INVESTIGATION INTO THE CONVERSION FACTOR
IN SOME SUDANESE SAWMILLS AND SUGGESTED
METHODS FOR ITS IMPROVEMENT

BY

MAHER SALIH SULIEMAN
B.Sc. (Forestry) Hons.
University of Khartoum
1981

A Thesis submitted in partial fulfilment of the Requirements
for the Degree of M.Sc. (Forestry)

Department of Forestry
Faculty of Agriculture,
University of Khartoum
November 1987
تحتوي علامة مسح الكل في الاعمال المختلفة جداً والممتع معاً بعض كلفة عدد من المواد والطرق لتحديد نسبة الحاد في الحذاء، ومراقبة بوجب معها معرفة الاعمال بالحلف، في نواة ومصغرة الحاد من بداية رسمه الحاد من الحذاء، وكان يوحي هذا التدخل بين المواد إلى هوية جميع العلاقات أو طبيبات، تدريجًا أثر الكل في المتوقع.

يشمل كيف된다 في الاعمال امتقاء خارج نظر الكل، ورفع نسبة الحاد جيدًا حتى يُبقي لنا تجربة استدعال هذه المواد.

أظهرت هذه الدراسة تدفق معرفة النسب المخففة للالاتجاهات الكلية لمعالجة الحاد منها في تجربة الحذاء. تعويض وتوضيح أسباب تدفق نسبة الاتجاه، وامتقاة، وفسح هذه النسبة في طريق تحسين طريق، وادوات وانتماء وتوزي الكل.

كذا تعودت الدراسة نرى موفرة، وتداخلات لحماية الكل في نسبة الحاد من تحويل الكل إلى خادم مثير.

أظهرت هذه الدراسة امكانية ربط الإنجاز من طريق، تحسين طريق، تجربة الإيجار وإعداد كل، تمامًا، من الحذاء في محصلة ما اقترب.

كما يمكن زيادة نسبة الحاد براقة نوبة الكل وتخفيف لوبة الإنتاج بعض، تدفقه وحجم الكل.

كذا كانت الدراسة أثير البيان الذي يلعبه الطاحون، وناسل الخدمات في تجديد نسبة الناجحة الكل من الحذاء المثير.
أولاً وقبل أن نتحدث عن الدراسة التي تتناول علاقةً قياسية بين العوامل

تأثر الكل والبيئة المحيطة بهما.

أما فيما يتعلق بدراسة هذه الظاهرة، فقد كشفت هذه الدراسة عن تعدد العوامل التي تؤثر على هذه العلاقة. وتشمل هذه العوامل:

1. العوامل البيئية
2. العوامل الديموغرافية
3. العوامل الاجتماعية
4. العوامل الاقتصادية
5. العوامل السياسية

وتتمثل هذه العوامل في تأثيرات عديدة على مستويات الصحة العامة، فعلى سبيل المثال، العوامل البيئية تؤثر على صحة الإنسان من خلال تكوينات الملوثات الجوية أو المائية. العوامل الاجتماعية تؤثر على الصحة العامة من خلال البيئات المعيشية والتعليمية، بينما العوامل الاقتصادية تؤثر على الصحة العامة من خلال الأماكن المعيشية والتعليمية.
Sawing is a complex operation influenced by a multitude of factors. The situation is further complicated by the fact that these factors interact among themselves and timber recovery is also influenced by these interactions, thus the relationship between timber recovery and log characteristics are more subtle than realized. The raw material for sawmilling is becoming scarce and the need for efficient conversion and utilization becomes important. This can be achieved through increasing timber recovery at the sawmill. The effects of five treatments on timber recovery were investigated in this study: namely: CBCS, CBC, CBS, CBS and RMS treatment. The effects of log characteristics on recovery were also investigated, within CBS & RMS treatment.

Log treatments were found to have significant effect on timber recovery. Improved bucking controlled sawing (IBCS) was found to have the highest recovery, while current bucking normal sawing (CNS) gave the lowest value. The increased recovery with IBCS treatment was due to the improvement in log quality through controlled felling and bucking, and also due to controlled sawing operation. Sawyer's skills and judgement were found to have considerable effect on recovery. This
was shown by an increase in recovery when sawing operation was controlled. Sawing larger dimensions such as railway sleepers resulted in increased recovery compared to sawing of smaller sizes. Investigating the effect of sawing pattern on recovery it was found that slant sawing gave higher recovery than live sawing.

With respect to the effect of log characteristics, crookiness showed highly significant variation with timber recovery, where the recovery decreased with increased crookedness. Shape and overlength showed slight negative correlation with timber recovery which was not statistically significant. The weak correlations obtained in this investigation was due to the interaction between the different factors affecting timber recovery, where the effect of one factor masked the effect of others. Therefore, to find the true effect of an individual factor on recovery, all other factors should be kept constant.
encouragement and counsel throughout this study, and Dr. S. Gosa, for his valuable comments, ideas and encouragement. He would also like to thank the other members of the department of forestry, University of Khartoum particularly Dr. O.S. Yousa and Dr. B. A. El Hassan for their contribution during the study. The writer would also like to express his thanks and appreciation to the British O. D. A. who funded this study. The contribution of the conservator of forests in Senar, and his staff in Singa and Lambaa Samill through the permission and their continuous help during the field work is well acknowledged. The writer is also greatly indebted to the people of Sabonabi village especially the family of Saith El Fadul for hosting him throughout the field work. Finally the contribution of his family, parents, and wife through encouragement and unfailing patience was appreciated.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENT</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. LITERATURE REVIEW</td>
<td>4</td>
</tr>
<tr>
<td>2.1. Timber recovery</td>
<td>7</td>
</tr>
<tr>
<td>2.1.1. Factors related to the log</td>
<td>7</td>
</tr>
<tr>
<td>2.1.2. Factors related to sawyers</td>
<td>11</td>
</tr>
<tr>
<td>2.1.3. Factors related to sawmill machinery</td>
<td>22</td>
</tr>
<tr>
<td>2.2. Extrapolating in the Sudan</td>
<td>29</td>
</tr>
<tr>
<td>2.2.1. Background</td>
<td>29</td>
</tr>
<tr>
<td>2.2.2. Logging</td>
<td>30</td>
</tr>
<tr>
<td>2.2.3. Quality of logs available</td>
<td>31</td>
</tr>
<tr>
<td>2.2.4. Species used and products</td>
<td>32</td>
</tr>
<tr>
<td>2.2.5. Recovery</td>
<td>33</td>
</tr>
<tr>
<td>2.3. The saw timber</td>
<td>34</td>
</tr>
<tr>
<td>2.4. Log volume determination</td>
<td>35</td>
</tr>
<tr>
<td>3. MATERIAL AND METHODS</td>
<td>37</td>
</tr>
<tr>
<td>3.1. Material</td>
<td>39</td>
</tr>
<tr>
<td>3.2. Methods</td>
<td>40</td>
</tr>
</tbody>
</table>
for CBRS treat.

17 Analysis of variance showing the effect of overlapped on recovery for CBRS treat.
18 Log crookedness class distribution with frit treat.
19 Log taper class distribution for CBRS treat.
20 Sealing patterns and corresponding average recoveries (%) by diameter classes.
21 Analysis of variance showing effect of sealing pattern on recovery
22 Average timber recoveries (%) for the five log treatments.
23 Analysis of variance for the five log treatments and log diameter classes.
24 Result of the least significant difference comparison test for recoveries obtained for five log treatments.
25 Preserved and thicker sawn in Subhance sawmills
26 Correlation matrix showing correlation coefficients for CBRS treat.
LIST OF FIGURES

Fig.  
1. Shows log crookedness measurements. 104
2. Shows crooked logs at the sawmill logyard. 105
3. Edgings and trimmings resulting from crooked and tapered logs. 106
4. Offcuts resulting from logs with excessive overlength. 107
5. Forked logs were used at the sawmill. 108
6. The effect of log crookedness on recovery for CBSTreatment. 109
7. The influence of log crookedness on recovery in the CBSTreat. 110
8. The relationship between log taper and recovery for CBSTreat. 111
9. Good quality logs resulting from improved bucking. 112
10. Sawdust at the sawmill logyard. 113
Wood is an important renewable resource, which should be efficiently utilized, so as to correct the serious imbalance between production and consumption of wood to increase the revenue from forest investments.

The conversion of logs into sawnwood is generally accompanied by very high percentage of waste. The process starts in the forest, where the component is prepared and goes through the sawmill and planermill till it becomes a finished product ready for shipping to the purchaser.

Each step in the process is characterized by certain types of waste, in felling and bucking (for instance) losses such as splitting, high stumpage, miscutting to proper length. In the sawmill common wastes areas—dust, shims, offcuts, edgings and trim.

Records about the waste factor in Guinean sawmills are inaccurate, but generally it is estimated at 60 percent, which is a low sawmilling efficiency that should be improved so as to maximize the use of the available timber resources. For this the following factors are considered: log diameter, log length, log form and quality, sawmill
condition and saving pattern, skill of operators, accuracy, and size of final product.

The present study was conducted to investigate the factors influencing sawmill waste and developing methods of improving timber recovery.

The main objective is to find out means of improving the sawmill recovery and thereby promoting efficient utilization of the available resources.

This goal will be achieved through the following specific objectives:

1. To study the actual sawmill recovery using the current practices, considering factors affecting sawmill recovery.
2. To study felling and bucking conditions in the forest, with the aim of improving log quality.
3. To introduce log of smaller diameters which are not used at present in government sawmills.
4. To test the effect of saving pattern and log diameter on recovery.

Increasing the sawmill recovery will represent a possible increase in revenue, in addition to the saving in the hard currency.
new need for importing timber, and the great saving in the consumption of raw material.

The study has been carried out in the Blue Nile sawmill group which include El Sohi and Nad el Mail sawmills.

The practical side being done in Lumbwa sawmill (near El Sahambi village). Legs were taken from Lumbwa Forest during the final felling of 1984.
Chapter Two

LITERATURE REVIEW

2.1 Lumber Recovery:

The main objectives in the process of manufacturing wood products is to increase significantly both lumber recovery and sawmill productivity. The process begins with felling trees in the forest and is completed when the lumber becomes a finished product.

Different means were used to measure sawmill efficiencies; among these are the sawmill productivity, recovery, and lumber recovery factor.

Sawmill productivity or production rate was defined as the volume of production per man hour or cubic metres per day (Hallis 1963). Sawmill recovery on the other hand, was defined as the cubic metres of lumber produced per cubic metres of logs going into the mill (Hilliston 1977); while lumber recovery factor was defined as the volume of lumber produced from scaled log volume, measured in board feet and cubic respectively (Hewson 1974).

