to 2.74 l/min.

(d) Oxygen consumption rate was on the average 1.23 l/min ranging from 1.11 - 1.30 l/min when using raker-toothed saws. The demand averaged 1.28 l/min with peg-toothed saws ranging from 1.14 - 1.38 l/min. Thus energy demand when using peg-toothed saws was about 28% higher than for raker-toothed saw cutting. This indicated that raker- toothed saws could be a better choice for cutting operation.

(e) Physical workload on the workers when cutting using the two types of saws showed no significant differences. The workload indices during effective cutting time using raker and peg-toothed saws were 43.7 - 52.6 % and 44.8 - 53.6% respectively. This showed that the cutting operation was a moderate energy demanding job.

DECLARATION

I, EMILSON JEREMIAH MALISA do hereby declare to the Senate of Sokoine University of Agriculture that the work presented here is my own, and has not been submitted for higher degree in any other University.

Signature ____________

Date 09/03/1992

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ACKNOWLEDGEMENTS

I greatly appreciate the extensive help, advice, criticism and information obtained from various organizations and individuals who have made this dissertation possible. It is unfortunate that the contribution of each cannot be personally recognized. However, the following deserve special mention:

- Sokoine University of Agriculture for financing my studies.
- My supervisor Professor W.S.Abeli for his effective supervision from planning, execution and write up of the dissertation. I feel privileged to have had a chance to be supervised by him.
- Ministry of Tourism, Environment and Natural Resources for granting me a study leave.
- All staff members in the Department of Forest Engineering, the Faculty of forest and University in general who in one way or another assissted me during data analysis. Particular thanks go to Messers G.Migunga, Y.Ngaga, J.S.Lugole and G.Fue.
- My thanks should also go to the Sao Hill Forest Project and Sao Hill Sawmill (Ltd) management for allowing me to conduct this research at their work places. Dr. Msami assisted me so much during field work in the organization of the study crews.

- My deepest gratitude goes to my wife, Monica and my sons Erick and Enock for being patient and understanding during the years of this study. Without their encouragement this study would not have been possible.
- Dr. E. Malisa who took care of my family for the whole period of my studies.
- Mrs. C. Sakaya for typing this dissertation.
- Finally to my parents, I am still indebted to their unreserved and immeasurable sacrifices towards my education.

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1. INTRODUCTION

1.1 Forest work in Tanzania

Forest and wood processing industries in Tanzania provide many employment opportunities directly or indirectly to the rural people.It has been estimated that about 15,000 people are employed by this sector (Dykstra 1983). This figure is about 2.8% of the total employed labour force in the country.

Despite its potential of employment opportunities, forestry work is very unpopular.In many forests for example,labour turnover is relatively high. This is because very few trained and skilled workers are willing to stay and work in the forest for long periods due to unfavourable working and living conditions (Abeli 1979).

Most of the forest operations and in particular timber cutting are done manually. The reason is that labour is abundant and cheap while capital for investment in mechanization is limited. On the other hand, manual work in forest is characterized by heavy physical workload, which impair the physical working capacity of the workers and reduce labour productivity (Elgstrand 1979; Harstela 1987; Sood 1988). The workload becomes higher if the workers do not use proper working tools, techniques and methods.

Forestry like any other production activity should not be managed without considering the human aspect. Forest management must ensure that workers in the forests are in good health and that working and living standards are improved. There is need to increase labour productivity but at the same time reduce the physical workloads on the workers. This requires proper working tools, training and an incentive to keep the workers interested in their job.

Low labour productivity in forestry has an adverse effect on the socio-economic condition of the workers. The situation is well explained by the "Economic cycle of disease" and is denoted as vicious circle of low productivity, low income, malnutrition, diseases and low working capacity of workers (Ayaz 1986). Dykstra (1983) observed that labour intensive methods cost less than capital intensive methods provided they are managed in a way that maximizes labour productivity. In order to alleviate the problem of low productivity and low working capacity of the workers, ergonomic research is needed.

Ergonomic research provides useful information that assists in establishing proper relation between man and work situation. The objective is to achieve higher work output while maintaining worker's safety, health and well-being (Sood 1988).

Physical workload is the physiological effects of muscular work on human body causing exhaustion (Ayaz 1986). It can be static or dynamic depending on the nature of the activity being performed. Workload varies from light to extreme heavy depending on the work intensity and the aerobic power of the worker. In forest operations, the physical workloads in silvicultural activities are moderate while in logging they are heavy (Strehlke 1979).

Physical work capacity is measured as the maximal aerobic power of the worker (Davies 1979). It is the capability of man's cardiovascular system to supply the adequate quantity of oxygen to the working muscles (Apud *et al.*1989). Aerobic power is a personal capability that limits worker's productivity. In order to ensure that worker's health is not impaired by excessive workload, work should be carried out under aerobic conditions. Research findings recommend that manual activities in the tropics should not exceed 40 to 50% of the aerobic capacity of the worker (Grandjean 1986).

Time studies that have been conducted in Tanzanian softwood plantations show that production rates for different cutting tools are relatively low (Nangawe 1976; Kimaryo 1979; Migunga 1982; Abeli and Ndossi 1984; Abeli *et al.*1988). The workload imposed on the workers during cutting operation has not been assessed to ascertain if the work is physiologically tolerable and feasible based on the worker's ability and the tools used in cutting.

1.2. Study objectives

The general objective of the study was to assess and compare the physical workload on workers and labour productivity during timber cutting when using two different cutting tools in Sao Hill softwood plantation. The cutting tools compared were two-man raker-toothed crosscut and two-man peg-toothed crosscut saws.

The specific objectives are:

- To determine the maximum aerobic power of the workers clearfelling a mature *Pinus elliottii* stand in Sao Hill softwood plantation;
- To measure physical workloads on the workers when using two-man raker and peg-toothed crosscut saws during cutting operation;
- To measure and compare cutting production rates for the above cutting tools;

- To suggest the appropriate two-man crosscut saw to be used in cutting softwoods and
- To identify the most energy demanding work elements which require further work and method improvements.

1.3. Limitations of the study

Due to time constraint and other limitations, results of this study are confined to the workers and work place conditions which were prevailing during the study period as follows:

- One stand of *Pinus elliottii* in Sao Hill softwood plantation;
- Only six male workers were studied.

2 LITERATURE REVIEW

Timber cutting is the first step in logging operation. It is an essential phase in preparing the trees for further processing. Cutting operation includes felling of trees, limbing, scaling, bucking and piling of logs or tree lengths depending on the logging system in operation. The main objective in cutting operation is to maximize timber values and maintain a high level of cutting efficiency in terms of productivity and costs (FAO 1974; Conway 1978; Dykstra 1983). In order to meet this objective, factors that influence productivity during cutting operation must be analyzed carefully. These factors are grouped into two broad categories and they are briefly discussed as follows (FAO 1974; 1976):

2.1 Physical factors influencing timber cutting

2.1.1 Climatic factors

Temperature, relative humidity, amount and distribution of rainfall, season and wind speed are some of the climatic factors that influence labour productivity in cutting operation. Unfavourable climate particularly in the tropics where temperatures and relative humidity are high cause discomfort to the workers. Heat stress influence heart rate, body temperature and recovery time during forestry operations (Zander 1979). An increase of 1°C (dry bulb temperature) cause an increase of about 1.4% in heart rate in the tropics (Grandjean 1986; Chandra 1987). According to FAO (1974), heavy work should be done in the early morning or late in the afternoon otherwise lower work rate and frequent breaks have to be encouraged.

2.1.2 Terrain factors

Important terrain features affecting logging productivity include ground slope, roughness, soil condition and brush density. In steep terrain, logging crews have to spend more time walking from one tree to another. The cut trees tend to run down slopes causing unnecessary movements to the cutting crews and it is more difficult to walk in steeper slopes (Conway 1976).

2.1.3 Stand factors

Stand factors include timber type, size, stand density and volume per unit area (FAO 1974). Significant tree parameters that have been found to influence cutting production are presented in Table 1.

2.2. Human factors

To be able to perform heavy physical work, the human body

Table 1 **Tree parameters influencing cutting production rates**

Source	Cutting tool	Significant factors influencing cutting production
Samset *et al.* 1969	Chain saw	Dbh, TrVoL, CrL felling/bucking cross-sectional area, NLogs
FAO 1974	Chain saw	Dbh, NLogs
Aluma 1976	Chain/crosscut saw	Dbh
FAO 1976	Axe/Chain saw	Dbh, TrHT, CrL, Skill and ability of labour force
Dallu 1977	Crosscut saw/ Axe	Dbh
Ngibuini 1977	Crosscut saw/ Chain saw	Dbh
Mitra and Sood 1979	Crosscut saw/ Chain saw	Dbh, TrVoL, TrHT
Migunga 1982	Crosscut saw/ Chain saw	Dbh, NLogs
Ole-Meiludie 1984	Crosscut saw	Dbh, SDia, TrHT, NLogs
Sirito 1987	Crosscut saw	Dbh, BBA
Saarilahti and Ole-Meiludie 1987	Crosscut saw	Dbh, TrVoL

Where: Dbh = Diameter of the tree at breast height (1.3m), in cm
TrHT = Total height of tree, in m
TrVoL = Total volume of the tree, in m^3
CrL = Crown length, in m
NLogs = Number of logs bucked from the tree
SDia = Stump diameter of the tree, in cm
BBA = Bucking basal area, in m^2

must be furnished with adequate chemical energy. This energy is obtained from the foodstuff consumed (carbohydrates, fats and proteins). Inadequate nutrition has been stated as one of the major factor contributing to poor labour productivity in forestry operations. According to Kantola and Virtanen (1986), a healthy European male worker weighing an average of 65 kg, requires about 4000 - 4500 kcal of energy per day in order to perform heavy forest work. If the daily calorie demand falls to 70%, work output can be reduced to about 50% due to reduction in physical work capacity in the form of slow work movements, frequent pauses and short workplace time (Abeli 1991). Nutrition may also influence absenteeism and labour turnover. In order to maintain an energy balance, man has to take enough calories required to satisfy the body's energy requirements.

Other human factors influencing productivity in logging include training, experience, skills, health and motivational factors (FAO 1974). The human factors are influenced by physical factors and thus it is difficult to isolate and measure them accurately (FAO 1976).

2.3 Need for work and ergonomic studies in forestry

Ergonomics is defined as an interdisciplinary approach to human work problems. It applies human biological sciences in conjunction with the engineering sciences in order to achieve optimum mutual adjustment of man and his work (Van Loon *et al*. 1979; Skaar 1982; Sood 1988). Various aspects can be evaluated ergonomically in cutting operation including:

- the way in which the task is performed,
- the tools used and
- the physical workload on the workers.

This means therefore, consistent application of ergonomics is a basic consideration in timber cutting in order to achieve optimum output without undue strain on the workers.

Due to high energy demands in forest work (Strehlke 1979; Bostrand 1986) and the relatively poor nutrition of the workers in the developing countries, urgent measures are required to reduce work stress. This can be done through work and ergonomic research. Ergonomics should find its application in the planning, organization and supervision of forest work in order to reduce work strain on the workers.

The objective of the work study and ergonomic research in all forestry operations is to develop optimum techniques and systems for the worker and for the enterprise. Whereas the enterprise aims at increased efficiency in the production, the worker is more interested in maintaining his capacity to work, getting adequate compensation for his efforts and making the best use for tools and equipment (Wenter 1985).

2.4 Work study

Work study is the systematic procedure for gathering both qualitative and quantitative information about a complete or part of a work system. It includes the material, technical and organization aspects affecting work performance. The purpose of work study is to increase productivity and the effectiveness of management (Wittering 1973; ILO 1979). The discipline associates method and time study techniques.

2.4.1 Method study

This is the systematic recording and critical examination of existing and proposed ways of doing work. It aims at developing and applying easier and more effective methods and reducing costs (ILO 1979). Method study has a wide application in forestry and particularly in comparing productivity of different workers using identical tools or the same worker using different tools (Dykstra 1982a).

2.4.2 Time study

Time study is the application of techniques designed to establish the work content of a specified task by determining the time required by qualified worker to carry it out at a defined standard of performance (Apud *et al.*1989). It is the most used approach to collect work measurement data in forestry. The objectives met through time study include evaluation of labour performance, assessing the effectiveness of training or work productivity and to improve planning through more reliable estimates of production rates and costs (Dykstra 1982a). Forestry operation can be studied using either shift-level or detailed time study.

2.4.2.1 Shift-level time study

Shift-level or "gross" time study measures and records the production levels achieved by a work system, crew or a machine during one shift, day or a given period or entire working season. During shift-level data collection timing does not require precision. The results obtained from such study are used to indicate to the management where detailed studies are required (Dykstra 1982a).

The limitations of shift-level time study include:

- the lengthy study period required to accumulate sufficient data for analysis

- the problem to determine whether the results obtained from the study apply to conditions other than those investigated (Migunga and Dykstra 1983).

2.4.2.2 Detailed time study

Detailed time studies are undertaken where details of information about work method, worker's productivity, operating costs and procedures beyond the level of details available from shift-level studies are required (Dykstra 1982a). In these studies, work cycles are broken down into individual work elements which are studied independently. Such breakdown enables work element times for a given operation and another to be compared. The study analyst can also isolate time consuming elements and subject them to more comprehensive method studies (Dykstra 1982a).

Stop watch is the most used equipment in measuring time in detailed time studies. Depending on the purpose of the study, the timing procedures used in detailed time study are either continuous timing or work sampling (activity sampling).

(a) Continuous timing

In this method, every event is timed and recorded through out the day from the moment work starts until it terminates. In this way, the maximum amount of data is obtained on regular or irregular events and on delays. Two methods are used in continuous timing namely: Cumulative and Snap-back timing.

Cumulative timing

The stopwatch is started at the beginning of the day and left to run continuously throughout the day without resetting. The cumulative time since the beginning of the day is then recorded at the start of each work element. The method has the following advantages (Migunga and Dykstra 1983):

- a good record or the sequence of activities is kept;
- it provides unbiased measurements especially where productive and unproductive times are to be studied.

The disadvantage with this method is that the elapsed time for each work element must be determined later in the office by subtraction. Thus it is difficult to check the sensitivity of activity times in the field (Dykstra 1982a).

Snap-back timing

The stop watch is started at the beginning of each activity and at the end of the activity, the snap-back button of the watch is depressed to reset the hands of the watch to zero. In this way the analyst can easily judge the relative variations in event times during the study (Wittering 1973).

Unlike in continuous timing, snap-back method does not require subtraction to get the work element times thus, less prone to errors. However, the order of events is not recorded for the day's activities (Wittering 1973).

(b) Work sampling

Sometimes it is refereed to as activity sampling. In this method, it is not the time duration of an activity which is recorded but the frequency of occurrence of the activity or work element. The objective is to determine the proportion of time in a work cycle that is devoted to each work element. Observations are made at regular or random intervals. The element being performed at that particular time is noted and recorded. The time interval chosen depends upon the length of the work cycle. A mark or a symbol is inscribed on a recording form with columns for each activity. The mark indicates the activity currently being performed. When the study is completed at the end of the day, all the marks for each work element are added and divided by the length of observation interval set for the study. The pre-requisite for this method is that observations must strictly adhere to the interval set.

The main **advantages** of work sampling are:

- one study man can observe many workers at the same time.
- it is cheap and simple to learn and practice.
- even very short work elements can be recorded.

Disadvantages

- The work sequence can not be reconstructed.
- with quick changing of place, the work study analyst can easily make a mistake
- mistakes made in the field can only be discovered at the end of the work cycle by checking through the columns.

Time studies have been used to determine production rates and costs for different cutting methods in forestry (Dykstra 1975; FAO 1976; Abeli 1979; Ole-Meiludie 1984; Sirito 1987). Production rates and efficiency of different cutting tools have been compared in clearfelling and thinning operations using time studies. Results obtained from different cutting time studies in Tanzanian softwood plantations are presented in Table 2.