There are different opinions as to which is the best way of measuring the efficiency of sawmills. In discussion about the production of unusable products Mason (1981) mentioned that to have a profit is not a factor of increasing the recovery only, because it is difficult, but to increase the rate of production (m³/day) whereas Hallis (1963) suggested that sawmill efficiency is not to be measured only in terms of volume of production per man hour, because although care in sawing may lower the rate of production
but this may be noticeably reflected in a higher quality product, and lower cost in seasoning, remanufacturing, machining and general yard handling.

As the cost of logs rises and raw material for sawmills becomes scarcer, tendency towards improving the recovery also increases. Juvonen (1961) reported that the cost of round logs is more than half the cost of production of sawn timber. Therefore the question of recovery in saw-milling is of utmost importance as the more sawn timber is cut out of the round logs, the higher is the profit. Similarly Saunders (1979) stated that lumber recovery should be a major consideration because raw material represents about eighty percent of the cost of wood and labour. This agrees with what was reported by Newby (1974), that the lumber recovery factor (LRF) is the most important single item affecting costs in a sawmill, and it becomes more important as log costs rise; because it reduces log costs and increases the productivity of sawmill. Also it agrees with Brown (1979), who stated that improving lumber recovery is way to increase profits and at the same time more efficient utilization of the raw material.
Many factors contribute to differences in sawmill recovery. A log of a given diameter and length, if sound and straight, may yield different amounts of lumber due to the following factors: thickness of saw, thickness of lumber, and method of sawing the log (Chapman and Meyer 1949). However, Heman (1974) added grade requirements and log scales as factors contributing to differences in recovery.

Whereas Wachowicz, et al. (1985) stated that factors such as blade thickness, log taper, thickness of the slab, loss due to crook and defects, and skill of the sawyer, all affect the yield of lumber from logs. Also a study made by Richards (1977) indicated that factors such as kerf width, lumber thickness, edging method, log diameter, log taper, and sawing method had an important effect on saw log yield, and Millison (1977) stated that log diameter, log length, taper, defects and other defects, shape in cross section, crook, presence of foreign bodies such as nails in the wood, will determine the sawmill recovery. A report by the U.S. department of agriculture (1973) added mill type and condition, processing decision, and product size as factors affecting lumber recovery factor. However, DeMontague, et al. (1971) and Steel (1980) reported that log diameter, log length, log taper, kerf width, drying, and sawing inaccuracy, over size, size sawn, and log defects, affect the volumetric yield in sawmills.
Generally factors affecting small recovery can be grouped into:

1. Factors related to the log.
2. Factors related to the mill equipment or machinery.
3. Factors related to sawyers and labourers.

Factors related to the log:

Knots: are the most injurious defect in timber especially in some temperate zone softwoods. They are less common in hardwoods and less likely to govern the grades of home-grown hardwoods supplied for construction (Rasmussen, 1979).

Defects such as heart rot, burling, reduced volumetric yield as well as grade yield (DeMontaigue et al., 1971). This agrees with what was stated by Juvonen (1961), that inherent defects in the sawlog may result in extra cut-off in the sawn timber and perhaps in the rejection of the whole piece. Bruce (1961), tested the effects of several factors, including proportion of defects on logs, on the sawmill output, and found that there is no correlation between them i.e. proportion of defect on sawlog has no significant influence on yield. He pointed out that this was because the logs studied had very small proportion of defects.
Doble and Middleton (1960) found that timber recovery increased with increasing log diameter. This goes inline with what was stated by Williston (1976). That the relation between diameter and log recovery is a direct relationship. In a comparison between computer simulations and values obtained from mechanical studies Savvar and Varnavago (1982), concluded that in both cases, timber recovery increased with increase in log diameter. A regression equation was developed by Clark (1976) in which, the independent variables scaling diameter, log length accounted for most of the variation associated with regression, he concluded that recovery increases as log size increases. Wood (1968) studied the same timber recovery in cypress limitation and related it to log size classes. He found that recovery increased with increasing girth classes. Also Doble and McBride (1964) in second-growth Douglas Tis, found that timber recovery factor increased with tree diameter.

The magnitude of this direct relation is not the same through the whole range of diameters, but it increases sharply with diameter for smaller logs, then more slowly for logs of 300 mm top diameter and above (Demontaigue, et al. 1971).
Studying the effect of log length on recovery, Dobie and Middleton (1980) found at two sawmills that log length is positively correlated with the sawmill recovery. Therefore in order to maximize both volume and value recovery, logs should be bucked to the longest straight length (Middleton 1976). However different results were obtained by Demers and etal. (1971) who stated that yield increases with decreasing length and constant taper. They reported an increase of 3 to 4% for 3.5 m logs versus 4.5 m logs.

Taper is the term applied to the loss in log diameter with length. It is expressed in inches for a given length. Taper is affected by the size of the crown, the greater the crown, the greater the taper. Thus thinning promotes and pruning reduces taper (Chapman and Meyer 1949).

Dobie (1964a) found that log taper increase is accompanied by increase in log output if diameter and length are fixed, but the ratio of lumber recovered to volume of log decreases with increasing taper.

Demers and etal. (1971) Dobie and Middleton (1980) agreed that larger taper of logs results in a poorer recovery when yield is compared with actual log volume. However, Kollman and Cole (1968)
stated that excessive taper in a log leads to greater waste than round
and causes inclined grain, unless taper sawing can be done. Therefore
badly tapered logs should be cut to shorter lengths (U.S. Dep. of Agric.

Sweep and crook are terms usually used in literature to denote
deviation from straightness of logs. Crook is the deviation lengthwise
(Weitstcin, 1976). However in U.S. long bends are called sweep, while
crooks are short pronounced bends (Laatsch et al., 1973a). The first variable
for measuring bend is the departure of the log centre line of the portion
with sweep from a straight line between the mid-points of the two ends.
The second variable is the length of the crook or sweep (Laatsch et al.
Wachman et al. (1965), and Jovunon (1961), concluded that sweepy logs
give less and lower quality sawn timber. Delmontagne et al. (1971) stated
that sweep is the easiest defect on log to measure, and reported that
badly swept logs give very low timber recovery, that an increase of 35
percent in the volume of logs required to produce a certain standard of
sawn timber speeds was found as sweep increased from zero to 100 mm. in
logs of 5.2 m. long and 180 mm. diameter.
Hardwood stems are typically crooked, with sweep in both directions from the center line, and this is the main reason for cutting the logs into relatively shorter lengths, rather than long length logs. (Saunders, 1979). Skjellumrud (1963) and Sjedl (1984) reported that sweep of log is a factor of considerable importance, as it rapidly decreases yield regardless of the type of machine used, but the influence is less with circular saws where it is to some extent possible to compensate for the effect of log sweep, through manual means, by shifting the block during sawing to make the cut follow the sweep of the log.

2.1.2 Factors Related to Sawyers:

In the conversion of logs in the forest and at the sawmill, errors occur at each stage of processing, which results in losses in the volume and value output. The most serious losses result from inaccurate log lengths from the forest, damage to logs during loading and unloading, variations in rough lumber sizes, poor lumber trimming practices, and inadequate supervision directed to maximize lumber-grade recovery. These losses can be reduced and in some cases eliminated through the introduction and management of an effective quality-control program (Heinrich, 1979). The above statement made clear that errors usually occur at all
stages of lumber manufacturing process, which starts in the wood. Human factor is involved in all these stages, and the recovery control should start from the woods. Man is the one who will participate in all these stages of improvement. Regardless of the mechanical sophistication, and capability of quality control systems, ultimate recovery results are dependent upon the human element i.e., the mill employees (U.S. Dept. of Agric. For. Serv. 1973b). Also Thowoo (1947) studied the present situation in some Sudanese sawmills, mainly, Suki and Wad El mill sawmills, and reported that one of the major factors for the low recovery is the lack of proper training of labourers. The decision as how a log will be broken down on the head saw is made by the sawyer; therefore the success of the sawmilling operation may and frequently does, depend upon the soundness of the sawyers judgement in making those decisions (Nelson, et al. 1956). However, Williston (1976) added that the head sawyer can be called the key to better recovery. In circular sawmill the main reason for the variation occurring are found in the sawyers ability to utilize the machine, and skilled circular mill sawyer, operating the simple type of sawmill, can obtain results comparable to the better ones obtained at the more
5 percent increase when the problem was identified and corrected.

Bucking of logs depends on many factors. For instance, a 42-foot long log can have as many as 15 different cutting combinations of log lengths. It is advisable to first measure the logs so that
adjustment can be made. But in tall trees, it is not necessary to
measure off all the logs before actual bucking, but after two or
more logs have been bucked from the butt, the top limit of merchant-
ability should be determined, so that remaining length can be
adjusted to fit the remainder of the tree (MacKerrow, et al., 1966).

There is no absolute criteria or rule for defining the large end
and small end limits for a saw log, many small personnel consider
that an 8 inch (20.0 cm) top diameter is the limit for practical
smallesting (I.e., Dept. of Agnc. For. Serv. 1977b). Generally it is
desirable to mark off the log lengths prior to bucking, even in tall
trees.

In hardwoods the bucking of logs from forked trees is a
common problem. Because in forked trees the diameter of each fork
is always considerably smaller than the diameter of the trunk below the
fork, bucking a forked section in such a way that one of the logs
includes the forked section is to lose much of the best portion of the
in the mill. Whenever possible, log lengths bucked from the portion of the tree below a fork should be arranged so that the log cut is made just below the fork. Then logs can be cut independently from each forked section.

For proper bucking, the following rules should be applied whenever possible to increase recovery:

1. Cross cut at defects.
2. Cross cut at bends.
3. Don't cut logs much longer than the length of the products required from them. (Utilization Sect. Uganda 1965).

However a report by the U.S. Dept. of Agric. For. Serv. (1973a), added that severely tapered logs should be reduced to shorter lengths.

These operations necessitate cutting of trees into relatively short lengths, and random lengths, (Sawyers, 1979).

(2) Overcut and saving (inaccuracy) because it is impossible to buck tree logs exactly at right angles to the tree all the way through and because of lumber sawn at the mill should be long enough to permit for trimming off rough green ends, logs should be bucked from several inches to a foot longer, depending on their diameter, than the full length of the finished products to be cut from them (Buckman, et al.)
Target size of rough green lumber is the sum of four factors; a finished size based on an appropriate grading rule, shrinkage allowance, planning allowance, and ganging variation (Brown, 1970). But, overgenerous oversize allowance reduces recovery rate. U.S. Dept. of Agric. For. Serv. (1973a) reported that about 12 -18 percent of the log volume is considered waste due to oversizing, sawing variations and planning allowances.

1) Positioning of log on the carriage—the first cut establishes all faces since all other faces will be parallel to at right angle to the first face (Hallock, et al. 1971, Williston, 1976). Therefore, if necessary, because of poor log shape, the poorest face in saw first by slabbing it lightly so as to provide a flat face for a good bearing when sawing the better faces (Rock and Raubitschek, 1977, Williston, 1976, Bouquet and Flann, 1975, F.A.C. 1981). Also it is a good practice to locate defects on edges and corners, where they can be edged off during sawing (Williston 1976). However, Hallock, et al. (1971), reported that an average difference of 27, 21, and 8 percent between the best and poorest openings were obtained in
greatest effect on recovery (W. S. Dept. of Agric. For. Serv., 1973b).

(4) Product size—Taylor and Carman (1970) investigated the
effect of cant size and log diameter in relation to yield by a
transparent overlay procedure. They concluded that the best yield
from a given diameter resulted when the largest possible cant was
produced. When thicker pieces are cut from a log, less saw kerf loss
occurs, resulting in increased sawmill recovery (Seltor; Ford,
Milliston, (1976), gave a numerical example to clarify the effect
of product size. He reported that it is a common practice to take
three 2 x 4 in. (5 x 10 cm) from a 6½ in. (16.2 cm) diameter
log. However, it is possible to get two 2 x 4 in. (5 x 10 cm) and one
2 x 6 in. (5 x 15 cm) from the same log. This represents an increase
of 16.6 percent.

Brown and Reibel (1958) classified lumber into three main
categories according to its rough green size and these are: boards,
dimension, and planks. Whereas Henderson (1961) classified products
into planks or doits, boards, battens, and scrapings. And Shlady
1. Boards of about 25 mm thickness and width from 100 mm to 300 mm in 25 mm increments. These are suitable for concrete framework, roofing, flooring and box making.

2. Planks of about 50 mm thickness and in width from 100 to 200 mm in 50 mm increments. These are suitable for framing timber for concrete form work, house frames, floor joists, roof rafter, and furniture.

3. Timber with thickness of 75 mm to 300 mm in 25 or 50 mm increments and width from 75 mm to 300 mm also in 25 or 50 mm increments. These are suitable for posts, beams, girders, railway ties, mining props and for remanufacturing secondary industries.

(3) Sawing patterns— the way in which a log is cut is of extreme importance, because sawing pattern will affect sawmill recovery. Sawing methods are outlined as follows:

1. Live sawing or through and through method, is the simplest way of sawing logs. It is the ripping of the log into boards by means of a series of parallel saw cuts.
Sawing around, includes all other methods which involve turning of logs as sawing proceeds, so as to separate materials of different quality, and cuts are made in different planes. There are two main methods of around sawing, each with a large number of minor modifications to suit different species, different sizes of logs and different market demands. The two methods are:

1. Back-sawing, which aims at the production of back-sawn boards i.e. boards whose faces are in general, tangential to the growth rings. It is also known as backing off, plain sawing, flat sawing, or slash sawing.

2. Quarter-sawing is planned to produce boards whose faces are generally at right angle to the growth rings. It is also known as rift-sawing, or edge-sawing (Wallis, 1963, Doremus and Houland, 1978).

Wallis, (1963), outlines advantages and disadvantages of the different sawing methods as follows:

- well suited to mass production.
- gives the highest recovery from the log, at lowest milling cost.
disadvantages of live-sawing:

1. the method lacks plasticity, and it is not suited to the production of timber of varied sizes and qualities.
2. it is not possible with live-sawing to separate clear from knotty timber, nor can defective logs be handled without heavy loss.
3. suitable with light and easily seasoned timbers, other wise heavy seasoning defects is encountered in the form of cupping, warping, and unequal shrinkage.

Back-sawing compared to quarter-sawing has the following advantages:

1. gives a higher recovery from the log.
2. defects can be separated more effectively and with less loss.
3. a greater portion of wide boards may be obtained.
4. back-sawn boards season more rapidly and with less shrinkage in thickness.
5. nails can successfully driven into the back-sawn face.

On the other hand quarter-sawing has the following advantages:

Joinery stock are frequently quarter-sawn to produce edge-grained material of higher value.

1. In case of gum vines, these are shown as narrow lines of far less serious character in case of quarter-sawn faces, while the vines are shown as broad splashes, which is a serious detriment to finished board in case of back-sawn face.

4. Quarter-sawn boards dry more slowly, therefore markedly less likely to develop defects in seasoning. This is very important in case of some species as Eucalyptus, where the saving in avoidance of seasoning losses is frequently more than sufficient to offset the disadvantages of lower recovery of the sawmill.

Other variants of sawing methods are:

1. Taper sawing, is a variant of around sawing, where the sawing is done parallel to the bark of the log on all the four faces (Pnevmatikos and Moulant, 1978).
the log on the carriage between selected cuts in an effort
to maximize the yield of higher grade lumber (Richards
and Neuman, 1979).

3. cant-sawing or modified live-sawing is a combination of
live and around sawing methods (Ponemaitis and Neuland
1978).

live-sawing produces a higher value and volume lumber, whereas Richards
(1977). and Richards and Neuman (1979) stated that live saving without
skilled rechopping shows no great advantage over four-sided grade saving.

Juvonen (1961)) on the other hand found that the around saving
results in 10 percent to 15 percent better recovery than live saving
system. Because the side boards from the two sides are split and cut into
edging in live saving. Whereas Bouquet and Flinn (1973) and Stell, (1984)
concluded that sawing method had no apparent effect on percent recovery.
And Saunders (1979), Flinn and Bouquet (1974), and Williston (1976),
agreed that live-sawing gives more yield, when saving medium and high
quality logs, whereas around saving resulted in better recovery in case
planned with due regard to the properties of available logs and the kinds of products (Wyper 1963, and Turnbull, 1966).

Any improvement in lumber recovery in existing mills can be put into one of two categories: with approximately 50 percent of the recovery improvement attainable through manpower training and 50 percent through equipment modification (Newman, 1974). Training of manpower to perform efficiently, can be achieved through the following:

1. a better understanding of grading rules.
2. keeping the sawyer informed about market requirements.
3. making the sawyer conscious of the losses involved in over and under cutting (Gusaway, 1974).

2.4.5 Factors Related to Sawmill Machinery:

was sawdust.

When the saw kerf is reduced additional boards or lumber can be obtained. Hackerman, et al. (1966) stated that some have cut a kerf of 1 in. each time they pass through a log. Thus if 1 in. boards are being produced from a log with such a saw, the equivalent of at least one board is cut into sawdust for every four boards obtained. However, Hallgren, (1966b) pointed out that the increased recovery from a decreased kerf or decreased oversizing actually results from three factors independently or in combination. These factors are:

1. Increase occur in logs that have one jacket board which due to the same resulting from log taper, must be trimmed to a length shorter than the log. In such case even a slight reduction in the kerf or oversize, when multiplied by one or more sawdusts, is sufficient to turn the face of this money jacket board into the log center enough to increase its usable length by two feet.
reduced. This result in effect, is to move the outside face of the jacket boards nearer to the log centre.

3. The most important increase in recovery through a decreased kerf width or oversizing is the decreased log diameter required to produce a given combination of products.

The same author (1964a) reported that the percentage increase to be expected through decreased kerf is greater in the smaller logs than in larger logs.

Sawing accuracy: Sawing variation can be within-board or between-board variation. Brown (197?) stated that the within-board thickness variation results from saw blade snake, vibration, slipping dogs, crooked roll, and relief of timber bind. The between-board thickness variation, however, is due to sawmarks which are not accurate.

Types of saw marks are customarily classified on the basis of the kind of machine used to perform the breakdown operation. The types of equipment used for this purpose are
1. HAND SAW - these were the first means of producing lumber. A two saw hand saw was used to rip the slab or board from the log. The log is supported in such a way that one sawer works from the upper side and the other from underneath. This was done either by placing the log on a platform or placing it over a pit (Brown and Bechel, 1958).

2. SASH AND SASH GANG SAWs were known as reciprocating saws. Sash saw was the mechanical call off spring of the pipe saw. The blade mounted in a wooden sash was operated by a crank arm. However the gang saw was the logical successor to the sash saw. In its most primitive form it was a sash saw with several blades mounted in the sash. The saws are spaced to cut a pre-determined thickness (Valls, 1961, Brown and Bechel, 1958, Kiplinger and Cote, 1968, Koch, 1975).

3. CIRCULAR SAWs as the name implies, consists of a circular metal plate with teeth on the outer side circumference. The original circular saw was solid mounted. An early improvement was the development of the gullet tooth, which provided larger saw dust chambers. A subsequent advance was the invention of the inverted-tooth saw.
4. **BAND SAW** consists of a continuous or an endless steel band with saw teeth in one edge or in both edges, running over two wide wheels. It may be horizontal or vertical.

Koll and Cote, (1968), Brown and Belish, (1958),
Kork, (1975), Turnbull, (1966), discussed the advantages and disadvantages of these saws, which can be outlined as follows:

advantages of circular saws:
1. relatively of low cost,
2. less skill is required for operation,
3. they can stand more rugged usage than band saws.

disadvantages of circular saws:
1. relatively wide kerf resulting in greater waste,
2. require more power than other saws,
3. they are not suitable for deep cutting.

advantages of band saws:
1. produce little sawdust leading to higher recovery,
2. deep cutting is possible i.e. they can handle large logs.
1. Less power is required.
   Disadvantages of band saws:
   1. High initial cost of equipment.
   2. Greater skill of sawyers is required.
   3. Will not withstand rough work as circular saw.
   Advantages of gang saws:
   1. High production rate.
   2. Simple i.e., minimum skill is required.
   4. Accuracy in sawing.
   Disadvantages of gang saws:
   1. Relatively high initial cost.
   2. Blind sawing method i.e., inflexibility of operation.
   3. Suitable only for limited class of work.

Tooth settings: Normally saw need setting or space for their teeth to work in, to prevent the blade of the saw from rubbing against the wood whilst cutting and so becoming heated by friction. The two types of setting are the following:

1. Spring-set, where each tooth is bent a slight angle
to the face of the saw. Neighbouring teeth are bent in opposite directions. It is used mainly for cross cutting i.e. cutting at right angle to the grain.

7. 

saw-set, where the cutting edge of each tooth is pressed out so that it extends slightly beyond each face of the saw. This is common in hand saws and used for rip-sawing.

2.2. Sawmill in the Sudan

2.2.1. Background:

Sawmilling was started in the Sudan in 1932, in the Blue Nile and Northern Sudan. Later locally made portable circular sawmills were established in Western Sudan and some other provinces (Awad El Karem, 1981). He also reported the following types of sawmills:

1. permanent boiler-operated sawmills e.g. El Sukk, Nal El Nal, Nwata and Kasseria.