Table 2 Selected cutting time studies in Tanzanian Softwood plantations

Source	Cutting tools	Species	Operation	Production rate (m3/h)	Work element time (min/tree)			
					Felling	Limbing	Bucking	Total
Dallu 1977	Raker saw	*P.patula*	C/Felling	0.69	-	-	-	-
Kimaryo 1979	Bow saw	Cypress	"	0.58				
Micsk and Stridsberg 1981	Raker saw	*P.patula*	"	2.4-3.20	-	-	-	-
Migunga 1982	Raker saw	*P.radiata*	"	1.93	3.95	9.89	4.31	20.06
"	Power saw	*P.radiata*	"	2.60	2.6	6.48	2.07	13.37
Ole-Meiludie 1984	Raker saw	Cypress	Thinning	1.11	2.71	7.39	2.88	14.78
"	Raker saw	*P.radiata*	"	1.49	1.36	3.08	-	7.66
Minja 1985	Raker saw	Cypress	C/Felling	2.30	4.42	10.40	6.57	22.50
Bakena 1985	Raker saw	Cypress	"	2.40	-	-	-	-
Abeli and Ndossi 1984	Raker saw	*P.patula*	"	1.50	-	-	-	-
Saarilahti and Ole-Meiludie 1987	Raker saw	*P.patula*	"	3.50	-	-	-	-
Ole-Meiludie *et al.* 1989	Raker saw	*P.patula*	"	1.22	-	-	-	-

Activity sampling method has been used in workload studies in different operations (Maleta and Sood 1984; Smith *et al.*1985; Ayaz 1986). Ilmarinen *et al.*(1984) used activity sampling method to study workload on workers for different postal delivery modes.

If telemetric devices are used to record heart rates, the regular interval set for the device is equivalent to work sampling procedures. Vik (1986) concluded that work sampling method makes it possible to simultaneously perform work study with reasonable accuracy since the subjects being studied continue their work without any interference from the analyst. Migunga (1986), Harstela and Saarilahti (1986) compared work sampling and continuous timing methods. They concluded that two methods yield the same results. The same conclusion was drawn by Smith (1986) when he compared two methods of nursery pot filling using flyback timing technique.

2.5. Physical working capacity.

Man's ability to perform physical work is based upon energy provided by the bioenergetics system. The source of this energy is through splitting of high energy rich Adenosine tri-phosphate molecules (ATP) to lower energy molecules adenosine-diphosphate (ADP) yielding energy equivalent to 8 cal/mole. The reaction is reversible.

ATP is resynthesized from ADP through energy from oxidation of food stuffs in the body (aerobic processes). Since oxygen is the main factor in the aerobic process, its quantity absorbed (in l/min) gives an indication of the efficiency of pulmonary and cardiovascular systems to absorb and utilize the oxygen for liberating the desired energy (Apud *et al*.1989).

The maximal power of the oxidation metabolism is measured by the maximal oxygen uptake (VO_2 max). Maximal oxygen uptake or maximal aerobic power is the highest attainable rate of oxygen during heavy rhythmic dynamic muscular work (Ayaz 1988). It is measured in l/min or milliliters per minute per kilogram of body weight (ml/kg/min). The maximum aerobic power is used in many occupational physical studies to assess the physical fitness of the workers. A physically fit worker is the one whose aerobic power is comparable with the sustained energy demands of the work (Vik 1971; Apud *et al*.1989). It varies with age, sex, ethnic background, physical training. body weight and composition (Apud *et al*.1989).

Research findings have shown a significant relationship between aerobic power and work output in forestry (Vik 1971; Davies 1979; Fibiger and Handerson 1984; Ilmarinen *et al*.1984; Smith *et al*.1985). Decline of aerobic power with age has been reported by Vik (1971) and

Apud *et al.*(1979) for Norwegian and Chilean forest workers respectively. It has also been noted that aerobic power of forest workers in the tropical regions is impaired by heat stress and higher relative humidity (FAO 1977; Chandra 1979). Davies (1979) reported a decline in aerobic power due to anemic diseases in Tanzania. Maximal aerobic power of forest workers selected from different countries is presented in Table 3.

On the basis of research findings, it is acceptable that not more than 40 to 50% of the aerobic power of the worker should be utilized for work during an eight hours shift. This is to ensure that work is carried out under aerobic conditions (Apud *et al.* 1989). In work situations where team work is required, selection of work partners should be based on workers with equal aerobic power as weak workers experience higher physical stress and fatigue earlier than the physically fit ones. In such cases, weak workers require frequent breaks than physically fit workers (Ayaz 1988).

Maximum aerobic power of workers in the tropical countries is said to be lower compared to those working in temperate countries (Abeli and Ndossi 1984). The reason could be due to poor nutritional status of workers, health and heat stresses. However, research reports show that aerobic

Table 3 **Maximum aerobic power of forest workers in different countries**

Source	Country	Age (y)	Weight (Kg)	Height (cm)	Vo_2max (l/min)
Vik 1971	Norway	<30	73.0	177.8	3.5
Van Loon and Spoelstra 1971	Netherlands	55-59	74.0	172.0	2.6
	,,	60-64	76.0	170.0	2.5
Staudt 1974	Surinam	28	64.0	166.0	2.7
	India	31	48.0	161.0	2.2
Mgalihya 1986	Tanzania	38	70.0	-	3.6
Apud *et al.*1989	Tanzania	-	56.9	-	3.0
Saarilahti and Ole-Meiludie 1987	Tanzania	32	66.0	173.0	2.9
Fue 1987	Tanzania	16	52.0	172.0	3.1
		22	53.0	173.0	2.8
		30	58.0	180.0	3.2
Lubambula 1988	Tanzania	20	58.0	160.0	2.4

power for forest workers in different parts of Tanzania range between 2.5 and 3.7 l/min (Abeli and Ndossi 1984; Bakena 1985; Nduwayezu 1986; Mgalihya 1986; Fue 1987; Lubambula 1988). This range is an indication that the forest workers are on the average fit for their work based on the fact that maximum aerobic power can go up to 6.0 l/min for higher achievers and as less than or equal to 2.0 l/min for lower achievers (Abeli 1991).

2.5.1 Assessment of maximum aerobic power

Maximum aerobic power and maximal oxygen uptake (VO_2 max.) are synonymous terms in physiological studies (Apud *et al.*1989). It can be measured directly or estimated by indirect methods.

2.5.1.1 Direct method of measuring maximal oxygen uptake

A standard equipment used for this test is a cycle ergometer. The subject to be tested has to exercise on the cycle ergometer at increasing workloads. The heart rate is monitored at each work load either manually or by means of a telemetric device. The consumption of oxygen at each workload is determined and the level where further increase in workload does not cause a corresponding increase in oxygen uptake is noted. At this stage the subject is assumed to be completely exhausted and has to stop the exercise. By collecting and analyzing the composition of the expired air, it is possible to estimate the amount of oxygen that has been used by the subject. Apud *et al.*(1989) recommended the use of the following formula for calculating oxygen uptake:

$$VO_2 = VE(\%O_2IA - \%\ O_2\ EA)/100 \quad \text{..................(1)}$$

Where;

VO_2 = oxygen uptake rate, in l/min

VE = pulmonary ventilation, in l/min

%IA = percentage of oxygen in inspired air

%EA = percentage of oxygen in expired air.

Pulmonary ventilation is calculated as follows;

$$V_E = \text{Volume of expired air}/t \quad \text{..................(2)}$$

Where; t = time for collecting the expired air in minutes.

Details of this method are discussed in Apud *et al.* (1989). In most cases, the direct method of determining the maximal oxygen uptake rate in the field is impractical. The workers tend to feel exhausted before attaining the maximal workload. In addition, breathing through a mouth piece may lead to hyperventilation and to some subjects it causes anxiety. In order to overcome these limitations, indirect techniques have been designed.

These are based on linear relationship between heart rate, oxygen uptake and workload. Two common techniques used are extrapolation method and the nomogram of Astrand and Rhyming (Apud *et al.*1989).

2.5.1.2 Indirect methods of estimating maximal aerobic power

(a) Extrapolation method

The subject exercises on a cycle ergometer, step test or tread-mill at three or four sub-maximal loads and heart rate and oxygen uptake (VO_2) measured during the steady states. The VO_2 max. is then determined by extrapolating the graph between heart rate and oxygen uptake at the sub-maximal loads to a predicted maximal heart rate for the subject's age. The following formula is used in determining the maximum heart rate in relation to age (Apud *et al.*1989):

Maximal heart rate = 220 - Age (yrs)................(3)

(b) The nomogram of Astrand and Rhyming

The maximal oxygen uptake can be calculated from a nomogram of Astrand and Rhyming (Appendix 1) when heart rate and oxygen uptake are measured simultaneously during steady state condition. The nomogram is based on findings by Astrand and Rodahl (Apud *et al.*(1989). If it is not possible to measure oxygen uptake during the test, heart rate and workload can be used to estimate VO_2 max if the subject is exercised on a cycle ergometer or step test under specified conditions. The calculated maximal oxygen uptake values should be corrected for the subject's age as the procedure is said to over estimate VO_2 max for subjects over 25 years of age. Age correction factors are provided for use in connection with the nomogram (Appendix 2).

2.6 Physical workload

Physical workload has been defined by Ayaz (1986) as the physiological effect of muscular activity in the human body. This workload produces strain (physiological and psychological changes) in the human body. The strain is observed in changes of heart rate, production of lactic acid, and secretion of hormones and feelings of tiredness.The severity of the strain depends on the work,the amount of energy demanded, the environmental factors and the maximum aerobic power of the worker (Harstela 1987). The same workload can cause different strains to different persons depending on their physical, mental capabilities and social conditions.

Workload studies are based on the physiological functions of human body during work. Under heavy strenuous and continuous work, oxygen supply to the working muscles is insufficient and thus anaerobic glycolysis occurs to cover this oxygen debt. Anaerobic glycolysis results into accumulation of lactic acid in the blood. Thus, the heaviness of the task can be determined by measuring the amount of lactic acid accumulated in the blood during work (Abeli 1991). Other indices proposed by Apud *et al.*(1989) for determining the heaviness of work include:

- Measurements of oxygen consumption (l/min) and heart rate during work and expressing the results in percentage of maximal aerobic power of the worker concerned;
- Measuring the work heart rate (beats/min);
- Measuring of body temperature at work and
- Measurement of sweat rate.

Measurement of oxygen uptake is very laborious and the procedure interferes with work performance (Vik 1971). Body temperature requires measuring both inner (core) and outer temperatures during work.The core temperature is measured by inserting a thermometer about 5 cm deep into the workers rectum. Although this method has been used in the tropics, it is not socially acceptable (Apud *et al.*1989).

Heart rate is a more convenient parameter to record in the field. It gives the possibility to measure both physical and mental workload (Vik 1971). The heart rate during work can be monitored manually or by telemetric devices. Although the manual method is the simplest, it is laborious for both the worker and the observer due to many interruptions involved during work. In addition, the observer has to be very fast in counting the heart beats before heart rate recovery starts. Recovery usually starts 10 seconds after the worker has stopped working (Apud *et al*.1989).

To overcome the limitations encountered above, electronic heart rate counters are widely used. Saarilahti and Abeli (1986) tried one of these telemetric devices (SPORT TESTER) in assessing physical workload in Tanzanian forestry workers.

Several studies have been conducted to measure physical workload in forestry using heart rate recording.The findings are presented in Table 4. The heart rate information is used in fixing the limit for sustained performance. The upper limit of heart rate during physical activities in forest operation has been set as 110 beats/min (Ayaz 1988). Grandjean (1986) recommended 30 beats/min above the subject's resting heart rate as a upper limit. The limit ensures that work is performed under aerobic conditions. In any case, the workload should not exceed 40 - 50% of the worker's aerobic capacity (Apud

Table 4 **Workload indices for different forestry operations**

Source	Operation	WLI%
Maleta and Sood 1984	Timber cutting by axe	60.25
	" " by local saws	52.0
	" " by improved saws	49.0
Abeli and Ndossi 1984	Timber cutting by crosscut saws	45.0
Bakena 1985	Timber cutting by crosscut saws	38.0
Mgalihya 1986	Timber cutting by axes	57.3
Fue 1987	Sulky forwarding	41.6
	Sulky skidding	49.5
	Manual dragging	61.1
Saarilahti and Ole-Meiludie 1987	Timber cutting by crosscut saws	36.0
Lubambula 1988	Timber cutting by chain saws	72.9

*et al.*1972; Skaar 1982; Saarilahti 1986). The indices used in assessing work intensity are presented in Appendix 3.

3 MATERIALS AND METHODS

3.1 The study area

Sao Hill forest project is located at longitudes 35°6′E to 35°20′E and latitudes 8° 18′S to 8° 33′S in Mufindi district, Iringa region. The plantation covers about 95,000 ha of land of which about 42,000 ha have already been planted (Mhando 1991). The main tree species planted are; *Pinus patula, Pinus elliottii, Pinus caribea, Pinus kesiya, Pinus oocarpa, Eucalyptus grandis, Eucalyptus saligna* and *Cupressus spp*.

The main wood consumers in this forest are the Southern Pulp and Paper Mill (SPM) and Sao Hill Sawmill Limited. SPM has an annual capacity of about 300,000 m^3 of round logs (under bark) while Sao Hill sawmill has a annual log input of about 50,000m^3 (u.b.). The allowable cut from the plantation is estimated at 600,000 m^3 of round logs annually. The forest project is state owned and managed by the Forest and Beekeeping Division in the Ministry of Tourism, Natural Resources and Environment.

During the Study, a 29 year old *Pinus elliottii* stand in compartment $S_{2.c}$ was being clearfelled. The stand which was about 9.3 ha, had an estimated standing volume of about 7,500 m^3. The ground slope was about 6% and temperatures fluctuated between 10° and 20°C during the study period. The location of the study area is shown in figure 1 and the study compartment in figure 2.

3.2 Description of the lobour force

Sao Hill sawmill had about 50 casual labourers employed in timber cutting operation during the study period. These labourers reside in their home villages about 25-35 km from the Sawmill Head Office. A survey carried out during this study showed that about 40% of the labourers belonged to Hehe ethnic group, 35% Benas and 25% were from other ethnic groups. All of them had completed primary school education but they had no formal training in forestry job. After work hours (in the evenings), weekends and on public holidays they usually work in their shambas. These workers underwent medical examination before being engaged in cutting operation. This explains why all workers were medically fit during the study period.

The labourers were working on task - bonus payment system. The task was 20 trees/crew-day and in addition a bonus was paid for any extra tree(s) cut. The minimum bonus paid was Tsh 12.00 per tree. Free transport was provided to pick the labourers from their villages to the work site (07.00 hours) and return them to their villages after work (14.30 hours). In addition, they were provided with free