2. locally made, mobile, tractor power sawmills, e.g. Bunzaga, Smali, Loba and Kolfoai.
Tractors are used for extraction of logs, they simply drag logs fastened to a wire rope. Loading and unloading are performed manually, and log transportation is done by different types of vehicles. Recently mechanized felling was introduced, and some motor-driven chain saws are used for felling and bucking but on small scale. Thommesson (1992) stated that considerable increase in yield of saw logs and sleeper logs can be attained using the improved cutting methods, as improved axe and chain saws. Another advantage of chain saws is avoiding log splits, which can not be avoided using hand tools. Splitting has a significant economic value so, one of the most valuable log part can only be used for fuel wood.

2.2.3. Quality of logs available:

The quality of logs varies considerably; crooked and forked logs are commonly used at both Suki and Wel At Vall sawmills. Sometimes, lack of proper cross-cutting results in log sizes which are not suitable for mechanical conversion. In most cases, the only factor considered in bucking is the sleeper length (Atwell et al, 1976; Thommesson 1992, Callant, 1961). However Thommesson (1982) stated that by making accurate bucking and allowing bucking of shorter saw logs, the yield can be raised at the sawmill by 5 percent.
2.2.4. Species used and products:

Mohammad (1979) reported that 80 percent of the sawn timber is in the form of sleepers for Sudan railways and Gezira Board lines. Whereas Gallant (1961) stated that it is indeed fortunate for the Sudanese sawmilling industry in its present condition that there is a ready demand for short fixed lengths for specialized purposes e.g., native bed tramps and legs, stanch for doors and windows, and telegraph cross-beams. In addition to the main product types which includes Sudan Gezira Board sleepers and Sudan railways sleepers. He reported that 80 percent of the products in Blue Nile sawmills are sleepers and 20 percent other sawn timber.

Sunt is the main species on which the Blue Nile sawmill operations are based. Only rarely are other species such as Mahagany (Khaya senegalensis), Angeli (Peltophorum pterocarpus) and basoz (Acoel aubida) seen. Sawmills in Southern Sudan, however exploit a variety of species including vaba (Ischodia dika), Podocarpus sp and Khaya sp (F.A.O. 1956, Gallant, 1961). Also Awad El Kareem (1981) reported that 90 percent of wood processed was hardwoods and 10 percent soft woods.
Sawmills are run with a big percentage of waste exceeding 70 percent in some cases (Yahktar, 1979). However, Zivko et al. (1976) reported a recovery of about 40 percent in the Blue Nile sawmills, while 47.2 percent recovery was reported by Amd El Kareem (1981). Whereas F.A.O. (1956) and Callant (1961) reported recovery of 39.6 and 39.2 percent respectively. However, the highest recovery was reported by Honestro oy (1987) at about 42 percent in the Blue Nile.

According to Zivko et al. (1976), Amd El Kareem (1981) and Thoroestro oy (1982), this lower recovery is attributed to the following factors:

1. Low log quality.
2. Old plant facilities and lack of proper maintenance.
3. The basis on which incentives are given.
4. No proper logging tools.
5. Widely inserted teeth.
6. Improper felling and bucking.
7. Concentrating on sleepers production without considering log qualities.
Acacia nilotica is a tree of moderate size attaining heights up to 30 m in favourable sites. The species is easily identified by the bright yellow sweet-scented flower heads, sweet-smelling grey or black pods and paired whitish spines at the base of each leaf. Foliage is feathery.

Four subspecies were identified and these are:

1. *Acacia nilotica* subsp. *nilotica*.
2. *Acacia nilotica* subsp. *lomentoides*.
3. *Acacia nilotica* subsp. *astringens*.
4. *Acacia nilotica* subsp. *subalata*.

Subspecies *lomentoides* and *astringens* are characterized by their pods which are constricted between seeds in contrast to the pods of subspecies *astringens* and *subalata* which have no constriction (Gods, 1985).

According to El-Antia (1976) subspecies *nilotica* is found mainly along the White Nile, while *lomentoides* along the Blue Nile. Subspecies *astringens* is a characteristic of the banks of seasonal rivers on alluvial light soils, while subspecies *subalata* is restricted to South-East Equatoria on gravelly soils. But *astringens* generally occurs in Northern and Central parts and in the Red Sea Province. It is also
Sant has an attractive timber, with a warm, reddish brown heartwood. Sapwood and heartwood are well defined, and the sapwood is narrow and pale in colour. The grain is interlocked, often irregular and sometimes straight in general direction. Knots are of common occurrence (Ministry of Technology for prod. Res. Lab. 1968). The same source showed that in comparison with teak, sant is more than twice as hard, about twice as tough and shock resistant and nearly 30 percent stiffer and stronger in bending and compression. Also Naaroun (1979) discussed the important physical and mechanical properties of sant. He showed that sant timber moulds well and glues satisfactory. He also found that the timber is difficult to nail and requires pre-boring.

Sant timber is suitable for heavy construction and buildings. Also it provide satisfactory sleeveings for railway sleepers. As it can be planed to a good finish and turns well, it would make very attractive bowls, toys, images.......... etc. It would also make handsome, but rather heavy furniture and cabinet work. The timber is
Log Volume Determination

Logs are the round pieces with square-cut ends into which thebole is further divided in the process of manufacture of a tree into its final products. Logs are usually of 8 ft. (2.4 m.) long or over, while pieces of less than 8 ft. are called bolts. (Chapman and Meyer, 1944).

The basal area can be calculated as follows from log diameter:

\[ B = \frac{3.14 \times D^2}{4} \]

Where:

- \( B \) - basal area
- \( D \) - log diameter

Then the volume can be calculated as:

\[ V = BL \]

Where:

- \( V \) - log volume
- \( L \) - log length

Actually logs are not cylindrical in shape. Therefore, specific methods are used for log volume calculation, among these are, Robers', Smalian's, and Newton's formula (Chatterjee, 1926, Spruce, 1932).
Where:

\[ V = \frac{b_1 + b_3}{2} \times h \times L \]

Where:

- \( b_1 \) - basal area at the large end.
- \( b_3 \) - basal area at the middle of the log.
- \( b_2 \) - basal area at the small end.

This is the most accurate, and it is more adapted to all loci than Rober’s or Smalian’s which are more adapted to paraboloid (Haseh, et al. 1972, Chapman and Hoy, 1940).

Smalian formula states:

\[ V = (b_1 + b_3) 	imes L \]
b₀ = basal area at the large end.

b₁ = basal area at the small end.

In spite of the relatively greater accuracy of the Huber's formula, the Smalian is the one most commonly used in mensuration (Chapman and Meyer, 1948).
The material for this study consisted of the timber of Acacia nitidula trees of the Blue Nile forests. Logs were obtained from Laiheh forest during the final felling of 1980.

The tree is locally known as qanuq; it is the main afforestation species on the flood plains of the Blue Nile river. It also occurs naturally in many other areas a long water courses. It is strong, hard and dense; wood is used as main timber for railway ties, marters, roof trusses and bedsteads. It is also used in the round for building purposes, for charcoal and firewood.

The study was carried out in the Laiheh conventional portable circular sawmill. The sawmill consists of four circular saws, of which two are used as heads and the other two for resawing and trimming operations.

All saws were operated by normal agricultural tractors (Massey Ferguson, Ford, and Ruffield). Each two axes were driven by a tractor.
Crookedness or sweep of the log using a wooden stick one metre long and a pocket measuring tape. This is done by holding the stick close to the log at the sweep and measuring the deepest deviation between the log and the stick. In case of sweep on both sides, measurements were taken for each side alone then added to each other to have the total crookedness of the log in cm.

Fig 1 shows log crookedness measuring.

Length of the log using a measuring tape (in cm).

It should be noted that all the measurements were in metric system.

In addition, observations about any defects such as rot, insect holes, splits etc were also recorded.

The under-bark log diameters were calculated as follows:

\[ d_{u.b} - d_{o.b} = 2r \]

where

- \( d_{o.b} \) = diameter overbark in cm.
- \( d_{u.b} \) = diameter underbark in cm.
- \( r \) = bark thickness in cm.
where

\[ \begin{align*}
Y & = \text{log caper in m}^3 \\
L & = \text{log length in m}
\end{align*} \]

Before sawing each log was numbered and marked using different colours. Logs were divided into six diameter classes. Each log carried a serial number and a diameter class. Sawing was done in the Bmildor sawmill as normal. Then the finished products were recorded and random samples were taken to determine average dimensions. The samples consisted of 50 railway sleepers, 50 alleys and 100 bade stools. Timber volume produced by each log was then calculated and the conversion factor (timber recovery) was determined, as the volume of sawn product expressed as a percentage of log volume.

2. **Measurement of timber recovery under controlled sawing**

In logs were taken randomly from the sawmill yard with the aim of reducing the sawyers' effort in trying to do it the easy way, rather than trying to get the maximum out of the log. These logs received the same treatment as the previous 200 logs except for instructions which were given to sawyers to produce as much timber as possible from each log, i.e., there was some sort of interference by the investigator, in the form of reducing slab and requiring it to produce smaller size products.
50 trees were randomly selected before felling. They were then felled using a power chain saw and cut according to the following recommendations:

- Cross cutting at points of defects.
- Cross cutting at points of brads.
- Cross cutting at as closely as possible to length required. The following lengths were used: 125, 155, 185, 200, 210 and 310 cm. These lengths were marked by a paint on the felled trees.
- Backing out extensive rot.
- Backing should be across the log.
- Backing before the fork in case of forked trees.

After backing the logs were transported to the mill.

At the mill log yard measurements were done as in (1) and the output measured after sawing.

From these improved logs 175 logs were then selected at random for sawing in the same sawmill and with the same sawyers, and sawing patterns. The only difference was that sawing operation was controlled: when each log was placed in the carriage it was put in such a way as
to slab the poorest face first to provide a flat face for the following
cuts. Also we made sure that the products from each log were the largest
and longest possible products which could be obtained from the logs.
For instance, a log 210 cm long will produce sleepers. If this is not
possible it is sawn into at least 200 cm. If this is not possible it should
be sawn to produce at least 180 cm and so on. The products of each
log were recorded and the timber recovered from each log was calculated,
and conversion factor (timber recovery) was obtained.

6. **Sawing patterns:**

To study the effect of sawing pattern 30 logs were collected
randomly from improved logs obtained under (3), choosing 10 logs from
each diameter class. Then 25 logs (5 logs from each diameter class)
were sawn in the same sawmill using live or through-and-through sawing
pattern, while the remaining 25 logs were sawn using the ground sawing
pattern.

For all measurements log samples were taken at random. Basic
parameters such as log volume and recovery were computed by standard
formulas as indicated earlier. Averages were obtained for all parameters
by diameter classes.

Correlation and multiple regression analysis were carried
out using the computer for examining the effect of the different factors (log characters) on the conversion factor (timber recovery). In the regression analysis, timber recovery was the dependent variable and log diameter, taper, sweep and crown-length were the independent variables. A two-way classification analysis of variance (Randomized complete block design) was also carried out for all logs used in the study to examine effect of different log treatments. Five blocks representing log treatments (CROS, CRCS, CRCS, SILS, and DORS treatment) and five levels of diameter classes were used. Also randomized complete block design was used to examine the effect of live and ground cutting patterns, with 5 levels of diameter classes. Least significant difference test was used for pair comparisons in case of log treatments because it is the simplest and most commonly used in such cases. L.S.D. was calculated as follows:

$$L.S.D. = \frac{t \times s_d}{\sqrt{n}}$$

where

- **L.S.D.** = Least significant difference at α level of significance.
- **s_d** = Standard error of the mean difference.
- **t** = Tabular (t) value at α level of significance and
  with n-2 degrees of freedom.
\[ S_0 = \sqrt{\frac{\sum S^2}{r}} \]

\[ S^2 \quad \text{The mean square error in the analysis of variance (ANOVA table)} \]

\[ r \quad \text{Number of replications (blocks).} \]

Variation between means was then compared with the L.S.D. If the variation is more than the L.S.D., then the variation is significant; otherwise, the variation is not significant. One-way classification analysis of variance was used to detect the effect of different variables as crookedness, taper, log length, and overlength on recovery. If the variation is significant, then it is followed by least significant difference test (L.S.D.).

For L.S.D. value determination, there are two cases: first

If \( n_1 = n_2 = \ldots = n_m \), i.e., the number of experimental units are equal within each treatment,

\[ \text{L.S.D.} = \sqrt{\text{error degrees of freedom, } \infty} \frac{1}{2} \sqrt{\frac{\text{MSE}}{n}} \]

where

- L.S.D. = Least significant difference at a level of significance
- MSE = Mean Square of Error from ANOVA table.
\[ n_a = \text{number of experimental units in each treatment.} \]

Second if \( n_1 \neq n_2 \neq \cdots \neq n_a \)

\[ \text{L.S.D.} = \left( \text{error df, } \infty \right) \sqrt{\frac{\text{M.S.E.}}{n_1} + \frac{1}{n_2} + \cdots + \frac{1}{n_a}} \]

Then absolute values of the different treatment differences, when obtained and compared with the L.S.D. value.
RESULTS AND DISCUSSION

Timber recovery as obtained in this study refers to the volume of timber produced by the sawmill, expressed as a percentage of total log volume fed into the sawmill.

The results obtained can be grouped into two categories:

Firstly the effect of some log treatments on recovery. This part of the study included the investigation of the effect of five log treatments tested on the timber recovery. Secondly recovery - log characteristics relationships, which included the study of interrelationships between the different log properties in relation to timber recovery.

4.1. The effect of some log treatments on recovery

This comprised five log treatments: current bucking normal sawing (CNS), current bucking controlled sawing (CCS), improved bucking controlled sawing (IBCS). The other two treatments were variants of the third treatment. These were improved bucking live sawing (IBLS) and improved bucking around sawing (IBAS).

4.1.1 Current Bucking Normal Sawing (CNS):

The average recovery obtained with this treatment (CNS), was 91.42 percent. A combination of factors contributed to this low recovery. Among these factors were the following: improper falling and bucking resulting in log splitting, crooked logs, tapered logs and logs...
with excessive overlength. This is in addition to inaccurate processing decisions, improper incentive system, log diameter and sawyer’s skills and ability.

Damage caused by some of these factors are illustrated in figures 2 – 5.

The most important factor was crookedness. For the purpose of this study crookedness was divided into six classes. Table 1 shows log crookedness distribution and recovery for DDS treatment. The table shows a general trend whereby lower recovery decreases with increasing crookedness. This was confirmed by the results of the analysis of variance as shown in table 2, which indicated a significant variation at 0.01 level of significance, and results at the least significant difference test as given in table 3. As depicted in table 3, most of the variation was due to differences between crookedness class six (recovery 38.7%), crookedness class five (recovery 39.16%) and crookedness class one (recovery 48.6%). The graphical relation between recovery and crookedness as given in figure 6, showed decreasing recovery with increase in the degree of crookedness.

These results agree with results obtained by many investigators such as Skjelbred (1965) and Steel (1984) who reported that crookedness
Leads to rapidly decreased yield regardless of the type of sawing machine used. Similarly DeBontagne et al. (1975) reported an increase of 35 percent in the volume of logs required to produce a certain product as crookedness (sweep) increased from zero to 100 mm in logs 5.2 m long and of 190 mm diameter. This is logical because during sawing the machine will cut in straight lines and any deviation will be cut off as waste.

The high percentage of crooked logs as shown in Table 1 indicates that no attention was paid to reduction of crookedness during bucking operation. As more than 70 percent of the logs had crookedness of more than 4.0 cm/m and 12 percent of the logs had crookedness of more than 10.0 cm/m. Labourers only concentrate on having railway sleeper length log (210 cm) even if the log contains a very crooked portion, forgetting or ignoring that such a log may not produce railway sleeper at the sawmill.

The effect of log diameter illustrated in Table 4 indicated a steady increase in recovery with increasing log diameter among bigger diameter classes. However, results of the analysis of variance showed that this variation was not significant as shown in Table 5. This is due to the variation in log qualities used. In this respect Steel (1984) stated that hardwood sawmills, may saw older timber and if the logs contain...
high volume of unsound material, the typical relationship of increased recovery with increased log diameter may not hold. To have clear recovery diameter relationship a computer modelling should be used, where all variables except diameter can held constant. Also Dobie and Middlebon (1980) and Senna and Razzavie (1982) studied the effect of log diameter on recovery, keeping other variables constant. They concluded that recovery increases with increase in log diameter.

It is to be noted that only 4.3 percent of the logs were of diameter less than 25.0 cm. This is mainly due to the Blue Nile sawmill's policy, which emphasizes railway sleeper production. It would be more useful if smaller sites such as atrab and local bed parts could be seen from smaller diameter logs.

Regarding the variation of recovery with log taper, Table 6 shows a general trend whereby recovery decreases with increasing taper; but this trend was not significant as shown by the results of the analysis of variance given in Table 7. The reason for this non-significant variation may be due to the small proportion of taper found in the studied logs, since about 70 percent of the logs had a taper of less than 2.0 cm/m and only 4.0 percent of the logs had taper ranging from 4.0 to 8.0 cm/m.
The effect of overlength was given in table 8. The table showed no specific variation of recovery with overlength classes. Nevertheless there was an indication that as overlength increases, the recovery decreases. This should be one of the major factors leading to lower recovery, as this overlength will be nothing but waste in the form of offsets as shown in figure 4. Table 8 shows that 41.5 percent of logs had an overlength of more than 10.0 cm and 5.5 percent of the logs had an overlength of more than 25.0 cm. In fact, the non significant variation obtained in this study may be due to the interaction between the different factors affecting timber recovery, where the effect of one factor may mask the effect of another factor.

It is to be emphasized that most of the defects can be eliminated in the bucking operation. For instance, crookedness can be reduced by following specific rules such as bucking at the bends. Also overlength can be minimized through accurate bucking operation. Therefore, Krutel (1981), Williston (1970), Wackerman et al (1973) considered the bucking process as one of the most decisive phases of rational wood processing.
4.1.2. Current Bucking Controlled Saws (CBCS)

The average recovery with this treatment (CBCS) was 49.25 percent. Compared with the previous treatment (CBM) (42.42 percent), the recovery was increased by about 13 percent. This increase in recovery reflects the effect of sawyers, as the only variation between the two treatments was that in the case of CBM treatment sawyers were left without any interference, whereas in the case of CBM treatment sawyers were guided to make the best out of the logs.

The sawmill personnel is an important element for better recovery especially in the case of circular saws. Since the sawyer is responsible for the processing decisions, what to produce from a certain log, the opening face, thickness of stabs, the best orientation of logs on the carriage and when to turn the log during sawing.

The accuracy of the sawyers was found fairly high as indicated in table 9, where the coefficient of variation was ranging between 1.2 to 8.5 percent. This agrees with the statement of professor Fischer (1985), who noted that the skills of Scandinavian sawmill personnel were good considering the type of machines used. However, under the piece work system, sawyers are interested in producing the largest number of pieces irrespective of the recovery. It is obvious that
will try to complete the task in theonest way and shortest time.

Taking into consideration the fact that there was no sorting of logs
according to products, sawyers will take the nearest best logs re
complete the job, without paying any attention to recovery. In this
respect the U.S. Dep't. of Agric. For. Serv. (1933b) stated that
regardless of the mechanical sophistication, and the capability of
quality control systems, ultimate recovery results are dependent upon
the human element.

The factors influencing timber recovery (crookedness, taper
log diameter and overlength) were also checked in this treatment
seeking for any change in trends as a result of inducing sawyers
effect. The results were as follows:

In the case of log crookedness, there was no marked change
from results of the CRNS treatment. This is shown in Table 10 and
supported by the results of the analysis of variance as given in
Table 11. In both treatments there was a significant variation of
recovery with crookedness. That is, recovery decreased as the degree
of log crookedness increased. This is also shown in Figure 7. There
was, however, a little change in the log taper – recovery relationship from results obtained in the CRUS treatment. Table 12 shows log taper distribution and corresponding average recoveries for the CRUS treatment. The table shows a general trend, whereby recovery decreased with increased taper. But the analysis of variance showed that this trend was still statistically non significant as given in table 13. This trend means that there was slight change towards the expected inverse relationship between recovery and log taper. This is also supported by the graphical relationship given in Figure 9, which showed decreasing recovery with increasing taper.

As far as log diameter and overlength are concerned, this study showed that the variation of recovery with these two factors remained non significant as given in tables 14 and 15 for diameter – recovery relationship and tables 16 and 17 for overlength – recovery relationship.

4.1.3. Improved Bucking Controlled Sawing (ICCS):

Better felling techniques and appropriate bucking resulted in better quality logs, with significantly reduced crookedness, overlength, taper and splitting as shown in Figure 9. These improvements led to appreciable increase in timber recovery. The average
CHBS treatment (i.e. 32.7% increase) and 69.25 percent for CRBS treatment (i.e. 17% increase).

The magnitude of log improvements were as follows: crookedness as given in table 18, was reduced significantly, an 85.6 percent of the logs had crookedness of less 2.0 cm/m and only 2.9 percent of the logs had crookedness of more than 4.0 cm/m. The average crookedness was reduced from 3.2 cm/m in the case of CRBS treatment, to only 0.5 cm/m in the case of CHBS treatment.

Overlength was one of the important factors contributing to lower recovery in the current practices. This was significantly minimized in this treatment (18G3). The average overlength was reduced from 26.46 cm in case of CRBS treatment to zero in the case of 18G3 treatment. This was done by measuring and marking logs before bucking. The utilization section, Uganda (1985) reported an increase of 25.7 percent in timber recovery as a result of improved felling and bucking.