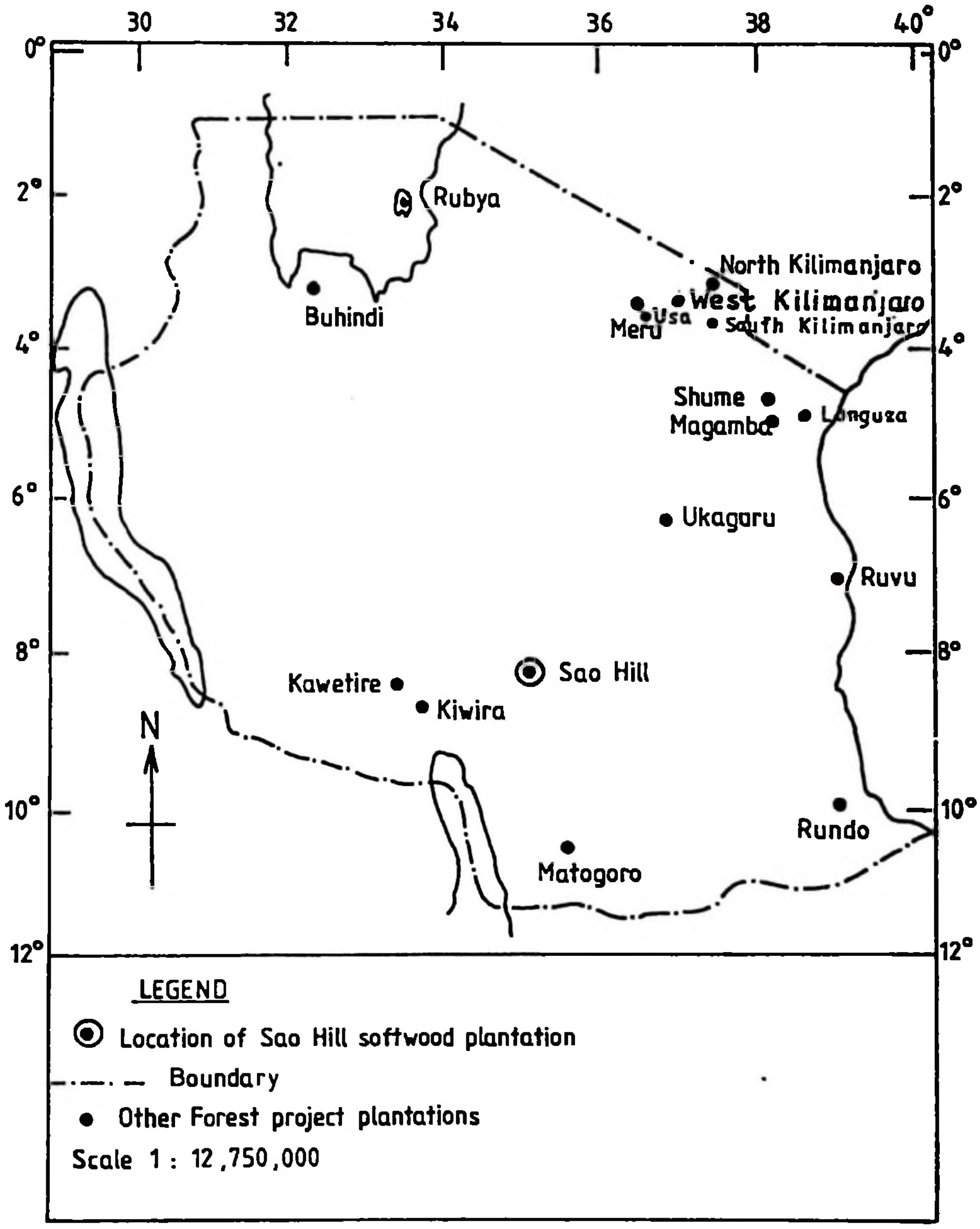
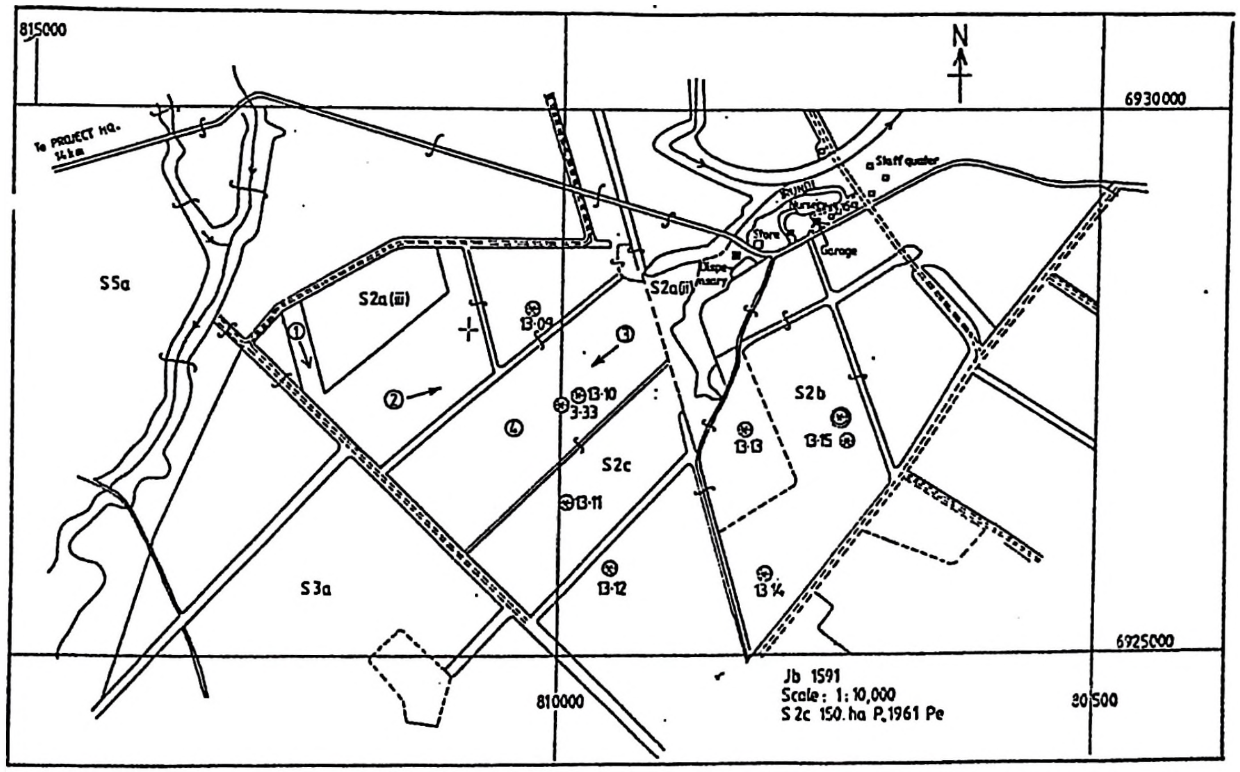


Figure 1 . Location of different forest projects in Tanzania



Key: ⟶ Movement of cutting crews during the study

Fig. 2 . Location of the study compartment

medical services including their families. Uniforms and other protective gears were also given to the labourers. These included overalls, boots and helmets. All working tools were provided by the sawmill and weekly maintenance of the tools was done by the Sawmill. Lunch was provided from 13.30 to 14.30 hours. Cutting crews did not work on Saturdays unless there was shortage of logs at the mill logyard. Nobody worked on Sundays and public holidays. During the study period the cutting crews started work at around 08.15 hours and stopped working at around 13.00 hours. The normal work-place time was 6.5 hours. Each crew was made up of two workers who permanently worked together. Formation of the cutting crews was not based on any criteria other than individuals selection. In case one of the crew member was absent, the remaining was allowed to join another crew or else return home.

3.3 Description of the cutting tools

3.3.1 Two-man raker-toothed crosscut saws

Raker-toothed saws manufactured by Sandvik A.B. These were fitted with horn shaped and detachable wooden handles.The saw length was 1500 mm, sway-backed and made from good quality steel with champion teeth - BM.

3.3.2 Two-man peg-toothed crosscut saws

Sandvik peg-toothed saws, hard tempered, made from good quality steel. The saw lengths were 1200 mm, straight backed and fitted with horn shaped detachable wooden handles.

Raker and peg-toothed crosscut saws were used for making undercuts, back cuts and bucking while notches were chopped off with axes.

3.3.3 Felling axes

The axes in use were Yankee type from Sweden.These were made from good quality steel, hardened, tempered and polished.The axe weight was 0.9 kg and were fitted to wooden handles 650 mm long.The axes were used for limbing and chopping off notches during felling.

3.3.4 Peavies

Peavies made of metal had a hook hinged on a metal head which incorporated a socket into which a good sized wooden handle was fitted. The cutting crews used these peavies for dislodging trees by rolling their butts.

3.3.5 Cycle ergometer

Cycle ergometer with the trade mark of Body Guard 90 had a drive disc which was mechanically braked. This disc was driven by pedalling and disc revolutions were measured by use of mounted counter device. The cycle ergometer was calibrated in order to be able to measure work performance in kilopond-meters or in watts. The relationship used was as follows:

Performance = work/time ....(4)

= (Force x distance)/Time

= kpm/sec.

Conversion of kilopond-meters into watts was made according to the following formula:

1kpm/sec = 9.18 watt ....(5)

The cycle ergometer was used during sub-maximal tests.

3.3.6 SPORT TESTER

A Sport Tester - PE 200 system was used in recording the heart rate of the workers during work. The system consisted of a pulse transmitter and a receiver micro-computer. The transmitter was tied around the subject's chest by an elastic belt. This transmitted heart rate signals in FM waves to the receiver. The receiver was put into the worker's shirt pocket or hung on the antennae of the transmitter in order to allow proper reception (i.e. the transmission distance was less than 1.0 m). The receiver allowed the display of the heart rate values every 5 seconds. These values were stored in the microcomputer memory every 30 seconds. The microcomputer had a capacity of storing 128 heart rate readings. After one hour of recording, the receiver microcomputer was retrieved and the stored readings recorded. It was then returned to the subject for further recording. The technical specifications for the system are given in Appendix 4.

3.4 Study procedure

Selection of workers to be studied was based on age group. Four crews were initially selected for the study. After a pilot study, two workers, one from crew B and another one from crew C were unwilling to participate in the study. They were thus dropped from the study. The study was conducted in 3 stages as follows:

Training stage

Training of the study workers on the procedures which were to be followed during the study. This stage was also used to train the study assistants on the methods which were to be used in collecting the required information and measurement procedures.

Preliminary study

The purpose of the preliminary study was to test the data forms and study procedures. Data forms to be used in the actual study were tested and re-designed according to the irregularities noted at this stage (See Appendix 5).

Actual study

After two weeks it was assumed that the crews having worked with the heart rate equipment had gained enough confidence and experience. The crew to be studied worked in clearly defined work cycles and a single tree formed a work cycle. Work on the next tree was started only when the first tree was completed. Each crew member was observed and studied after every other day.

In order to ensure that time and heart rate data were representative of a typical cutting operation in Sao Hill softwood plantations, interference or modification on the production process was minimized by the research personnel. As far as possible the cutting crews were encouraged to follow the normal working practices as stipulated by the Sawmill management.

3.5 Data collection

The cutting operation was segregated into productive and non-productive work element times. Productive or effective time consisted of work element times which contributed directly to the cutting production. Non-productive times comprised of interruptions which interfered with the continuity of work in a cutting cycle. Non- productive times were further sub-divided into necessary and unnecessary delays.

Necessary delays were those related to continuation of work operations or occurring due to unforeseeable events. Unnecessary delays were those times during which the studied worker was diverted from his normal duties. These unnecessary delays could be eliminated or reduced by improving supervision.

In this study, productive time consisted of the following three work elements;

Felling: Felling time started when the worker picked up the felling tools and started clearing brush around the tree to be felled. It also included time taken to determine the direction of fall, time to move from one tree to another, time for making notches, undercuts and backcuts, wedging, until the tree was brought down to the ground and the butt freed from the stump.

Limbing: This was time required to severe the branches from the tree stem. Limbing time begun when the worker picked up the limbing axe, cut the tree limbs, throwing away severed branches and ended when the last branch was severed from the stem.

Bucking: Bucking time was time required to crosscut the tree into logs. It started when the worker picked up the crosscut saw, drove wedges to release pinched saws until the last log was bucked from the stem. It also included topping and time to move from one bucking point to another.

Delays: Non-productive times were those times observed when cutting operation was interrupted and ended when cutting resumed.

Necessary delays: These were classified as follows:

Saw pinching: Time required to release a pinched saw.

Saw maintenance: Time required to maintain the saw blade. such time included applying oil/diesel to the saw blade in order to remove resins. It also included time spent on changing blunt saws.

Handle fixing: Time spent on adjusting saw and axe handles when loose or damaged.

Hang up: Time spent on bringing down a lodged tree.

Piling of logs: Time required to arrange the bucked logs in the required piles.

Instruction time: Time spent by the worker to receive necessary information or instructions from the supervisor or the researcher. It also included time taken to remove and install back the SPORT TESTER system in its proper position.

Unnecessary delays: Included all time spent on other non-productive activities which were not related to the cutting operation. Such activities included chatting, smoking or attending to other unscheduled activities. Figure 3 shows the breakdown of the cutting work cycle into productive and non-productive element times.

3.5.1 Activity sampling

Activity sampling technique was used during work and heart rate studies. This technique was used because the objectives of the study were to compare efficiency of the two cutting tools and workload imposed on the worker by the same tools during work. Thus heart rate studies were to be conducted parallel to the time studies (Ayaz 1986). In addition, the activity sampling method was found to be less costly and simple to conduct than continuous timing.

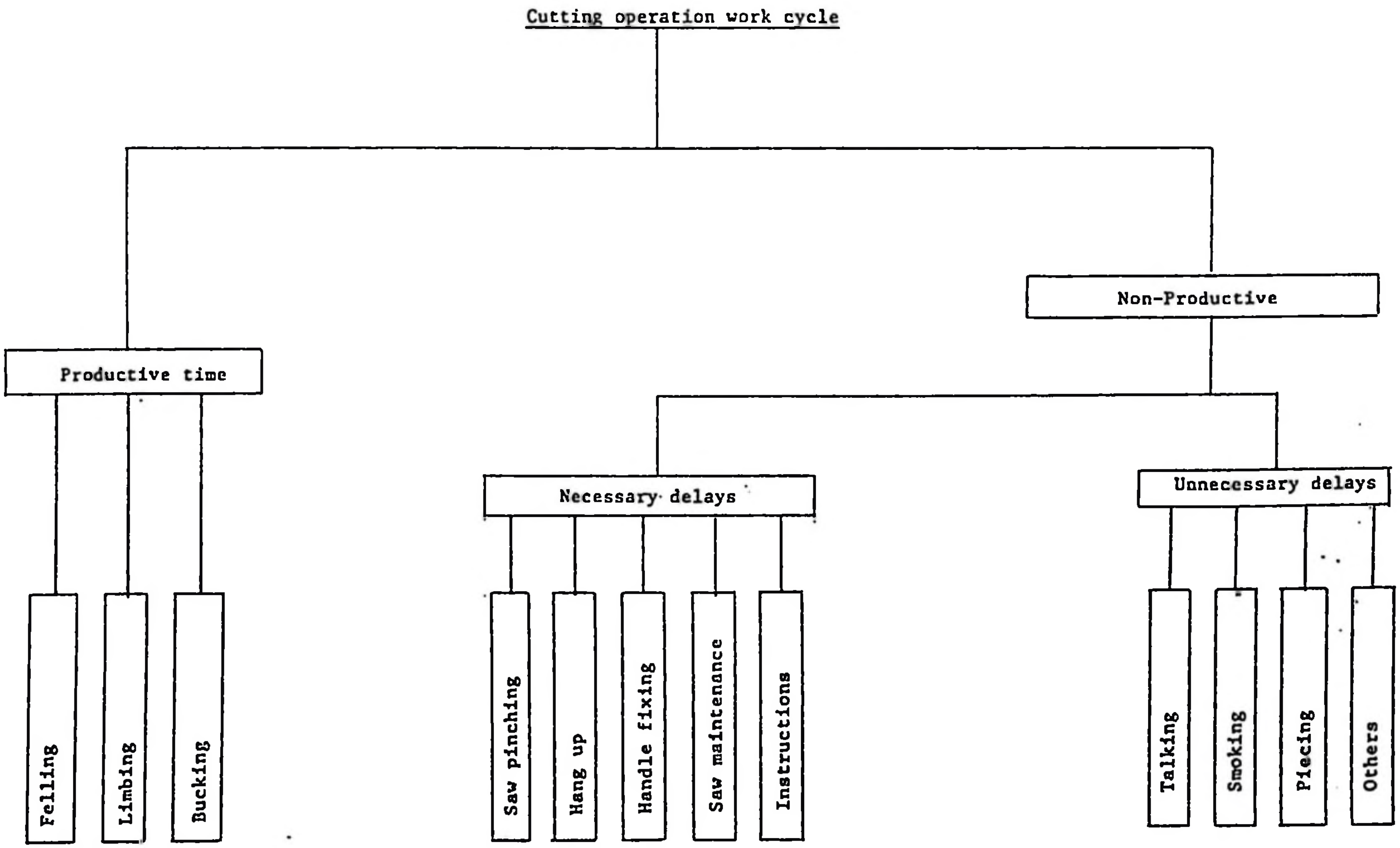


Fig. 3. Breakdown of the cutting operation work cycle

The necessary information which was desired was the proportion of time in a work cycle devoted to each work element. This information could easily be obtained through activity sampling (Dykstra 1982a).

The observation interval chosen was 30 seconds. This was in view of the nature of the operation being purely manual with sufficient long work cycles (Ayaz 1986). Appendix 5 shows the sample data sheet used for recording the heart rate information during the study.

3.5.2 Sample size determination

In order to have sufficient number of observations needed for a statistically valid sample, the following formula was used (ILO 1979):

$$n = pq/E^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where n = number of work cycles to be timed

p = percentage of non-productive time

q = percentage of effective working time

E = standard error of proportion

p and q were pre-determined during preliminary study. Confidence interval and margin of error used in activity sampling was 95% and 10% respectively (ILO 1979).

3.5.3 Measurement of independent variables

In addition to the work element times, independent variables upon which work element times were assumed to be dependent upon were measured and recorded in the appropriate data sheet (Appendix 6).These variables were abbreviated as follows:

SDIA = stump diameter (o.b), in cm

DBH = Diameter at breast height (o.b), in cm

TRHT = total tree height, in m

CRL = total crown length of the tree, in m

LOGL = total merchantable log length, in m

BUDIA = bucking diameter of each log (o.b), in cm;

Other independent variables were calculated based on the field data. They included:

TRVOL = total tree volume (o.b), in m^3.The tree volume was computed by summing up the volumes of individual logs bucked from the tree and the crown volume.

VLOG = log volume (o.b), in m^3. The merchantable log volume was computed using Smalian formula (Carron 1968) as follows in formula (7):

$$VLoG = \frac{S_1 + S_2) \cdot L}{2} \quad \text{.................}(7)$$

Where; S_1 and S_2 = the cross sectional areas in m^2 of the larger (bottom) and the smaller (top) end of the log respectively.