Taper as studied in treatment CHBS was not a critical factor affecting recovery, as very few of the logs had pronounced taper. In this treatment (18G3) 71 percent of the logs had a taper degree of less than 2.6 cm/m and only 4.8 percent of the logs had a taper of more
from 1.6 cm² for CRNS treatment to 1.8 cm² for IBNS treatment.

The remaining two treatments were variants of this treatment (1RCS). IBNS treatment varied from the main treatment (10G) in that it does not include railway sleeper production. In IBNS treatment, however, the sawing pattern was live sawing and without railway sleeper production.

1.4. Sawing patterns:

There is no fixed sawing pattern used at present, but generally sawyers turn the log many times during sawing to maximize the quantity and quality of product. This can be considered as sawing around.

Table 20 shows the variation of recovery with sawing patterns. With live sawing the average recovery was 50.02 percent, whereas the value obtained for around sawing was 34.62 percent (i.e., about 32
decrease). The results of the analysis of variance as shown in table 21, indicated that the variation of recovery was significant at 0.05 level of significance. The higher recovery in case of around sawing may be attributed to the following:

1. Locally logs may contain natural defects, insert hazards or rots, and it may be necessary to turn the logs many times to cut the
and will be included in most of the products, and a big proportion of the products may be rejected. Secondly in the case of live saving, many parts of the logs become waste in the form of small pieces cut off in trimming and edging operation. This is reduced to minimum in case of around sawing. Thirdly it was observed during sawing, that sawyers prefer around sawing, because they think that live saving takes more time than around sawing. Therefore, the recovery may be affected by their willingness and ability to use around sawing. However, these results are similar to the findings of Truman (1924), who found that around sawing (block - sawing) system resulted in 10 to 13 percent better recovery than live saving. Simonds (1939), Flann, and Bowes (1974), Williston (1975), on the other hand, found that live saving gave more yield, when saving high quality logs, whereas around sawing resulted in better recovery in case of large low grade logs suitable for railroad ties. This is particularly true with tropical hardwoods. Other authors reported different results, such as Peters (1967), Robinson et al. (1974), Adams (1970), who agreed that live saving produces
a higher value and volume lumber. On the other hand, Bouquet and Flinn (1975), Steel (1966) concluded that sawing in turn had no apparent effect on percentage recovery.

4. Log treatment - recovery interrelationships

Table 22 shows average timber recoveries for the five treatments under investigation. It was evident from the table that the recovery was increased from 43.47 per cent in the case of GRYD treatment following improvement in felling and bucking, in addition to controlled sawing, to reach 57.49 per cent for the ICOS treatment. The results of the analysis of variance given in Table 23, indicated a highly significant variation between average recoveries from different treatments. This was supported by the least significance difference test at 5% level of significance.

Differences between recoveries at different treatments were compared with the L.S.D. value, and the results as given in Table 24, showed that ICOS was the best treatment (recovery 57.49%), followed by ICOS (recovery 56.05%), whereas GRYD (recovery 49.75%) and GCRS (recovery 49.42%) gave the lowest recovery.

The reason for getting the best recovery with the ICOS treatment may be explained as follows:
1. Improvement in log quality, where the average crookedness was reduced, and overlength was minimized.

2. Decision taken by sawyers was one of the important factors affecting timber recovery. For instance, a log of an average diameter 43.3 cm, 200 cm long, taper 7.0 cm/m, and crookedness of 7.0 cm/m, gave a recovery of 54.17 percent, whereas another log of an average diameter 49.7 cm, 200 cm long, and negligible taper and crookedness gave a recovery of 40.98 percent. This will, no doubt, be due to inappropriate production decisions which may be encountered in the CHNS treatment. This may also be due to the incentive and piecework system used. Both of these factors do not result in the right product from the right log. This was avoided in the case of the CHNS treatment, as logs were bucked from the forest to produce specific products, and at the sawmill sawyers were guided to produce these specific products.

3. The policy of the Blue Nile sawmill group is to produce mainly railway sleepers, accordingly most of the logs were bucked to sleeper length (210 cm), but due to other factors many of these sleeper length logs were used to produce other
smaller products and the proportion of off-cuts increased
and recovery was thereby reduced. This may be due to one or
two reasons; first that log quality may not produce a rail-
way sleeper, although the length was that of the sleeper.
The second reason is that sometimes the market demand for
specific product increased, and operators start to use sleeper
logs to produce those smaller products. In the case of IML
treatment smaller diameter logs were introduced to produce
small items, and buckling was carried out considering log
capabilities. It is easier less to buck logs to sleeper
length, if the log quality is not suitable for the production
of sleepers.

The common product sizes as shown in Table 25 are as follows:

1. Railway sleepers of 12.5 x 12.5 x 232.5 cm for Sudan railway
sleepers, 10 x 10 x 120 cm for Costa Board sleepers.

2. Atrash of 6.3 x 17.5 cm in cross-section with different lengths
ranging from 120 cm to 195 cm.

3. Local nettled bedsheets and single beds of 4.5 x 1.5 cm cross-
section of 97.5 cm and 195.0 cm lengths; 7.5 x 1.5 cm
cross-section with 42.5 cm and 75.0 cm lengths and 5.0 x 8.0
x 210.0 cm.
4. Bankers or building houses of 7 x 5 m, 10 x 10 m, 13 x 13 m on cross-section of various lengths ranging from 200 to 500 ft. Except for Giant screwers, all other estimates are not based on strong scientific grounds. They are determined by the market requirements. It was noted during the investigation that the main product was rook.

5. The saving pattern was improved as the poorest place was seen first, and runners were guided to produce the largest and largest possible product out of the globe.

With the improved backing and saving (IBS) treatment, the average recovery obtained was 94.6 percent, compared with the 92.62 percent recovery obtained with the IBS treatment. That is, there was 2 percent increase in the case of IBS. Considering that the only difference between the two treatments was that rook production was included in case of the IBS, these results can be easily seen in Table 1.

22. This result may be due to the fact that when saving smaller size products there will be more use and completely increase of smaller sizes the amount of leaf waste is larger. Thus, the cutting lines means more waste in the form of sand but, leading to decreased recovery.
thicker pieces (e.g., railway sleepers) are cut from a log, less saw kerf waste occurs, resulting in increased sawmill recovery. These results agree with what was found by Taylor and Carron (1970), and other authors such as Shjolien (1963), Delhommeau et al. (1971).

Figure 10 shows the sawdust at the sawmill. However, the least significance difference test results as given in Table 26, showed that the variation was not significant. It gave an idea about the effect of product size on recovery.
4.2 Log Characteristics - Recovery Relationships

Sawing is a complex operation influenced by a multitude of factors. The situation is further complicated by the fact that these factors interact among themselves and timber recovery is also influenced by these interactions. This investigation revealed that the relationship between timber recovery on one hand and log characteristics on the other, is more subtle than realized. Ascending procedure using both regression and correlation analysis were adopted to seek for any interrelations between log diameter, crookedness, taper and overlength as independent variables and timber recovery as the dependent variable.

The summary of the results of correlation analysis for the CENS treatment as given in table 26 showed that all tested variables showed very little correlation with the dependent variable. Crookedness showed the highest negative correlation with recovery (-0.32), followed by overlength which gave correlation coefficient of -0.19, whereas taper and diameter showed very low correlation 0.08 and 0.07 respectively). Test of significance showed that correlation between crookedness and recovery was significant at 1% level of significance.
whereas correlation with overlength was significant at 5% level. Other
correlations were non significant at 5% level of significance. This
low correlation may be due to the fact that there was some sort of
interrelationships between independent variables such as the correlation
between log diameter and taper (0.26).

Regression analysis for the CBR0 revealed that crookedness
and overlength are the only factors which had significant regression
coefficients. Moreover, the results showed that regression coefficient
for crookedness was highly significant (prob. < 0.0001), whereas overlength's
regression coefficient was significant (prob. < 0.04). The following model
was obtained showing the relationship between the four independent
variables and recovery:

\[ y = 50.1b - 0.08x_1 - 0.81x_2 + 0.63x_3 + 0.11x_4 \]  \( (1) \)

where:

- \( y \) = timber recovery
- \( x_1 \) = overlength
- \( x_2 \) = crookedness
- \( x_3 \) = taper
- \( x_4 \) = average under-bark diameter.

The regression coefficient of determination was 0.11 \( (R^2) \).
To test the significance of the regression model, analysis of variance was used. The results of analysis of variance showed that the regression was significant at the 0.01 level. Considering the fact that crookedness and overlength contributed to most of the variation, the best two-variable model was as follows:

\[ y = 50.1 + 0.08x_1 - 0.81x_2 \]  \hspace{1cm} (1)

where

\( y, x_1 \) and \( x_2 \) are the same as in (1).

The low percentage of the multiple coefficient of determination \( R^2 = 0.11 \) may explain that other factors such as the sawmill personnel, product size, the system of giving the incentives \( \ldots \ldots \ldots \ldots \) etc which were not tested contributed significantly to the variation. However, among the investigated variables, crookedness was the best factor which explained most of the variability in recovery.
CONCLUSIONS AND RECOMMENDATIONS

1. The question of recovery in sawmilling is of utmost importance, because improving recovery is a way to increase profitability and promote efficient utilization of the raw materials.

2. Smaller diameter logs (upto 20 cm diameter) should not be banned from government sawmills. They should be used for producing small size products.

3. Silvicultural treatments to improve form of trees and decisions about optimum rotation to produce acceptable diameter are necessary.

4. Bucking operation should be considered as one of the most decisive phases of rational wood processing, because at this stage it is necessary to eliminate all possible defects.

5. In most cases the only factor considered in bucking is the cloooper length. Some times lack of proper bucking results in log sizes and forms which are not suitable for mechanical conversion. Therefore it is important to make out standards of forest assortments which are suitable for conversion according to the kind of products desired. Accordingly trees should be bucked based on their qualities. But sometimes this may result in short length logs.
6. In this investigation crookedness was the most important element influencing recovery, because its effect was evident in spite of the interaction which masked the effect of the different elements.

7. Standardization of sawmill products and specifications based on scientific background is essential.

8. Decision on product types to be predicted should be based on log qualities or capabilities.

9. Forked trees or logs should be given more care in bucking.

10. To establish grading rules for grouping of logs based on log qualities, length, diameter and products expected from them.

11. Sawing is a complex operation influenced by a multitude of factors, and these factors may mask the effect of each other. Thus no high correlations were shown.

12. Sawyers' effect on recovery could be enormous. And training of sawyers to perform efficiently can be achieved through the following:

2. Keeping the sawyers informed about market requirements.
3. Making the sawyer conscious of the losses involved in over-cutting and under-cutting.
The following factors contributed to lower recovery in Sudanese sawmills as was shown by this investigation:

1. Lack of proper felling and bucking equipment.
2. Improper felling and bucking operations.
3. The basis on which incentives are given.
4. Concentrating on sleeper production without considering log qualities.