L = log length, in m

CRVOL = crown volume, in m^3, calculated as follows:

$$V = \frac{1}{3} (s \times l) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where V = crown volume (o.b) in m^3.

s = cross-sectional area of the base, in m^2.

l = length of the cone, in m.

3.5.4 Resting heart rate

The resting heart rate of each worker studied was measured manually each morning before the actual work started. A resting period of 10 - 15 minutes was given to the crew members to be studied when they arrived at the felling site. They were allowed to sit on a log but not allowed to smoke or do any activity. After 10 - 15 minutes of rest, the pulse rate was taken by feeling the pulsation of the radial artery at the carotid artery near the Adam's apple by fingers. Time taken to count 10 beats was measured with a stop watch. After taking the pulse rate, the workers were allowed to stand up and continue with work. The resting heart rate was then calculated using the following equation (Apud *et al.* 1989):

$$\text{Heart rate} = \frac{10 \times 60}{\text{Time for 10 beats (sec.)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

3.5.5 Estimation of maximum aerobic power

The maximum aerobic power of individual workers was determined using sub-maximal tests on a cycle ergometer. The tests were conducted in a well ventilated room near the felling site. The exercise was done on Saturdays when the cutting crews were free.

Before the actual test, the workers were given time to practice with the cycle ergometer. The objectives of the study and the idea behind the tests were explained to them. After being convinced that the procedures to be followed during the test on cycle ergometer were clearly understood, the actual tests then started. Again before the tests the worker's resting heart rates were measured manually and recorded as explained in section 3.5.4.

Actual exercises on the cycle ergometer took 6 minutes. The workloads were varied from 50 to 150 watts while the pedalling speed was kept constant (50 revolutions per minute). The heart rate was monitored continuously by use of the SPORT TESTER worn by the study subject. After 4 minutes, it was anticipated that the subject's heart rate was at a steady state (Wenter 1983; Apud *et al.* 1989). The subject was allowed to stop the exercise after 6 minutes and rest for 10 - 15 minutes. The rest period was aimed at making the subjects heart beats go back to the resting

3.6 Techniques of data analysis

3.6.1 Organization of data

The data collected during cutting operation were classified into two data sets for each worker as follows:

- Data on time and labour output (production rate)
- Data on heart rate (workload).

Each data set comprised of field data collected when using raker and peg-toothed crosscut saws.

3.6.2 Statistical analysis

Statistical analysis was performed using Statistical Program for Social Sciences (SPSS /PC) supplied with IBM computers at the Sokoine University of Agriculture. Both, descriptive and multiple regression analyses were performed using this package.

3.6.2.1 Descriptive statistics

Descriptive statistics on data sets gave summaries about the mean, standard deviation, the range, standard error of the mean and 95 confidence interval (lower and upper limit). For each work element in the study, a statistical summary was developed.

3.6.2.2 Multiple linear regression analysis

In order to derive the general relationships among dependent and independent variables, linear multiple regression equations were used. The general regression model by Steel and Torrie (1980) was used;

$$Y = b_o + b_1 X_1 + b_2 X_2 + \text{-----} + b_n X_n + E \ldots\ldots\ldots\ldots\ldots (10)$$

Where; $b_1, b_2 \ldots b_n$ = regression coefficients

$X_1, X_2 \ldots X_n$ = independent variables

b_o = Y intercept (constant)

E = error term

Y = response variable.

The independent variables thought to influence the response variable (dependent) were chosen and entered in the final equation to see if they significantly contributed to the response ($P \leq 0.05$). Analysis of variance tables gave the value of R-squared (coefficient of determination) while the confidence level used in all statistical analyses was 95%. The difference between means of corresponding variables for the two study levels was tested by the two sample t - test as follows:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{[(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2 / n_1 + n_2 - 2 (n_1 + n_2 / n_1 n_2)]} \ldots (11)$$

The null hypotheses (Ho) were that, the mean values for the two study levels did not differ ($\mu_1 = \mu_2$).

Where; t = student's t - test

$\overline{X}_1$ and $\overline{X}_2$ = mean values obtained during cutting using raker and peg toothed crosscut saws respectively;

n_1 and n_2 = number of observations or work cycles timed for raker and peg toothed saws respectively;

S_1^2 and S_2^2 = sample variances obtained for the two saws respectively;

μ_1 and μ_2 = population means assumed to be equal.

If calculated t was higher than the tabulated t-value at 0.05 probability level and (n-2) degree of freedom, then Ho was rejected and the conclusion was that there was a significant difference in the means. The dependent variables used in the statistical summaries and regression equations are abbreviated as follows:

Tfel = felling time, in minutes

TLimb = limbing time, in minutes

TBu = bucking time, in minutes

ETCuT = total effective cutting time, in minutes.

3.6.3 Assessment of Workload in timber cutting

The upper limit for sustained performance has been set as 40-50% of the worker's maximum aerobic power (Apud *et al.*1972; Skaar 1982). The following equation was used to calculate the workload indices for different work elements during timber cutting (Mälkiä 1974):

$$WLI\% = \frac{HR - RHR \times 100}{MP - RHR} \qquad (12)$$

Where WLI% = workload index in percentage

HR = heart rate during work, in beats/min;

RHR = resting heart rate, in beats/min.

MP = maximum heart rate during sub-maximal test, in beats/min.

3.6.4 Schedule of work

The study was carried out for about 3 months from July to October 1990. Table 5 summarizes the total number of trees cut and time spent on the cutting operation.

Table 5 **Summary of total number of trees cut using the two crosscut saws**

Type of saw used	No of days	Hours spent	No of trees	Vol/tree (m^3)	Total Vol (m^3)
Raker-toothed	31	98	639	0.70	447.3
Peg-toothed	45	109	632	0.65	410.8

4. RESULTS AND DISCUSSION

4.1 Personal characteristics of the workers

Personal characteristics of the six workers who volunteered to be studied are presented in Table 6. Age varied between 19 and 30 years with an average of 26 years. Workers here were relatively younger than other forest workers reported by Saarilahti and Ole-Meiludie (1987) and Mgalihya (1986). The mean height was 164 cm and body weight was 59 kg ranging from 50 to 67 kg. The youngest worker had a working experience of 1 year while the oldest had worked as a logger for 5 years. The average resting heart rates of the workers measured while seated ranged between 60 and 75 beats/min (average 68 beats/min). For forest workers working in Tropical High Forests, Mgalihya (1986) found the resting heart rate to be 72 beats/min. Again compared to other forest workers these workers were lighter since the average weights of forest workers found by Saarilahti and Ole-Meiludie (1987) and Mgalihya (1986) were 66 kg and 70 kg respectively.

4.2. Physical working capacities of the workers

Physical work capacity of each worker was determined by measuring individual's maximal aerobic power using a cycle ergometer. The results are shown in Table 7. The increase in heart rates of the six workers due to increase in workload during sub-maximal tests is shown in Figure 4.

Table 6 **Personal data of the workers**

Crew	Worker No	Age (yr)	Height (cm)	Weight (Kg)	Exp (yr)	RHR (beats/min)
A	1	30	158	55.0	2	70
	2	25	165	62.0	4	72
B	3	21	172	54.0	4	60
	4	29	162	50.0	4	60
C	5	32	163	67.0	5	64
	6	19	166	65.0	1	75
Average		26	164	59.0	3	68

Where: RHR = Resting heart rate.

The maximum workload that the workers could attain during sub-maximal tests was 150 watts. Average maximum aerobic power of the workers ranged from 2.37 to 2.70 l/min averaging 2.54 l/min for the six workers. The results are similar to those reported by Abeli and Ndossi (1984) and Lubambula (1988) for forest workers at Olmotonyi near Arusha and Sao Hill respectively. However higher aerobic powers have been reported for Tanzanian forest workers by Bakena (1985) and Fue (1987).Their findings were 3.7 and 3.02 l/min for forest workers on the slopes of Usambara mountains near Tanga and Olmotonyi near Arusha respectively. The variations in maximum aerobic power could be due to personal differences. These include age, body weight, height, and ethnic background. Other studies conducted in Norway (Vik 1971) and Surinam (Staudt 1974) showed higher aerobic power i.e 3.5 and 2.7 l/min respectively. Again, these workers were heavier and taller than those reported in this study.

Table 7 **Estimated maximum aerobic power of the workers**

Crew No	Worker No	Age (years)	Heart rate at max.load (beats/min)	Vo_2 max. (l/min)
A	1	30	157	2.62
	2	25	159	2.70
B	3	21	174	2.60
	4	29	167	2.37
C	5	32	161	2.40
	6	19	171	2.54
Average		26	165	2.54

Where Vo_2 max = aerobic power of the worker (l/min).

4.3 Time study results

As indicated earlier, one of the study objectives was to compare production rates of the two crosscut saws during cutting operation in *Pinus elliottii* stand in Sao Hill softwood plantation. The time study data obtained were subjected to two statistical analyses; descriptive and multiple regression analysis.

4.3.1 Descriptive data analysis results

Summaries of effective cutting times for each work element are presented in Tables 8,9 and 10 for the two saws.

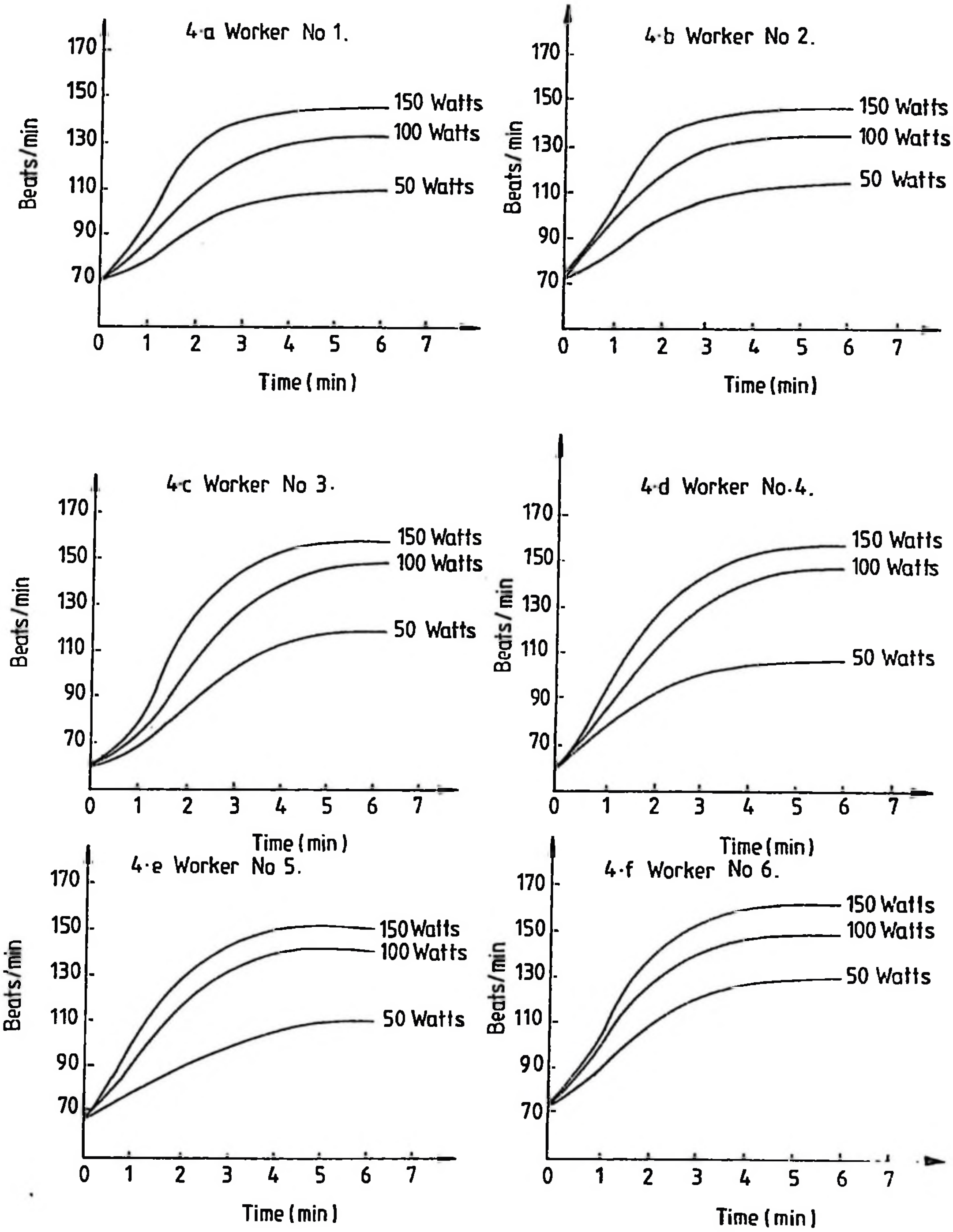


Fig. 4 . Heart rate during steady states at three submaximal workloads

4.3.1.1. **Felling time**

Average felling times for the three crews were 2.78 and 3.14 min/tree using raker and peg-toothed saws respectively. The felling for the raker and peg-toothed saws ranged between 2.53 -3.01 min/tree and between 2.80 and 3.38 min/tree respectively (Table 8).

Despite systematically using peg toothed saws for felling smaller trees, peg-toothed saws took more felling time than when using raker-toothed saws for all the three crews. Statistical analysis showed that peg-toothed saws had significant higher felling time than raker-toothed saws by about 10.7, 21.10 and 7.60% for crew A,B and C respectively ($P \leq 0.05$). Observed differences in felling time between the crews might have been caused by differences in maximum aerobic power of the workers (refer Table 7). The higher the physical working capacity (Vo_2max) the less the felling time and vice versa.

The above results show that raker-toothed saws are more efficient in felling trees than peg-toothed saws.The following might have been the reasons:

(a) **Saw design**

The basic design of the two saws differ due to the arrangement of the teeth. When cutting resinous wood using raker-toothed saw,the saw dust comes out in a form of

Table 8 Summary statistics for the average felling work element

Crew	Type of	Felling time (min/tree)			Stump diameter (cm)		
	saw	Mean	S.D	Range	Mean	S.D	Range
	Raker	2.53	1.16	0.5-6.5	31.7	8.51	16.0-58.0
A	Peg	2.80	1.06	1.0-6.5	31.25	7.40	13.0-50.0
	Change %	10.70			-1.4		
	Raker	2.79	1.04	0.5-5.5	30.24	6.99	14.0-50.0
B	Peg	3.38	1.11	0.5-6.50	29.94	7.38	14.0-48.0
	Change %	21.10			-1.0		
	Raker	3.01	0.98	0.5-5.50	31.66	7.42	14.0-50.0
C	Peg	3.24	1.08	0.5-8.0	30.30	8.30	10.0-60.0
	Change %	7.6			-4.5		

curled and long flakes leaving the saw teeth and kerf clean and clear. With peg toothed saw the dust mixes with the resin and sticks to the teeth of the saw lowering cutting efficiency (Kollman and Côte 1968). For equally maintained saws, raker-toothed saws ought to outweigh peg-toothed saws in terms of cutting efficiency and energy saving (Kantola and Virtanen 1986).

(b) The crews were observed to have higher interest and morale in working with raker compared to peg-toothed saws. Such attitude could have led to higher felling rate when using raker than peg-toothed saws.

Migunga (1982) and Minja (1985) have reported higher felling times in *Pinus radiata* and *Cuppressus lusitanica* compartments at Olmotonyi near Arusha using raker-toothed saws. Their figures were higher by 1.15 and 1.62 min/tree respectively. Compared to felling using peg-toothed saws, their figures were higher by 0.81 and 1.28 min/tree respectively. The differences in felling times might have been due to different nature of tree species, sizes, work organization, working conditions and supervision.

4.3.1.2 **Limbing time**

Average limbing time per tree for each worker is shown in Table 9. The sub-operation was carried out using axes. The

Table 9. Summary statistics for the average limbing work element

Crew	Worker	Limbing time (min/tree)			DBH (cm)			Crown Length (m)		
	No	Mean	S.D	Range	Mean	S.D	Range	Mean	S.D	Range
A	1	2.31	1.04	0.5-8.0	25.41	6.87	11.0-48.0	11.67	2.88	4.7-20.5
	2	2.51	1.16	0.5-8.0	25.35	6.45	10.0-40.0	11.07	2.21	5.0-17.0
B	3	2.88	1.0	0.5-5.5	24.65	6.16	12.0-42.0	11.90	2.93	5.5-21.5
	4	2.94	0.90	0.5-4.5	24.36	6.16	12.0-44.0	11.86	2.53	5.0-21.50
C	5	2.75	0.85	0.5-5.0	26.10	6.49	12.0-42.0	11.88	3.21	4.8-23.51
	6	2.90	0.98	0.5-5.5	24.74	7.04	8.0-53.0	12.45	3.0	6.0-20.40

results show that the most effective crew during limbing was A followed by C and B.

Limbing time ranged between 2.3 to 2.9 min/tree. The reason for the observed differences between the crews are most likely due to differences in maximum aerobic power of the workers (refer Table 7). The higher the aerobic power the less the limbing time and vice versa.

Pinus elliottii trees are normally selfprunned. Most of the branches that were found on the trees in this study were small and sparsely distributed along the stems. These two factors might have caused average limbing time to be lower than the findings that have been reported by other researchers. For example, while limbing took about 30% of the total effective cutting time, limbing other conifer trees has been reported to take about 40-50% of the total effective cutting time (Dallu 1977; Ole-Meiludie 1984; Minja 1985; Ole-Meiludie *et al*.1989). Heavy branchness, larger crowns and irregular distribution of limbs in *Pinus patula* and *Cupressus lusitanica* trees could have contributed to higher average limbing time.

4.3.1.3 **Bucking time**

Average bucking time per tree for the two cutting saws is presented in Table 10. Average bucking time for the raker

Table 9. Summary statistics for the average limbing work element

Crew	Worker	Limbing time (min/tree)			DBH (cm)			Tree height (m)		
	No	Mean	S.D	Range	Mean	S.D	Range	Mean	S.D	Range
A	1	2.31	1.04	0.5-8.0	25.41	6.87	11.0-48.0	11.67	2.88	4.7-20.5
	2	2.51	1.16	0.5-8.0	25.35	6.45	10.0-40.0	11.07	2.21	5.0-17.0
B	3	2.88	1.0	0.5-5.5	24.65	6.16	12.0-42.0	11.90	2.93	5.5-21.5
	4	2.94	0.90	0.5-4.5	24.36	6.16	12.0-44.0	11.86	2.53	5.0-21.50
C	5	2.75	0.85	0.5-5.0	26.10	6.49	12.0-42.0	11.88	3.21	4.8-23.51
	6	2.90	0.98	0.5-5.5	24.74	7.04	8.0-53.0	12.45	3.0	6.0-20.40

and peg-toothed saws were 3.30 and 3.69 min/tree respectively. Crew A was found to be relatively faster while crew C was the least efficient crew when bucking using raker-toothed saws. With peg-toothed saws, crew B was more efficient and crew C the least. Again peg-toothed saws had significant higher average bucking times than raker-toothed saws by about 17.14, 7.6 and 11.0% for crew A, B and C respectively. When compared to findings reported by Ole-Meiludie (1984) in thinning *Cuppressus lusitanica* near Arusha, the results in this study are higher by 0.42 and 0.81 min/tree when bucking using raker and peg-toothed saws respectively.In his study the trees were smaller compared to the ones in this study. Migunga (1982) and Minja (1985) reported higher bucking times by 1.01 and 3.27 min/tree compared to bucking time using raker-toothed saws in this study respectively. Higher bucking times in these two studies could be due to larger dimensions of the trees involved. There is similarity between felling and bucking sub-operations as both involves sawing. Thus, similar reasons given during felling applies to bucking.

4.3.1.4 **Total effective cutting time**

The results presented in Table 11 indicate that total effective (productive) cutting time per tree was significantly higher when using peg toothed saws than

Table 11. Summary statistics for total effective cutting time

Crew	Type of saw	Effective time (min/tree)			BuDia (cm)			VLog (m^3)			LogL (m)		
		Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
A	Raker	8.18	3.35	1.0-22.5	18.70	4.84	10-32.5	0.73	0.54	0.07-3.4	16.12	4.23	4.0-24.7
	Peg	8.99	3.65	2.0-25.0	18.93	4.77	9-32.0	0.67	0.38	0.04-2.06	16.20	3.92	4.0-24.5
	% Change	+10			+1.2			-8.9			+0.5		
B	Raker	8.99	2.87	2.0-19.0	19.01	4.68	10-34.0	0.63	0.37	0.05-2.39	15.55	4.08	4.0-24.0
	Peg	9.83	2.78	2.5-18.0	18.92	5.09	8-35.5	0.63	0.40	0.01-2.04	14.87	4.17	3.6-22.0
	% Change	9.30			-0.5			0			-4.6		
C	Raker	9.36	2.86	1.5-16.0	19.84	5.13	8-33.0	0.72	0.42	0.05-1.89	15.67	4.17	2.3-24.0
	Peg	9.97	3.09	1.5-22.5	18.87	6.47	8-43.0	0.66	0.47	0.06-3.28	15.44	4.71	4.5-26.5
	% Change	6.5			-5.0			-9.1			-1.5		

raker toothed saws for crews A, B and C. Average effective cutting time for the three crews was 8.84 and 9.60 min per tree using raker and peg-toothed saws respectively. Crew A was observed to work faster both when using raker and peg-tooted saws than the rest of the crews as indicated by lower average effective cutting time/tree. Crew C was the slowest in both cases. The possible explanation for higher cutting production rate observed for crew A compared to the rest of the crews might be due to higher maximum aerobic power of the crew members. Again despite the trees cut using raker-toothed saws being relatively bigger than those cut using peg-toothed saws, results shows that raker-toothed saws were more efficient than peg-toothed saws. The reasons could be due to saw design and higher interest the workers had in using raker as compared to peg-toothed saws.

Compared to other studies conducted in other Tanzanian softwood plantations, effective cutting time/tree in this study was relatively lower. For example, Migunga (1982) and Minja (1985) reported effective cutting time as high as 20.1 and 22.5 min/tree in *Pinus radiata* and *Cuppressus lusitanica* respectively when using raker saws. Variations in cutting times for these studies could have been due to differences in tree species, working conditions and personal characteristics of the cutting crews.

4.3.1.5 **Total cutting time**

Breakdown of total cutting time per tree into effective and non-productive or delay times is shown in Table 12. Average total cutting time per tree using raker and peg-toothed saws was 13.2 and 14.2 min/tree respectively. The proportion of effective cutting times to the total workplace time for the crews ranged from 64 - 69% and from 66 - 69% (averaging 67% and 68%) when using raker and peg-toothed saws respectively. The proportion of delay time was 33% and 32% when using raker and peg-toothed saws respectively. Bucking was the most time consuming sub-operation both when using raker and peg-toothed crosscut saws for all the three crews. This work element occupied about 37% and 38% of the total effective cutting time using raker and peg-toothed saws while felling element took about 31% and 33% of the total effective time respectively. Limbing took about 30%.

Dallu (1977) reported higher proportion of delay time per tree using raker-toothed saws during clearfelling in a *Pinus patula* compartment in the same area. His figure was 37% of the total workplace time. Kimaryo (1979) and Minja (1985) reported lower percentages of total delays using bow saws and raker-toothed saws in clearfelling *Cuppressus sp.* and *Pinus patula* stands in North Kilimanjaro and Sao Hill respectively. Their figures were 21 and 13%

Table 12. Breakdown of the total cutting time into effective and delay times

Crew	Type of saw	Effective time		Necessary delays		Unnecessary delays		Total delays		Total time
		Min/tree	%	Min/tree	%	Min/tree	%	Min/tree	%	Min/tree
	Raker	8.18	63.9	3.67	28.7	0.95	7.4	4.62	36.1	12.80
A	Peg	8.99	65.6	3.75	27.4	0.96	7.0	4.71	34.4	13.70
	Change	0.81		0.08		0.01		0.09		0.90
	Raker	8.99	67.7	3.54	27.7	0.74	5.6	4.28	32.3	13.27
B	Peg	9.83	68.0	3.87	26.8	0.76	5.2	4.63	32.0	14.46
	Change	0.84		0.33		0.02		0.35		1.19
	Raker	9.36	69.4	3.47	25.7	0.65	4.8	4.12	30.6	13.48
C	Peg	9.97	2 69.5	3.73	26.0	0.65	4.5	4.38	30.5	14.35
	Change	0.61		0.26		0		0.26		0.87

respectively. The variations in proportions of delay times to the total cutting times could be due to working efficiency of the crews, work organization and payment system.

4.3.2 Multiple linear regression analysis

Regression analysis was carried out to predict the effect of the measured tree parameters on felling, limbing, bucking and total productive time. For each saw a hypothesis was set relating the dependent variable (work element time) to a set of independent variables (tree parameters) that were expected to influence cutting work element times. The dependent and independent variables used in the models and prediction equations that follow are as defined in sections 3.5.3 and 4.3.

In the regression equations that follow;

R^2 = a statistic measuring the proportion of variance in the dependent variable explained by the linear relationship between that variable and the independent variables(s).

n = number of independent observations (complete work cycles).

: Also the coefficients associated with the independent variables in each equation are significantly different from zero at 5 percent probability level.

: numeric values entered parenthetically below regression coefficients in each equations are the standard errors of the respective coefficients.

: All the times estimated by the regression equations are in productive minutes per tree.

4.3.2.1 Felling time

Since felling involves sawing the cross-sectional area of the tree stump, the area sawn depends on the tree size. Thus, the time for felling a tree is expected to be proportional to the stump basal area. Since the basal area at the cutting point is calculated as $\pi D^2/4$, the square of this stump diameter ($SDia^2$) could be used as a surrogate of the cross-sectional area (Migunga 1982).

From the above theory, the following null hypothesis was set for the felling time:

Ho: TFeL = f(SDia, $SDia^2$,Dbh).

Regression equations for estimating felling time

(a) Two-man raker-toothed crosscut saws:

Crew A:

$$TFel = 0.245 + \underset{(0.013)}{0.065}\ Dbh + \underset{(0.0001)}{0.0012}\ SDia^2 \quad \ldots\ldots\ldots\ldots (13)$$

$$R^2 = 0.78 \qquad n = 210$$

Crew B:

$$TFel = 0.85 + 0.0021\ SDia^2 \qquad \text{.......................(14)}$$
$$(0.0001)$$

$$R^2 = 0.78 \qquad n = 213$$

Crew C:

$$TFel = 1.046 + 0.002\ SDia^2 \qquad \text{.......................(15)}$$
$$(0.0001)$$

$$R^2 = 0.80 \qquad n = 217$$

(b) Two-man peg-toothed crosscut saws:

Crew A:

$$TFel = 0.81 + 0.0019\ SDia^2 \qquad \text{.......................(16)}$$
$$(0.00002)$$

$$R^2 = 0.73 \qquad n = 210$$

Crew B:

$$TFel = 1.342 + 0.002\ SDia^2 \qquad \text{.......................(17)}$$
$$(0.0001)$$

$$R^2 = 0.75 \qquad n = 209$$

Crew C:

$$TFel = 1.598 + 0.002\ SDia^2 \qquad \text{.......................(18)}$$
$$(0.0001)$$

$$R^2 = 0.69 \qquad n = 209$$

Among the independent variables chosen for testing the null hypothesis, SDia was dropped from the final regression equations because the coefficients associated with it were not significantly different from zero at 5 percent probability level. Diameter at breast height (Dbh) appeared only once in the regression equation for estimating felling time per tree when using raker saws (crew A).In other equations, Dbh was not significantly contributing to the felling time. It was found that $SDia^2$ which is a surrogate for basal area was the most contributing independent variable to the felling time as indicated by higher R^2 value. The same variable has been used by Migunga (1982), Ole-Meiludie (1984) and Sirito (1987) for estimating felling time. Other researchers have used Dbh to predict felling time (Samset *et al.* 1969) while Minja (1985) used SDia and Dbh^2. Figure 5 shows that felling time per tree over the entire range of $SDia^2$ was consistently higher for peg-toothed saws for almost all crews.

4.3.2.2 Limbing time

Limbing involves severing branches from the stem. The sub-operation is largely dependent on the degree of branchness, crown length and size of the branches. The following null hypothesis was thus set for limbing time.

HO: TLimb = f(TrHT, CrL, Dbh, LogL).

Regression equations for limbing time

Worker No 1:

$$TLimb = -1.74 + \underset{(0.01)}{0.146\ TrHT} + \underset{(0.02)}{0.04\ CrL} \qquad (19)$$

$$R^2 = 0.46 \qquad n = 207$$

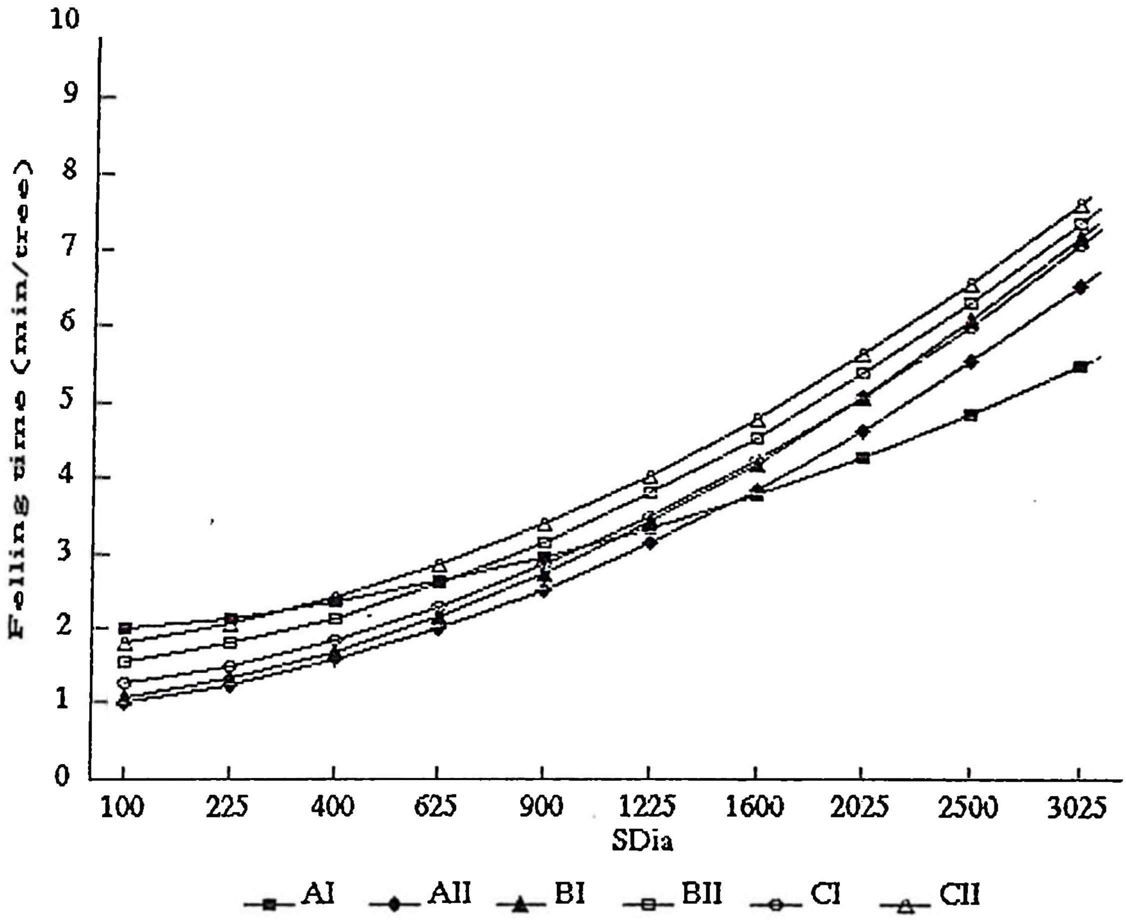


Fig 5. Felling time estimeted by the regressien equations

Key: SDia (cm.) = Square of stump diameter in cm

A.B and C = Crew code name

I and II = Raker and peg toothed saw respectively.