Incentive system if given consideration to timber recovery may result in improved recovery.

Research should be carried out to find the effect of individual factors influencing timber recovery. This can be done through testing the effect of one factor keeping the other factors constant.

Simulation studies should be carried out using different combinations of sawing patterns, practical sizes and various log proportions, to come out with certain saving decisions for each log group to guide the sawyers during the sawing operation.

Amed Akosom, H.A. 1981, sawmilling and forest industry in Sudan. Terminal report from associate regional adviser course with the FAO/UN/UNIDO forest industries advisory group for Africa, Addis Ababa.


Cassaway, R.L. 1964, the need to use more of the lot; in the production of timber and other ways which could lead to this. The australian timber journal, vol. 38(6).


Doble, M. J., 1964a, log taper related to lumber production. Forest products research branch contribution No. 236.


Ferguson, H. K. and Stein, A. I. 1974, report on an evaluation of Saco-Mill sawmill project, Tanzania, ministry of finance and planning, Norwegian agency for international development, Norway.

Flacher, H. 1933, personal communication, Tech. Univ. of Dresden, Germany.

Callant, M.N. 1964, Report to the government of the Sudan on the development of forest industries. FAO report No. 1722.


Krutel,P. 1981, sawmill production in integrated timber plant, First FAO/ UNDP Czechoslovakia seminar on planning and management of integrated mechanical forest industries, Zvolen, Czechoslovakia.


Moistoch, J.A. 1976, how to scrub wood losses and raise lumber recovery. Canadian forest industries.

Ministry of technology, forest prod. Lab. 1968, report on overseas timber. No. 12, report on a consignment of wood from the republic of the Sudan.


Slinn, F.L., 1962, the effect of log size, shape and quality and the sawing schedule on the sawing results. Translation N, 13, Bureau of Forestry, Dept. of the secretary of state.


Thomasto oy, 1967, development of blue pine mechanical forest industries. Report to the government of Democratic republic of the soviet union. TIMO OY, Ltd., Finland.

Utilization sect., 1955, wood news, No. 6, Uganda F.R. Dept.


Zlato, N., Dragjan, P. and Edenov, P. 1976, modernization of serbian forestry and wood working industry. Forest district Blue Nile, Ljubljana 25th oct. 76.
Table 1: Log crookedness class distribution and corresponding average recoveries(%) for CGS treatment.

<table>
<thead>
<tr>
<th>Crookedness classes</th>
<th>Range</th>
<th>Log Distribution</th>
<th>Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 1.9</td>
<td>18.28</td>
<td>48.39</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>10.28</td>
<td>63.01</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>28.09</td>
<td>65.10</td>
</tr>
<tr>
<td>4</td>
<td>6.0 - 7.9</td>
<td>22.85</td>
<td>40.85</td>
</tr>
<tr>
<td>5</td>
<td>8.0 - 9.9</td>
<td>8.00</td>
<td>39.16</td>
</tr>
<tr>
<td>6</td>
<td>≥ 10.0</td>
<td>12.57</td>
<td>38.73</td>
</tr>
</tbody>
</table>
Table 2: Analysis of variance showing the effect of crookedness on recovery for CHS treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>D.F</th>
<th>SS</th>
<th>MS</th>
<th>F calculated</th>
<th>F tabl. 7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>5</td>
<td>2103.66</td>
<td>420.73</td>
<td>4.67</td>
<td>3.14</td>
</tr>
<tr>
<td>Error</td>
<td>169</td>
<td>1537.92</td>
<td>9.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>174</td>
<td>17411.58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The difference is highly significant.*
Table 3: Results of L.S.D. comparison test for recoveries obtained for six crookedness classes within CSSG treatment.

<table>
<thead>
<tr>
<th>1</th>
<th>28.73</th>
<th>30.16</th>
<th>29.05</th>
<th>35.01</th>
<th>38.16</th>
<th>35.99</th>
</tr>
</thead>
<tbody>
<tr>
<td>(6)</td>
<td>0.43</td>
<td>3.12</td>
<td>4.48</td>
<td>6.37</td>
<td>10.76</td>
<td></td>
</tr>
<tr>
<td>(5)</td>
<td>0.79</td>
<td>3.95</td>
<td>6.94</td>
<td>9.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td>2.16</td>
<td>5.26</td>
<td>8.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7)</td>
<td>1.99</td>
<td>3.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td>3.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>3.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


* the difference is significant at 0.01 level.

1 - 6 are the crookedness classes given in Table 1.
Table 4: Log diameter class distribution and corresponding average recovery(%) for CNS treatment.

<table>
<thead>
<tr>
<th>Diameter class</th>
<th>Range</th>
<th>Percentage of</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>lung %</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20.0-24.9</td>
<td>4.6</td>
<td>46.19</td>
</tr>
<tr>
<td>2</td>
<td>25.0-29.9</td>
<td>26.8</td>
<td>43.97</td>
</tr>
<tr>
<td>3</td>
<td>30.0-34.9</td>
<td>33.2</td>
<td>40.38</td>
</tr>
<tr>
<td>4</td>
<td>35.0-39.9</td>
<td>23.4</td>
<td>44.87</td>
</tr>
<tr>
<td>5</td>
<td>40.0-44.9</td>
<td>6.0</td>
<td>45.02</td>
</tr>
<tr>
<td>6</td>
<td>≥ 45</td>
<td>5.7</td>
<td>46.85</td>
</tr>
</tbody>
</table>
Table 5: Analysis of variance showing the effect of log diameter on recovery for CEES treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F calculated</th>
<th>F tabular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>Diameter</td>
<td>5</td>
<td>951.06</td>
<td>191.20</td>
<td>1.77</td>
<td>2.77</td>
</tr>
<tr>
<td>Error</td>
<td>109</td>
<td>18213.00</td>
<td>167.37</td>
<td></td>
<td>2.36</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>19172.06</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* the different is not significant at 0.05 level.
Table 6: Log taper class distribution and recovery for CMS treatment.

<table>
<thead>
<tr>
<th>Taper class</th>
<th>Range (cm)</th>
<th>Log Distribution</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9 - 1.9</td>
<td>70</td>
<td>63.3</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>26</td>
<td>44.2</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>3</td>
<td>37.5</td>
</tr>
<tr>
<td>4</td>
<td>6.0 - 7.9</td>
<td>1</td>
<td>46.8</td>
</tr>
<tr>
<td>5</td>
<td>8.0 - 9.9</td>
<td>-</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>≥ 10</td>
<td>-</td>
<td>--</td>
</tr>
</tbody>
</table>
Table 7: Analysis of variance showing the effect of log taper on recovery for CPMG treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>Calculated</th>
<th>Tabular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5%</td>
<td>1%</td>
</tr>
<tr>
<td>Treatment</td>
<td>3</td>
<td>74.75</td>
<td>24.92</td>
<td>1.45</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.65</td>
</tr>
<tr>
<td>Error</td>
<td>189</td>
<td>100.18</td>
<td>0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>189</td>
<td>100.93</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* the difference is not significant.
Table 8: Log overlength class distribution and recovery for CCMQ treatment.

<table>
<thead>
<tr>
<th>Overlength class</th>
<th>Range (cm)</th>
<th>Log distribution (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 5.0</td>
<td>25.0</td>
<td>84.2</td>
</tr>
<tr>
<td>2</td>
<td>6.0 - 10.0</td>
<td>25.3</td>
<td>16.8</td>
</tr>
<tr>
<td>3</td>
<td>11.0 - 15.0</td>
<td>19.7</td>
<td>45.2</td>
</tr>
<tr>
<td>4</td>
<td>16.0 - 20.0</td>
<td>14.9</td>
<td>23.4</td>
</tr>
<tr>
<td>5</td>
<td>21.0 - 25.0</td>
<td>3.0</td>
<td>17.7</td>
</tr>
<tr>
<td>6</td>
<td>&gt; 25.0</td>
<td>5.5</td>
<td>40.4</td>
</tr>
</tbody>
</table>
Table 3: Variations in making accuracy

<table>
<thead>
<tr>
<th>Product</th>
<th>Smallest</th>
<th>Largest</th>
<th>Average</th>
<th>SD</th>
<th>CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attab</td>
<td>4.8</td>
<td>7.4</td>
<td>6.1</td>
<td>0.52</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>10.7</td>
<td>19.7</td>
<td>17.9</td>
<td>1.02</td>
<td>5.7</td>
</tr>
<tr>
<td>Sleeper</td>
<td>11.4</td>
<td>15.4</td>
<td>13.4</td>
<td>0.83</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>22.7</td>
<td>27.5</td>
<td>25.5</td>
<td>0.83</td>
<td>3.2</td>
</tr>
<tr>
<td>Local bed</td>
<td>4.5</td>
<td>5.0</td>
<td>4.7</td>
<td>0.3</td>
<td>6.7</td>
</tr>
<tr>
<td>parts</td>
<td>6.5</td>
<td>8.8</td>
<td>7.8</td>
<td>0.4</td>
<td>5.3</td>
</tr>
</tbody>
</table>

T = Thickness  
W = Width  
* All measurements were taken from air dried products.
Table 10: Log crookedness class distribution and corresponding average recoveries (%) for CRES treatment.

<table>
<thead>
<tr>
<th>Crookedness class</th>
<th>Range (CM/M)</th>
<th>Log distribution %</th>
<th>Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 1.9</td>
<td>16.2</td>
<td>17.48</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>20.0</td>
<td>55.15</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>33.3</td>
<td>58.14</td>
</tr>
<tr>
<td>4</td>
<td>6.0 - 7.9</td>
<td>20.0</td>
<td>38.40</td>
</tr>
<tr>
<td>5</td>
<td>8.0 - 9.9</td>
<td>16.0</td>
<td>47.70</td>
</tr>
</tbody>
</table>
Table 11: Analysis of variance showing the effect of log crocodilus on recovery for the CIQE treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F_{cal.}</th>
<th>F_{tab.}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>4</td>
<td>786.651</td>
<td>196.66</td>
<td>2.69*</td>
<td>1.0</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>1790.476</td>
<td>76.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The difference is significant at 0.05 level.
Table 12 : Taper class distribution and corresponding average recoveries (%) for CHBR treatment.

<table>
<thead>
<tr>
<th>Taper class</th>
<th>Range (cm²/h)</th>
<th>Log distribution (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 1.9</td>
<td>66.7</td>
<td>66.00</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>20.0</td>
<td>46.01</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>3.3</td>
<td>33.20</td>
</tr>
</tbody>
</table>
Table 13: Summary of analysis of variance results showing the effect of taper on recovery for CRUS treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F calc</th>
<th>F calculated 5%</th>
<th>F calculated 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>216.85</td>
<td>108.43</td>
<td>1.3</td>
<td>3.25</td>
<td>5.49</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>2267.24</td>
<td>83.97</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 14: Log diameter class distribution and corresponding average recovery(\%) for OBS treatment.