Worker No 2:

$$Tlimb = -1.69 + \underset{(0.01)}{0.1\ Dbh} + \underset{(0.02)}{0.07\ TrHT} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$R^2 = 0.52 \qquad n = 211$$

Worker No 3:

$$TLimb = -1.23 + \underset{(0.01)}{0.04\ Dbh} + \underset{(0.02)}{0.15\ TrHT} + \underset{(0.02)}{0.04\ CrL} \quad \ldots (21)$$

$$R^2 = 0.42 \qquad n = 212$$

Worker No 4:

$$TLimb = -1.15 + \underset{(0.02)}{0.17\ TrHT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$R^2 = 0.36 \qquad n = 210$$

Worker No 5:

$$TLimb = -1.5 + \underset{(0.01)}{0.02\ Dbh} + \underset{(0.01)}{0.11\ TrHT} + \underset{(0.01)}{0.05\ LogL} \quad \ldots (23)$$

$$R^2 = 0.67 \qquad n = 218$$

Worker No 6:

$$TLimb = -2.2 + \underset{(0.01)}{0.02\ Dbh} + \underset{(0.02)}{0.2\ TrHT} \quad \ldots\ldots\ldots\ldots\ldots\ldots (24)$$

$$R^2 = 0.60 \qquad n = 204$$

The regression results indicated that limbing time per tree could be estimated from Dbh, TrHT and Crown length. Comparison of the limbing times are presented in Figure 6. The figure shows that worker No 1 was the most efficient in limbing over the entire range of tree height. Worker No 2 was the least efficient for trees with height up to 18 m and for trees taller than 20 m, worker No 6 was the least efficient.

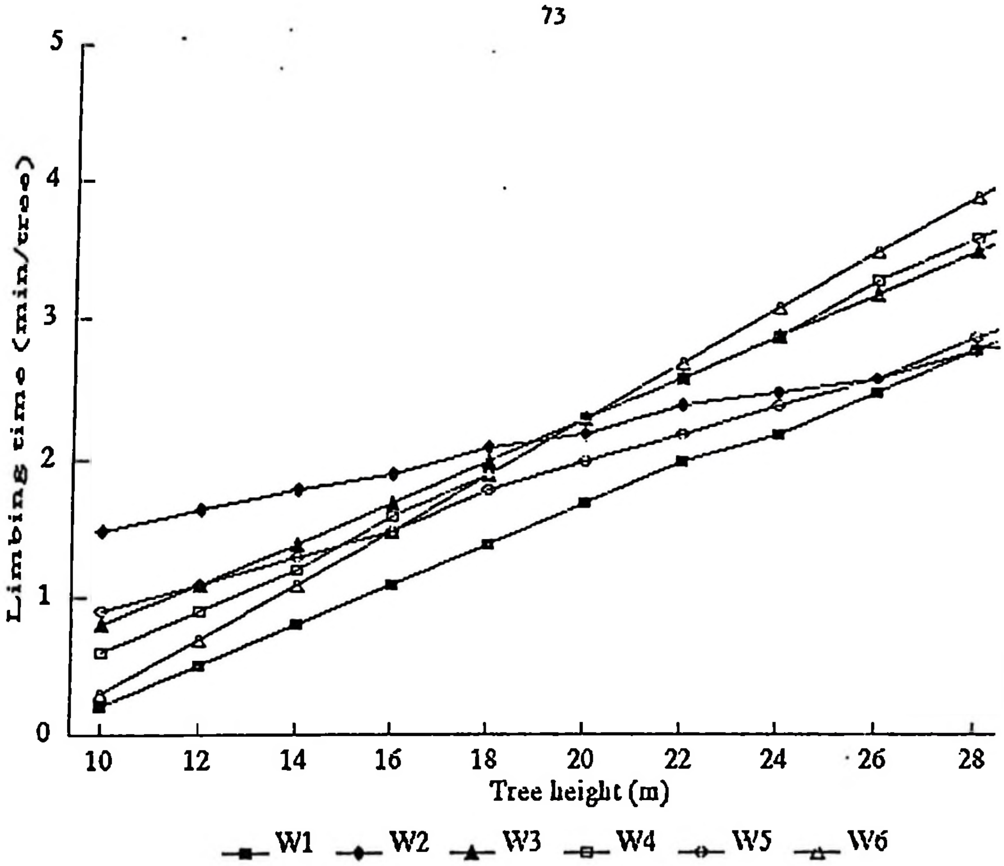


Fig. 6. Limbing time estimated by the regression equations

Key: W1 W2.....W6 = Workers code number.

4.3.2.3 **Bucking time**

Bucking time per tree was made up of the total bucking time of all the individual logs bucked from the tree and the time to move between the bucking points. Bucking time was expected to be proportional to the cross-sectional area cut. The cross-sectional area was calculated as $\pi D^2/_4$ at the bucking point and the square of the diameter (D^2) at this point was used as surrogate of the cross-sectional area. The required time to move between the bucking points was assumed to be influenced by the log length (LogL) and the number of logs bucked from each tree (Nlogs). With these assumptions the following hypothesis was set for the bucking time:

HO: TBU = f(Dbh, Budia, Budia^2, NLogs,TrHT, LogL).

Regression equations for bucking time

(a) **Two-man raker-toothed crosscut saws**

Crew A:

$$TBU = \underset{}{0.62} + \underset{(0.004)}{0.0033}\ Budia^2 + \underset{(0.05)}{0.355}\ NLogs \quad \ldots\ldots\ldots\ldots (25)$$

$$R^2 = 0.56 \quad n = 210$$

Crew B:

$$TBU = -0.74 + \underset{(0.005)}{0.0053}\ Budia^2 + \underset{(0.10)}{0.56}\ NLogs \quad \ldots\ldots\ldots\ldots (26)$$

$$R^2 = 0.71 \quad n = 213$$

Crew C:

$$TBU = -0.103 + \underset{(0.02)}{0.07}\ Dbh + \underset{(0.005)}{0.0026}\ Budia^2 + \underset{(0.05)}{0.19}\ NLogs \quad \ldots\ldots\ldots\ldots (27)$$

$$R^2 = 0.76 \quad n = 217$$

(b) Two-man peg-toothed crosscut saws

Crew A:

$$TBU = -0.38 + 0.0048\ Budia^2 + 0.6\ NLogs \qquad (28)$$
$$\qquad\qquad (0.0005) \qquad\qquad (0.08)$$
$$R^2 = 0.59 \quad n = 210$$

Crew B:

$$TBU = 1.21 + 0.0031\ Budia^2 + 0.36\ NLogs \qquad (29)$$
$$\qquad\qquad (0.0003) \qquad\qquad (0.05)$$
$$R^2 = 0.63 \quad n = 209$$

Crew C:

$$TBU = 1.21 + 0.0031\ Budia^2 + 0.38\ NLogs \qquad (30)$$
$$\qquad\qquad (0.0003) \qquad\qquad (0.06)$$
$$R^2 = 0.55 \quad n = 209$$

Among the independent variables chosen for estimating bucking time, Budia, TrHT and LogL had regression coefficients which were statistically not significant from zero at $P \le 0.05$). Thus, they were eliminated from the regression equations.

The number of logs bucked from each tree (NLogs)and $Budia^2$ were found to have influence on the bucking time for both crosscut saws as indicated by higher coefficients in all regression equations. Figure 7 shows that there is no much difference on bucking times when the $BuDia^2$ is less than 400 cm^2 for all crews and the two saw types. For $BuDia^2$ greater than 625 cm^2 the bucking time varies between saws and crews. Other researchers have used Dbh and Nlogs to estimate bucking time per tree (Ole-Meiludie 1984; Minja 1985). Sirito (1987) found bucking basal area, log volume

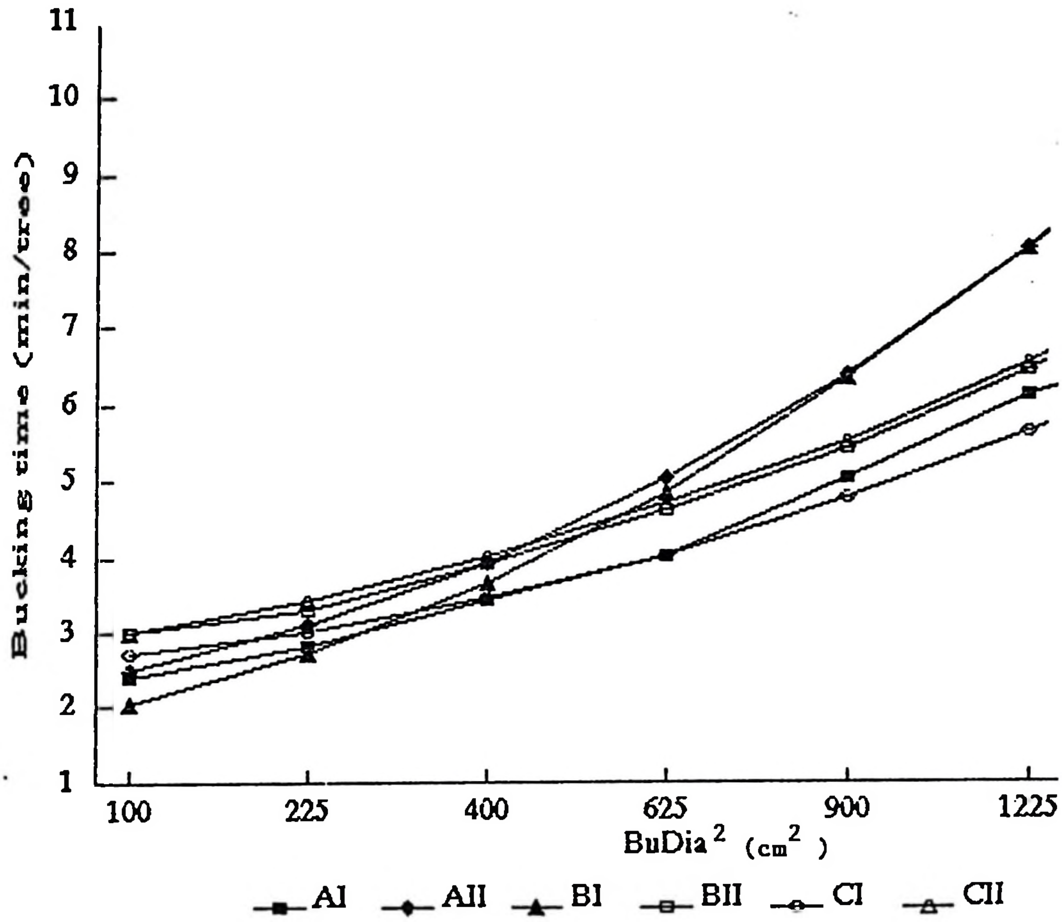


Fig.7 Bucking time estimated by the regression equations

Key: $BuDia^2$ = Square of the stump diameter in cm^2

A,B and C = Crew code name

I and II = Raker and peg toothed saw respectively and number of logs to influence bucking time while Migunga (1982) used $Budia^2$,log volume and bucking diameter in the regression equations for estimating bucking time.

4.3.2.4 Total effective cutting time

Total effective (productive) cutting time per tree comprises the sum of the individual productive work element times. The following null hypothesis was set for the total productive cutting time:

HO: ETCUT= f(SDia,$SDia^2$,Dbh,TrHT,CrL,Budia,$Budia^2$,NLogs).

Regression equations for total productive cutting time

(a) **Productive cutting time using raker-toothed saws.**

Crew A:

$$ETCUT = \underset{}{1.86} + \underset{(0.0004)}{0.0035\ SDia^2} + \underset{(0.0011)}{0.0029\ Budia^2} + \underset{(0.10)}{0.31\ NLogs} \quad \ldots\ldots (31)$$

R^2 = 0.74 n = 210

Crew B:

$$ETCUT = 0.15 + \underset{(0.00065)}{0.0036\ SDia^2} + \underset{(0.0015)}{0.003\ Budia^2} + \underset{(0.14)}{1.091\ NLogs} \quad \ldots\ldots (32)$$

R^2 = 0.86 n = 213

Crew C:

$$ETCUT = 2.53 + \underset{(0.0004)}{0.0030\ SDia^2} + \underset{(0.0008)}{0.004\ Budia^2} + \underset{(0.14)}{0.59NLogs} \quad \ldots\ldots (33)$$

R^2 = 0.85 n = 217

(b) productive cutting time using peg-toothed saws.

Crew A:

$$ETCUT = \underset{}{1.05} + \underset{(0.0004)}{0.0045\ SDia^2} + \underset{(0.0015)}{0.0028\ Budia^2} + \underset{(0.14)}{0.60\ NLogs} \quad \ldots\ldots (34)$$

$$R^2 = 0.72 \qquad n = 210$$

Crew B:

$$ETCUT = 3.42 + \underset{(0.0005)}{0.0028\ SDia^2} + \underset{(0.0009)}{0.0035\ Budia^2} + \underset{(0.118)}{0.787\ NLogs} \quad \ldots\ldots (35)$$

$$R^2 = 0.78 \qquad n = 209$$

Crew C:

$$ETCUT = 3.59 + \underset{(0.0005)}{0.0019\ SDia^2} + \underset{(0.001)}{0.0042\ Budia^2} + \underset{(0.11)}{0.76\ NLogs} \quad \ldots\ldots (36)$$

$$R^2 = 0.75 \qquad n = 209$$

Among the independent variables chosen for testing the hypothesis, Dbh, TrHT,and Budia were dropped from the regression equations since their coefficients were not significantly different from zero ($P \leq 0.05$). Number of logs bucked from the tree, felling and bucking cross-sectional areas were found to influence effective cutting times for the two saws more than other independent variables. These were indicated by higher coefficients and

R^2 values. The results are plotted in Figure 8 for comparison between the two saws. From this figure it is clear that crew A was the most efficient cutting crew when using raker toothed saws for the entire range of tree sizes. On the other hand crew B using peg-toothed saws was the least productive. Similar results have been reported by Migunga (1982) and Ole-Meiludie (1984).

4.3.3 Production rate estimates

Labour productivity in any forest operation is an essential basis for planning and cost estimation.
The time study results obtained were used to compare labour productivity for the two cutting saws. Production rates were estimated by the following formula:

$$P = \frac{VLog}{ETCuT} (F) (60) \quad \ldots\ldots\ldots\ldots (37)$$

where P = cutting production rate, in m^3 per workplace hour

VLog = merchantable tree volume overbark, in m^3

ETCUT = total productive (effective) cutting time in minutes per tree

60 = the number of workplace minutes per workplace hour

F = a fraction measuring the number of productive minutes per work minute

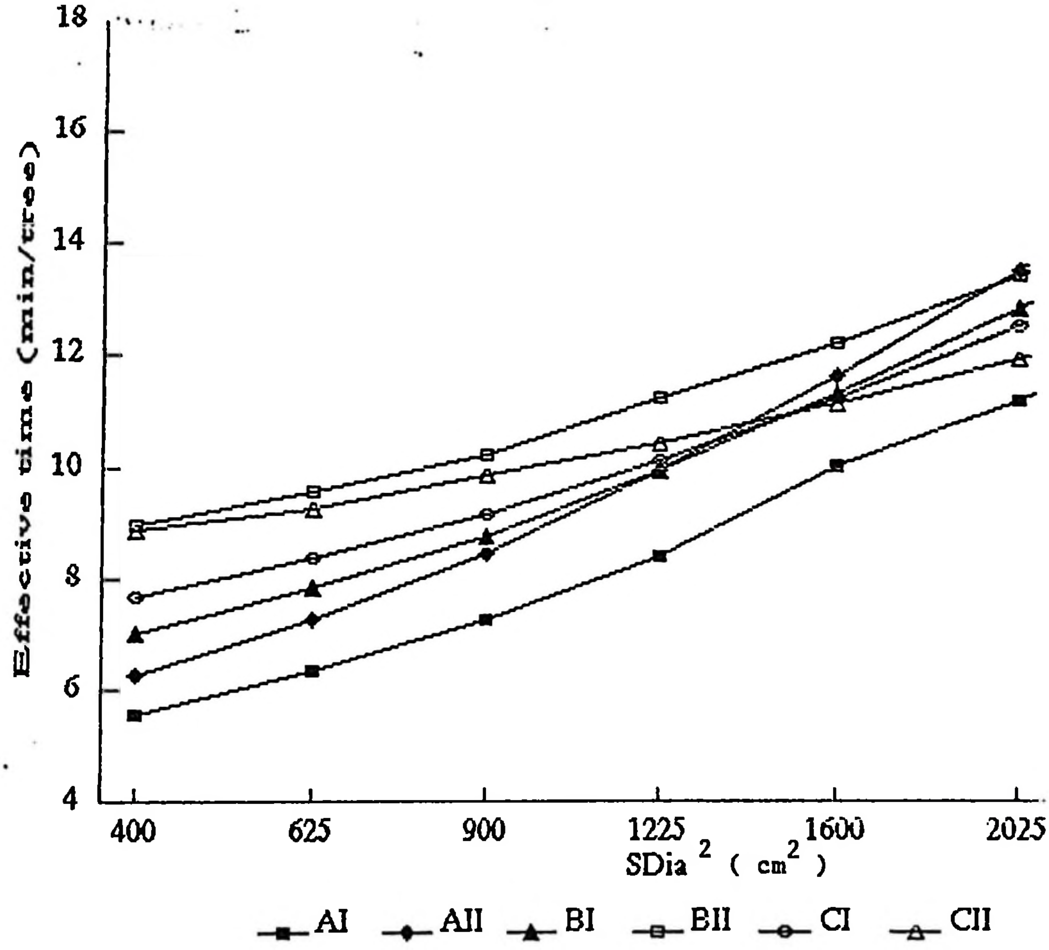


Fig. 8 Effective cutting time estimated by the regression equations

Key: $SDia^2$ = Square of the stump diameter in cm^2

A, B and C = Crew code name

I and II = Raker and peg toothed saw respectively.

$$F = \frac{100 - D}{100} \quad \text{..........................(38)}$$

D = total delay time expressed as percentage of total workplace time.

- The merchantable tree volume (VLog) was estimated from the following equation for all the trees cut during the study:

$$VLog = -0.77 + \underset{(0.0009)}{0.06}\ Dbh \quad \text{......................(39)}$$

$$R^2 = 0.75 \quad n = 1271$$

- Since Dbh is the most common variable measured during inventory survey in the forest, the linear relationships between Dbh and $SDia^2$ and $BUDia^2$ were developed for all the trees cut using the two saws for each crew as follows:

Crew A_I

$$SDia^2 = -792.52 + \underset{(2.9)}{73.27}\ Dbh \quad \text{...........................(40)}$$

$$R^2 = 0.75 \quad n = 211$$

$$BuDia^2 = -271.54 + \underset{(0.86)}{25.35}\ Dbh \quad \text{.........................(41)}$$

$$R^2 = 0.80 \quad n = 211$$

Crew A_{II}

$$SDia^2 = -702.94 + \underset{(1.71)}{68.38}\ Dbh \quad \text{..........................(42)}$$

$$R^2 = 0.88 \quad n = 217$$

$$BuDia^2 = -\ 285.67 + 26.35\ Dbh \quad \ldots\ldots (43)$$
$$(0.88)$$

$R^2 = 0.81 \quad n = 217$

Crew B_I

$$SDia^2 = -\ 704.62 + 67.54\ Dbh \quad \ldots\ldots (44)$$
$$(1.68)$$

$R^2 = 0.88 \quad n = 213$

$$BuDia^2 = -\ 306.46 + 27.98\ Dbh \quad \ldots\ldots (45)$$
$$(0.96)$$

$R^2 = 0.80 \quad n = 213$

Crew B_{II}

$$SDia^2 = -\ 729.65 + 69.99\ Dbh \quad \ldots\ldots (46)$$
$$(1.81)$$

$R^2 = 0.87 \quad n = 209$

$$BuDia^2 = -\ 366.41 + 30.74\ Dbh \quad \ldots\ldots (47)$$
$$(1.04)$$

$R^2 = 0.81 \quad n = 209$

Crew C_I

$$SDia^2 = -\ 714.80 + 67.92\ Dbh \quad \ldots\ldots (48)$$
$$(1.67)$$

$R^2 = 0.88 \quad n = 217$

$$BuDia^2 = -\ 348.97 + 29.48\ Dbh \quad \ldots\ldots (49)$$
$$(0.91)$$

$R^2 = 0.83 \quad n = 217$

Crew C_{II}

$$SDia^2 = -794.12 + 72.05\ Dbh \qquad (50)$$
$$(2.01)$$

$$R^2 = 0.86 \quad n = 209$$

$$BuDia^2 = -314.65 + 29.55\ Dbh \qquad (51)$$
$$(0.98)$$

$$R^2 = 0.81 \quad n = 209$$

By substituting equations 40 - 51 in the appropriate effective cutting time equations for each crew (equations 31 - 36), effective cutting time for each saw could then be estimated using Dbh as follows:

Crew A_I

$$ETCuT = -0.457 + 0.329\ Dbh \qquad (52)$$

Crew A_{II}

$$ETCuT = -0.51 + 0.384\ Dbh \qquad (53)$$

Crew B_I

$$ETCuT = 1.054 + 0.324\ Dbh \qquad (54)$$

Crew B_{II}

$$ETCuT = 2.27 + 0.30\ Dbh \qquad (55)$$

Crew C_I

$$ETCuT = 0.77 + 0.32\ Dbh \qquad (56)$$

Crew C_{II}

$$ETCuT = 3.69 + 0.26\ Dbh \quad \text{..........(57)}$$

Note that the average number of logs bucked from each tree was considered as 4 for crews A_I, A_{II}, B_I and C_{II} while for B_{II} and C_I it was 3 during this study.

- F depends on the cutting saw used and whether all delays or only necessary delays are included in the analysis.

Using the D values in Table 12, the appropriate equations (52 - 57) for effective cutting time, the following production rate equations were derived with all delays included:

Crew A:

$$P_I = \frac{-29.5 + 2.30\ Dbh}{-0.457 + 0.329\ Dbh} \quad \text{..........(58)}$$

$$P_{II} = \frac{-30.31 + 2.36\ Dbh}{-0.51 + 0.384\ Dbh} \quad \text{..........(59)}$$

Crew B:

$$P_I = \frac{-31.27 + 2.44\ Dbh}{1.054 + 0.324\ Dbh} \quad \text{..........(60)}$$

$$P_{II} = \frac{-31.42 + 2.45\ Dbh}{2.27 + 0.30\ Dbh} \quad \text{..........(61)}$$

Crew C:

$$P_I = \frac{-32.06 + 2.50\ Dbh}{0.77 + 0.32\ Dbh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (62)$$

$$P_{II} = \frac{-32.11 + 2.50\ Dbh}{3.69 + 0.26\ Dbh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (63)$$

where P_I = production rate for raker toothed saws, in m^3/crew h

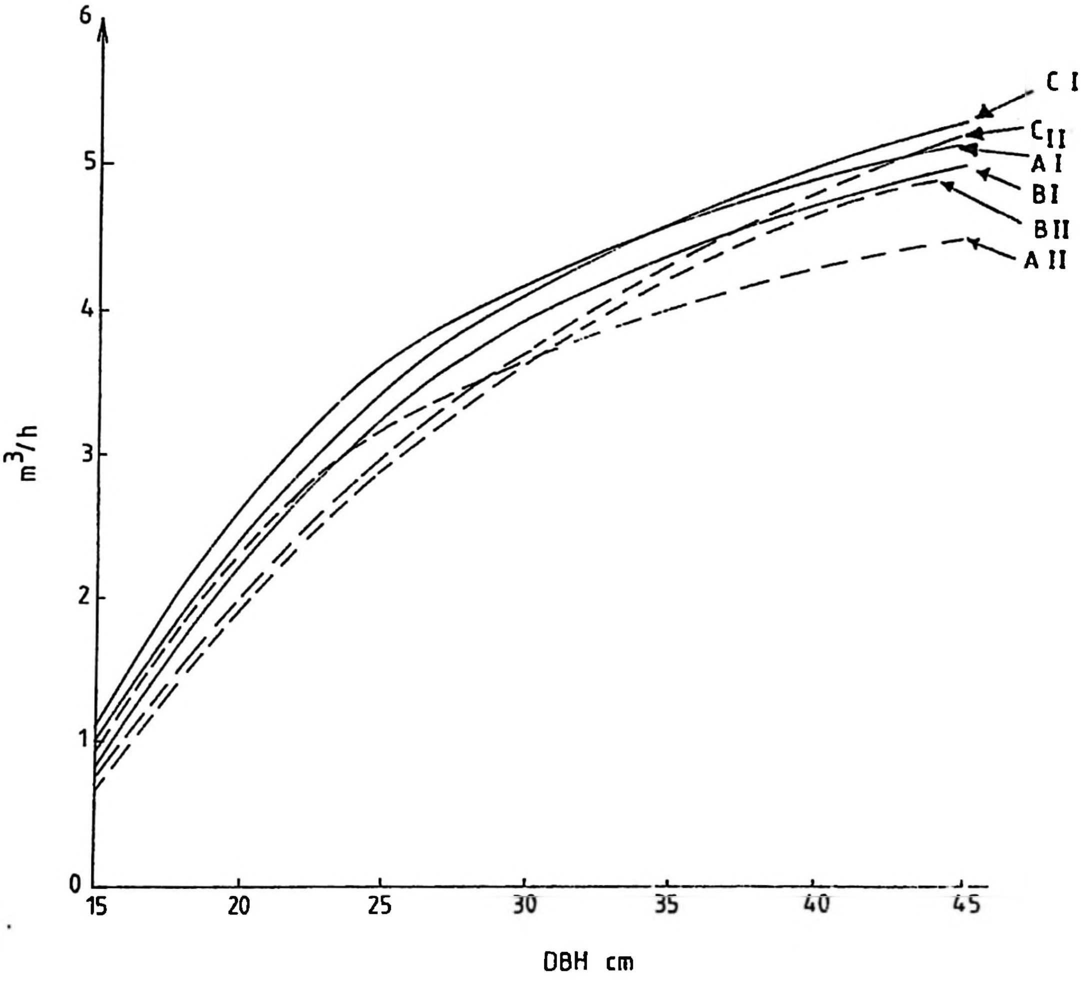
P_{II} = production rate for peg toothed saws, in m^3/crew - h

Clarification on how the production equations were derived is shown in appendix 7 for crew A as an example.

Production rate summaries for the two crosscut saws are presented in Table 13 and plotted in Figure 9 for Dbh range between 15 and 45 cm for comparison. The production trends are characterized by rapid rise over smaller diameters and taper off as maximum operating diameters are approached. The results show that raker-toothed saws were more productive than peg-toothed saws during cutting for almost all the trees less than 45 cm Dbh. Taking 25 cm as the average tree diameter, the average production rate was 3.34 m^3/crew-h for raker-toothed saws and 3.10 m^3/crew-h for peg-toothed saws. Crew A was the most productive when using raker and peg-toothed saws with an average of

Table 13. Production rate summary for the two cutting saws

Dbh cm.	Production rate m^3 /crew hour					
	A_I	A_{II}	B_I	B_{II}	C_I	C_{II}
15	1.11	0.97	0.90	0.79	0.98	0.71
20	2.69	2.36	2.33	2.12	2.50	2.01
25	3.60	3.16	3.25	3.05	3.47	2.98
30	4.19	3.68	3.89	3.73	4.14	3.73
35	4.61	4.04	4.36	4.25	4.63	4.33
40	4.91	4.31	4.73	4.67	5.00	4.81



Where : A, B & C = Crews code name
I = Raker toothed saw
II = Peg toothed saw

Fig. 9. Production rates of the two cutting saw

3.6 and 3.16 m^3/crew - h respectively. Crew B had a mean production rate of 3.25 m^3/crew -h when using raker-toothed saws and 3.05 m3/crew-h when using peg-toothed saws. Crew C with a mean production rate of 2.98 m3/crew-h was the least productive when using peg-toothed saws. Production rates between crews varied and raker-toothed saws had higher rates than peg-toothed saws by about 13%, 7% and 16% for crews A, B and C respectively. Reasons for variations in productivity between the crews could have been due to differences in maximum aerobic powers.

Higher production rates when using raker-toothed saw compared to peg-toothed saw can also be due to the following reasons:

(a) Differences in saw designs.
It was observed that the crews had to spend more time in trying to free pinched saws when cutting using peg-toothed saws than raker-toothed saw. The increase in delay time per tree for peg-toothed saws due to saw pinching might have contributed to the variation observed in production rates for the two saws.

(b) Despite the fact that the workers were equally experienced with the two types of saws,it was noted during the study that they had negative attitude towards using peg-toothed saws. Such attitude might have lead to lower working tempo and consequently lower production rates for peg-toothed saws.

Ayaz (1986) reported an increase of about 23% in productivity when cutting mulberry and shisham trees in Pakistan using raker-toothed saws as compared to peg-toothed saws.

Compared to other research findings, average production rates for raker-toothed saws in this study were relatively higher. For example, Micski and Stridsberg (1981) and Saarilahti and Ole-Meiludie (1987) reported average production rates of 2.8 m^3/h and 3.29 m^3/h for raker-toothed saws respectively during clearfelling *Pinus patula* compartments in the same area. Migunga (1982) reported average rate of about 1.9 m^3/h when clearfelling *Pinus radiata* with raker-toothed saw.

The differences in production rates observed for the studies are most likely due to differences in working conditions and personal characteristics of the workers (e.g. Skills, maximum aerobic power, nutritional status and motivation factors). Dykstra (1982b) reported an increase in productivity of about 35% (over task work) when bonus payment system was introduced in Sao Hill forest. Bonus payment could be an incentive to the workers leading to increased production and at the same time higher income. In addition, differences in tree species and sizes might have caused variations in productivity. An attempt was also made to relate the physical characteristics of the workers and production rates for the two saws. The following regression equations were developed to find the relationships between physical characteristics of the workers and the production rates.

(a) **Production rate for raker-toothed saw**

$$P = \underset{(0.2)}{6.34 + 2.30\ VO_2\ max} + \underset{(0.004)}{0.023\ BWT} - \underset{(0.005)}{0.06\ BHT} \quad \ldots\ldots (64)$$

$$R^2 = 0.98 \qquad n = 6$$

(b) **Production rate for peg toothed saws**

$$P = \underset{(0.17)}{4.95 + 1.46\ VO_2\ max} + \underset{(0.003)}{0.11\ BWT} - \underset{(0.004)}{0.04\ BHT} \quad \ldots\ldots (65)$$

$$R^2 = 0.96 \qquad n = 6$$

The regression results show that about 98% and 96% of the total variations in cutting production rate using raker and peg toothed saws could be explained by proportional variations in estimated maximum aerobic power of the workers (VO_2max), their body weight (BWT) and height (BHT) measured in l/min, kg and cm respectively.

4.4 Physical workload results

4.4.1 Heart rate results

Heart rates of the workers during timber cutting using raker and peg toothed saws are presented in Tables 14 and 15 respectively.

4.4.1.1 Heart rates during felling

Average heart rates of the crews during felling ranged from 112 - 117 beats/min and from 114 - 118 beats/min when using raker and peg toothed saws respectively. Felling was more strenuous on worker no 6 and least strenuous on worker no 4. Their average heart rates were 117 and 112 beats/min respectively.

Despite felling crews constantly felling smaller trees using peg-toothed saws, average heart rates were constantly higher than when using raker-toothed saws. However,the observed differences on the average heart rates were not statistically significant ($P \leq 0.05$) when using the two saws. The main reason for higher heart rates when using peg-toothed saws could be due to frequent saw pinching which required more effort to lift/roll the logs in order to release pinched saws.

Higher heart rates during felling hardwoods using peg-toothed saws compared to raker-toothed saws have been

Table 14 **Heart rates of the workers during cutting operation using raker-toothed saws**

Work element	Statistic	Heart beats/min.					
		W_1	W_2	W_3	W_4	W_5	W_6
Felling	Mean	113	114	115	112	115	117
	S.D	10.3	7.2	6.5	9.9	9.5	12.6
	Range	79-136	95-132	94-132	81-131	94-134	91-148
Limbing	Mean	113	112	113	112	111	115
	S.D	9.5	6.5	5.6	8.4	7.8	8.0
	Range	83-135	94-124	95-126	81-129	85-128	94-142
Bucking	Mean	117	117	117	111	118	119
	S.D	8.1	4.4	6.1	10.8	9.1	7.6
	Range	95-139	104-126	96-131	85-134	80-135	92-137
Effective time	Mean	114	114	115	112	115	117
	S.D	7.1	4.8	5.0	8.2	7.8	7.6
	Range	96-132	104-129	104-130	88-128	93-131	98-132

Table 15 Heart rate of the workers during cutting using peg-toothed saws

Work element	Statistic	Heart rate, beats/min.					
		W_1	W_2	W_3	W_4	W_5	W_6
Felling	Mean	115	115	115	114	116	118
	S.D	13.19	7.1	5.65	7.15	10.0	9.82
	Range	85-114	98-139	101-134	101-129	84-134	81-134
Limbing	Mean	113	112	113	112	111	115
	S.D	8.6	6.38	5.0	6.0	6.88	7.24
	Range	83-132	100-129	95-121	100-129	92-127	94-131
Bucking	Mean	119	118	119	121	119	122
	S.D	13.99	6.71	3.27	7.26	10.90	8.16
	Range	83-146	100-129	107-124	100-142	83-140	102-141
Effective time	Mean	116	115	116	116	116	118
	S.D	11.83	5.5	4.02	6.02	8.48	7.80
	Range	85-138	94-128	103-126	102-131	87-137	92-133

reported by Maleta and Sood (1984) in India and by Ayaz (1986) in Pakistan. Their figures were 117 and 132 beats/min for peg-toothed saws while for raker-toothed saws it was 114 and 108 beats/min respectively. Differences in felling heart rates for the different workers in these studies could be due to differences in tree species, personal characteristics and working conditions.

4.4.1.2 Heart rates during bucking

Heart rates of the workers indicated that bucking was the most strenuous work for both types of saws. Worker No 6 who was the youngest and less experienced was working under heavy stress both when using raker and peg-toothed saws when compared to the other workers. His average heart rate was 119 and 122 beats/min when using raker and peg-toothed saws respectively. Worker No 4 with a working experience of four years experienced less strain when using raker-toothed saws i.e, an average of 111 beats/min. Generally, all workers experienced less strain when working with raker-toothed saws than peg-toothed saws with an exception of worker No 2 whose average heart rate was 118 beats/min. Almost all workers showed no significant differences ($P \leq 0.05$) on average heart rates when using the two saws for bucking except for worker No 4 and 6.

Maleta and Sood (1984) reported lower heart rates of forest workers when bucking using raker and peg-toothed saws. Their findings were 115 and 117 beats/min for raker and peg-toothed saws respectively. Saarilahti and Ole-Meiludie (1987) reported an average of 112 beats/min for Sao Hill forest workers when using raker-toothed saw.

The differences in heart rates for the different workers in these studies might have been caused by personal differences and experience, differences in tree species and working conditions.

4.4.1.3 **Heart rates during limbing**

Limbing sub-operation involved working with axes.
The operation was undertaken immediately after felling.

The highest heart rate was observed on the least experienced worker i.e worker No 6 with a working experience of only one year. His average heart rate was 115 beats/min. The oldest and most experienced worker had the lowest heart rate during limbing i.e, 111 beats/min.

Despite limbing less heavily branched trees, these workers experienced higher workloads compared to findings reported by Saarilahti and Ole-Meiludie (1987) for workers limbing *Pinus patula* trees in the same area. They reported an average heart rate of about 107 beats/min. Probably the differences were due to differences in working experience of the workers. In their case the workers had 8 years experience compared to an average of 3 years in this study.

4.4.1.4 Heart rate during total effective cutting time

Total effective heart rate for each worker during cutting was calculated as an average of the three effective cutting work elements (i.e., heart rate during felling, limbing and bucking). The results indicated that working with peg-toothed saws was more strenuous than working with raker-toothed saws. The stress was highest on worker No 6 as indicated by highest average heart rates (i.e., 117 and 118 beats/min when using raker and peg-toothed saws respectively). Worker No 4 with an average heart rate of 111 beats/min was the least strained when using raker-toothed saws. On the other hand worker No 2 with an average heart rate of 115 beats/min was considered to be the least stressed when using peg-toothed saws.

4.4.2 Workload indices

Workload indices for different cutting work elements were calculated using equation (12) by Mälkiä (1974). The results are presented in Table 16.

Table 16 Workload indices for different work elements during cutting

Crew	Worker No.	Element	Workload index %	
			Raker saw	Peg saw
	1	Felling	49.4	51.7
		Limbing	49.4	49.4
A		Bucking	54.0	56.3
		Effective time	50.6	52.9
	2	Felling	48.3	49.4
		Limbing	46.0	46.0
		Bucking	51.7	52.9
		Effective time	48.3	49.4
	3	Felling	48.2	48.2
		Limbing	46.5	46.5
B		Bucking	50.0	51.7
		Effective time	48.2	49.4
	4	Felling	48.6	50.6
		Limbing	48.6	48.6
		Bucking	47.7	57.0
		Effective time	48.6	52.3
	5	Felling	52.6	53.6
		Limbing	48.4	48.4
		Bucking	55.7	56.7
C		Effective time	52.6	53.6
	6	Felling	43.7	44.8
		Limbing	41.7	41.7
		Bucking	45.8	48.9
		Effective time	43.7	44.8

Workload indices when using raker-toothed saws for felling ranged between 43.7% and 52.6% and averaged 48.5%. When using peg-toothed saws, the average was 49.7% ranging from 44.8% to 53.6%. During limbing, the average workload index was 46.8% ranging from 41.7% to 49.4%. Workload indices averaged 50.8% and 53.9% during bucking using raker and peg-toothed saws respectively. The range was between 43.7% and 55.7% for raker-toothed saws while for peg-toothed saws the workload ranged between 48.9% and 57%.

The results showed that overall workloads during timber cutting were higher when using peg-toothed saws than when using raker-toothed saws. The oldest worker indicated highest indices i.e. 52.6% and 53.6% when using raker and peg-toothed saws respectively. The youngest worker had the lowest workload indices averaging 43.7% when using raker and 44.8% when using peg-toothed saws.

By comparison, the workload indices found in this study were higher than those reported by other researchers. For example, Abeli and Ndossi (1984) reported an average workload of 45%. Bakena (1985) came up with WLI of 38% while Saarilahti and Ole-Meiludie (1987) reported an average of 36%. All these results were based on cutting softwoods using raker-toothed saws.

The variations between workload indices might have been due to differences in workers personal factors, tree species, working speed and environmental factors.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has provided detailed analysis of physical workload and labour productivity for two man raker and peg-toothed crosscut saws used in cutting *Pinus elliottii* compartment in Sao Hill forest plantation. Time study results indicated that:

-Cutting production rate when using raker-toothed saws was about 12% higher compared to peg-toothed saws. The average production rates were 3.6 and 3.16 m^3/crew - h for raker and peg-toothed saws respectively.

-Through regression analysis productive cutting time per tree could reliably be estimated as a function of the square of stump diameter ($SDia^2$), square of bucking diameter ($Budia^2$) and number of logs bucked from the tree (NLogs).

-The cutting crews were found to be involved in productive work for only 4.7 and 4.73 hours when using raker and peg- toothed saws respectively. These figures are based on the scheduled 7 working hours per day for Sao Hill Sawmill Ltd. Sawmill Ltd. Non-productive activities occupied about 33% and 32% of the workplace time when using raker and peg-toothed saws respectively.

-The maximum aerobic power of the workers engaged in cutting operation averaged 2.54 l/min ranging between 2.37 and 2.7 l/min. Maximum aerobic power correlated well with age, resting heart rate and body weight of the workers more than other personal characteristics.

-Analysis of physical workload during cutting indicated that peg-toothed saws imposed relatively higher physiological strain on the workers compared to raker- toothed saws. Average workload for the workers when using raker-toothed saws ranged from 43.7 - 52.6% while for peg- toothed saws it was 44.8 - 53.6% of the worker's maximum aerobic power.

-Based on the allowable workload of 40 - 50% of the estimated maximum aerobic power of the workers for a prolonged activity (Apud *et al.* 1972; Skaar 1982), the workers were working within the physiologically acceptable limits and the workload can be tolerated for 4.7 hours without symptoms of fatigue. Higher workloads above the acceptable limits were however occasionally observed during bucking work element.This made the bucking work element the most strenuous activity during cutting operation.

- Assessment of the workload indices based on oxygen consumption rate (Appendix 3) revealed that the workers were working under moderate workload as the oxygen consumption rate was 1.11 - 1.3 l/min and 1.14 - 1.38 l/min when cutting using raker and peg-toothed saws respectively.

- As the workload is moderate and the daily energy expenditure is within the recommended limits, this study suggests that both saws could satisfactorily be used in timber cutting in all plantation forests with similar working conditions and tree sizes.

5.2 Recommendations

-There are possibilities to increase the daily productivity but provisions for adequate food intake and more working time with enough resting period should be guaranteed. Saarilahti and Ole-Meiludie (1987) recommended a daily task to be 17.4 m^3/ crew day in clearfelling *Pinus patula* compartments for the sawmill. This study has revealed that this recommended daily task could be achieved in *Pinus elliottii* stands only if more time was spent at the workplace or task/bonus payment system was introduced under the latter system. The workers would be expected to exert their maximum efforts in order to achieve the highest pay. This could lead to excessive workloads which could be detrimental to the health of the workers in the long run. To be able to sustain higher productivity over a long period, workers need adequate energy and undergo further training on proper working techniques. As it is now, the maximum productivity expected from these crews when using peg-toothed and raker-toothed saws are 14.9 and 16.9 m^3 per day respectively.

-The data collected during this study was inadequate for general conclusions about the loggers at Sao Hill Sawmill. This was due to time and financial constraints. Further studies are required particularly on the physical working capacity of the workers, workload and energy expenditure. With sufficient information on these aspects, more concrete conclusions and recommendations can be drawn.

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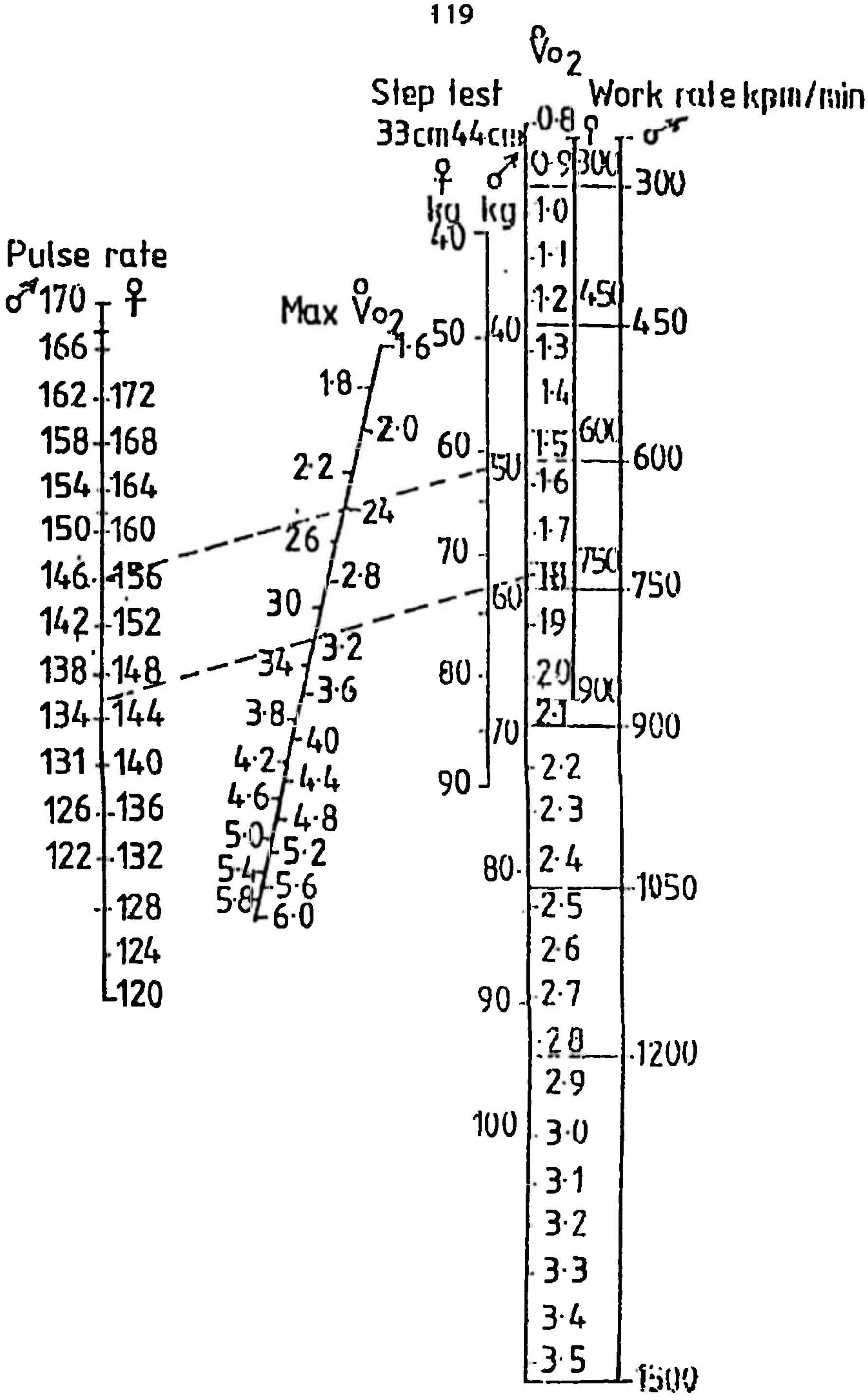

Appendix 1. A nomogram of Astrand and Ryhing used for estimating aerobic capacity

Source Apud et al 1989.

Appendix 2. Age correction factors used in connection with the Astrand and Ryhming nomogram

Age	Factor
15	1.10
25	1.00
35	0.87
40	0.83
45	0.78
50	0.75
55	0.71
60	0.68
65	0.65

Source: Apud *et. al.* (1989).

Appendix 3. Indices for workload assessment

Assessment of workload	Oxygen consumption (l/min)	Rectal temperature (C)	Heart rate (beats/min)
Very low (resting)	0.25-0.3	37.5	60-70
Low	0.5-1.0	37.5	75-100
Moderate	1.0-1.5	37.5	100-125
High	1.5-2.0	38.0-38.5	125-150
Very high	2.0-2.5	38.5-39.0	150-175
Extremely high	2.4-4.0	>39.0	>175

Source: Grandjean (1986).

Appendix 4. Technical specifications for SPORT TESTER PE 200

Pulse transmitter

Case: 135 x 25 x 11.5mm

Operating temperature: - 10 to + 50 C

Power consumption:

	Pulse rate	Maximum current
Active state:		
	75	130 µA
	150	210 µA
Passive (off) state:		1 µA

Battery: 160 m Ah Lithium battery, non-replaceable.

Receiver microcomputer

Microcomputer: CMOS 4 bit

Display: LCD 6 digits

Case: 55 x 44 x11.5 mm ABS plastic

Operating temperature: -10 to +50 C

Power consumption: min. 0.015 mA

max. 0.08 mA/3V

Battery: IEC SR 48 (Timex F,Duracell D 393B EV 393,70TC, RW-28-48)

Weight: 32g (1.0 oz).

Appendix 5 **Heart rate recording sheet**

Operation................ Subject............Recorder.....

Date.............. Slope...........

Time out......... Temperature: dry bulb reading.....

Time in......... Wet bulb reading.....

Time (min)	Operation	Heart rate (beats/min)	Time	Operation	Heart rate (beats/min)
0.5			10.5		
1.0			11.0		
1.5			11.5		
2.0			12.0		
2.5			12.5		
3.0			13.0		
3.5			13.5		
4.0			14.0		
4.5			14.5		
5.0			15.0		
5.5			15.5		
6.0			16.0		
6.5			16.5		
7.0			17.0		
7.5			17.5		
8.0			18.0		
8.5			18.5		
9.0			19.0		
9.5			19.5		
10.0			20.0		

Appendix 6. Independent variable data sheet

Sheet no.......Date...... .... Recorder............Compt:..........

Subject:................ . Type of saw used......... ..

Tree no	SDia (cm)	DBH (cm)	Log 1			Lo 2			Tree HT (m)	Crown length (m)
			DL	Ds	L	DL	Ds	L		

NB: Incase the number of logs are more than two, additional columns are drawn.

Appendix 7 Production rate for crew A using raker toothed saws

ETCuT = 1.86 + 0.0035 $SDia^2$ + 0.0029 $BuDia^2$ + 0.31 NLogs ......(31)

But $SDia^2$ and $BuDia^2$ can be estimated from equations 40 and 41 as follows:

$SDia^2$ = - 792.52 + 73.27 Dbh .... (40)

$BuDia^2$ = - 271.54 + 25.35 Dbh .... (41)

Hence equation 31 can be re-written as;

ETCuT = 1.86 + 0.0035 (- 792.57 + 73.27 Dbh) + 0.0029 (- 271.54 + 25.35 Dbh) + 0.31 NLogs

= - 1.70 + 0.329 Dbh + 0.31 NLogs

But average number of logs bucked from a tree for the crew were 4. By substituting 4 in the above equation, the final equation will be;

ETCuT = - 0.46 + 0.329 Dbh

Delay time occupied about 36.1% of the total cutting time/tree (Table 12). Thus;

$$F = \frac{100 - 36.1}{100} = 0.639$$

Merchantable log volume was estimated from Dbh as follows;

VLog = - 0.77 + 0.06 Dbh ....(39)

$$\text{Since production rate (P)} = \frac{\text{VLog}}{\text{ETCuT}} \text{(F) (60)}$$

Production rate for the crew can be calculated as;

$$P = \frac{- 0.77 + 0.06 \text{ Dbh}}{- 0.457 + 0.329 \text{ Dbh}} (0.639)(60) = \frac{- 29.50 + 2.30 \text{ Dbh}}{- 0.457 + 0.329 \text{ Dbh}}$$