<table>
<thead>
<tr>
<th>Diameter class</th>
<th>Range CM</th>
<th>Log distribution %</th>
<th>Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.0 - 24.9</td>
<td>3.3</td>
<td>54.50</td>
</tr>
<tr>
<td>2</td>
<td>25.0 - 29.9</td>
<td>10.0</td>
<td>48.71</td>
</tr>
<tr>
<td>3</td>
<td>30.0 - 34.9</td>
<td>16.7</td>
<td>44.37</td>
</tr>
<tr>
<td>4</td>
<td>35.0 - 39.9</td>
<td>33.3</td>
<td>46.69</td>
</tr>
<tr>
<td>5</td>
<td>40.0 - 44.9</td>
<td>33.3</td>
<td>53.26</td>
</tr>
<tr>
<td>6</td>
<td>45.0 - 49.9</td>
<td>16.7</td>
<td>47.95</td>
</tr>
</tbody>
</table>
Table 15: Analysis of variance showing the effect of diameter on recovery for the GBCS treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F_{cal}</th>
<th>F_{crit.}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>5</td>
<td>370.49</td>
<td>156.9</td>
<td>1.35*</td>
<td>3.63</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>1990.50</td>
<td>79.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>2360.99</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The difference is not significant at 0.05 level.*
### Table 16: Log overlength class distribution and corresponding average recoveries (%) for CES treatment

<table>
<thead>
<tr>
<th>Overlength class</th>
<th>Range (cm)</th>
<th>Log distribution (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 5.0</td>
<td>23.3</td>
<td>50.13</td>
</tr>
<tr>
<td>2</td>
<td>6.0 - 10.0</td>
<td>23.3</td>
<td>42.40</td>
</tr>
<tr>
<td>3</td>
<td>11.0 - 15.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>16.0 - 20.0</td>
<td>10.7</td>
<td>44.10</td>
</tr>
<tr>
<td>5</td>
<td>21.0 - 25.0</td>
<td>10.0</td>
<td>35.70</td>
</tr>
<tr>
<td>6</td>
<td>&gt; 25</td>
<td>26.7</td>
<td>53.14</td>
</tr>
</tbody>
</table>
**Table 7**: Analysis of variance showing the effect of overlength on recovery for the 0.20% treatment.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F cal.</th>
<th>F tab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>4</td>
<td>208.35</td>
<td>52.09</td>
<td>1.03</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2456.77</td>
<td>98.27</td>
<td>4.38</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>2665.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The difference is not significant at 0.05 level.*
Table 18: Log crookedness class distribution for 1922 treatment.

<table>
<thead>
<tr>
<th>Crookedness class</th>
<th>Range (CV%)</th>
<th>Log distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Table 19: Log taper class distribution for DCG treatment.

<table>
<thead>
<tr>
<th>Taper class</th>
<th>Range (cm/N)</th>
<th>Log distribution(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0 - 1.9</td>
<td>71.9</td>
</tr>
<tr>
<td>2</td>
<td>2.0 - 3.9</td>
<td>24.2</td>
</tr>
<tr>
<td>3</td>
<td>4.0 - 5.9</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>6.0 - 7.9</td>
<td>1.6</td>
</tr>
<tr>
<td>5</td>
<td>8.0 - 9.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 20: Sawing patterns and corresponding average recoveries (%) by diameter classes.

<table>
<thead>
<tr>
<th>Diameter classes</th>
<th>Saving patterns</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Live saving (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.0 - 24.9</td>
<td>53.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.0 - 29.9</td>
<td>52.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.0 - 34.9</td>
<td>48.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.0 - 39.9</td>
<td>51.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.0 - 44.9</td>
<td>46.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>50.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Around saving (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>59.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>54.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56.60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 21: Analysis of variance showing the effect of sawing pattern on recovery.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>SS</th>
<th>F</th>
<th>F_{tab, 0.05}</th>
<th>F_{tab, 0.01}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment (sawing pattern)</td>
<td>1</td>
<td>50.26</td>
<td>45.55</td>
<td>2.30</td>
<td>2.71</td>
<td>31.20</td>
</tr>
<tr>
<td>Diameter</td>
<td>4</td>
<td>28.43</td>
<td>14.69</td>
<td>3.36</td>
<td>4.32</td>
<td>16.96</td>
</tr>
<tr>
<td>Inner</td>
<td>4</td>
<td>19.44</td>
<td>4.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>118.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The variation is significant at 0.05 level.
Table 22: Average recoveries (%) for the five log treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Recovery for different diameter classes</th>
<th>Average Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBNR</td>
<td>(1) 43.28 (2) 43.42 (3) 39.27 (4) 43.92</td>
<td>(5) 46.57</td>
</tr>
<tr>
<td>CBSC</td>
<td>(1) 61.37 (2) 48.69 (3) 36.93 (4) 43.97</td>
<td>(5) 54.75</td>
</tr>
<tr>
<td>IBOS</td>
<td>(1) 57.28 (2) 58.67 (3) 37.86 (4) 56.23</td>
<td>(5) 57.43</td>
</tr>
<tr>
<td>TBLS</td>
<td>(1) 53.56 (2) 57.23 (3) 44.69 (4) 51.95</td>
<td>(5) 56.62</td>
</tr>
<tr>
<td>IBSR</td>
<td>(1) 59.05 (2) 56.00 (3) 30.75 (4) 52.99</td>
<td>(5) 54.57</td>
</tr>
</tbody>
</table>

where:

(1) to (5) are diameter classes ranging from 31.0 cm to 43.9 cm with 2.0 cm interval.

CBNS = current bucking normal sawing.
CBSC = current bucking controlled sawing.
IBOS = improved bucking controlled sawing.
TBLS = improved bucking live sawing.
IBSR = improved bucking around sawing.
Table 23: Analysis of variance showing the effect of log treatments on recovery.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F calc</th>
<th>F tab, 5%</th>
<th>F tab, 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>4</td>
<td>599.336</td>
<td>149.834</td>
<td>10.17</td>
<td>3.01</td>
<td>6.77</td>
</tr>
<tr>
<td>Diameter</td>
<td>4</td>
<td>138.516</td>
<td>34.629</td>
<td>2.38</td>
<td>3.01</td>
<td>6.77</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>216.26</td>
<td>13.516</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>964.111</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The variation is significant at 0.01 level.*
Table 24: Results of the L.S.D. comparison test for recoveries obtained for the five log treatments.

<table>
<thead>
<tr>
<th></th>
<th>43.42%</th>
<th>69.75%</th>
<th>90.62%</th>
<th>54.69%</th>
<th>39.63%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBS</td>
<td>5.83</td>
<td>7.20</td>
<td></td>
<td>4.75†</td>
<td>13.21</td>
</tr>
<tr>
<td>IPS</td>
<td>0.47</td>
<td></td>
<td></td>
<td>5.36†</td>
<td>7.99†</td>
</tr>
<tr>
<td>IBS</td>
<td>4.08</td>
<td></td>
<td></td>
<td>7.99†</td>
<td></td>
</tr>
<tr>
<td>IBAS</td>
<td>2.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The difference is significant at 0.01 level.

L.S.D. = 6.70

CBS = current bucking normal sawing.
CBSH = current bucking controlled sawing.
IBNS = improved bucking controlled sawing.
IBAS = improved bucking live sawing.
IBAS = improved bucking around sawing.
<table>
<thead>
<tr>
<th>Product type</th>
<th>Dimension</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atab</td>
<td>24, 7 in.</td>
<td>80, 10 in.</td>
</tr>
<tr>
<td></td>
<td>6.2, 17.5 cm</td>
<td>200, 0.0 cm</td>
</tr>
<tr>
<td>Sudan railway sleeper</td>
<td>5, 10 in.</td>
<td>84 in.</td>
</tr>
<tr>
<td></td>
<td>12.5, 32 cm</td>
<td>202.5 cm</td>
</tr>
<tr>
<td>Gazira BOARD rail-</td>
<td>4, 8 in.</td>
<td>48 in.</td>
</tr>
<tr>
<td>way sleeper</td>
<td></td>
<td>202.0 cm</td>
</tr>
<tr>
<td>Local Bed</td>
<td>3, 2 in.</td>
<td>30 in.</td>
</tr>
<tr>
<td>Pairs</td>
<td>2.5, 7.5 cm</td>
<td>75, 0 in.</td>
</tr>
<tr>
<td></td>
<td>2, 5 in.</td>
<td>84 in.</td>
</tr>
<tr>
<td></td>
<td>5, 13 cm.</td>
<td>202 cm.</td>
</tr>
<tr>
<td>Mirona</td>
<td>4, 10 in.</td>
<td>96 in.</td>
</tr>
<tr>
<td></td>
<td>10, 10 cm.</td>
<td>240 cm.</td>
</tr>
<tr>
<td></td>
<td>5, 13 cm.</td>
<td>Various lengths</td>
</tr>
<tr>
<td>Special orders</td>
<td>7, 10 in.</td>
<td>96 in.</td>
</tr>
<tr>
<td>for Sudan rail-</td>
<td>27.5, 70 cm</td>
<td>240 cm.</td>
</tr>
<tr>
<td>way</td>
<td>6, 18 in.</td>
<td>164 in.</td>
</tr>
<tr>
<td></td>
<td>15, 39 cm.</td>
<td>300 cm.</td>
</tr>
</tbody>
</table>
Table 26: Correlation matrix for correlation coefficients in the case of the CEBB treatment.

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>X_1</th>
<th>X_2</th>
<th>X_3</th>
<th>X_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X_1</td>
<td>-0.1928**</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X_2</td>
<td>-0.3233**</td>
<td>0.1303</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X_3</td>
<td>-0.0941</td>
<td>0.0378</td>
<td>0.0799</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>X_4</td>
<td>0.0733</td>
<td>-0.0595</td>
<td>-0.2445</td>
<td>-0.2613**</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

* significant at 0.05 level.
** significant at 0.01 level.

X_1 = overlength in cm.
X_2 = crookedness in cm/ft.
X_3 = taper in cm/ft.
X_4 = diameter in cm.
Y = recovery in %.
Fig. 1: Log crookedness measurement.
Fig. 2: Crooked logs at the sawmill logyard.
Fig. 3: Rigs and trimmings resulting from crooked and tapered logs.
Fig. 4: Off-cuts resulting from logs with excessive overlength.
Fig. 6: Effect of crookedness on recovery for the GHS treatment.
Fig. 2: The influence of log creosotedness on recovery for the GB35 treatment.
Fig. 3: The relationship between log vapor and recovery for the CMS treatment.
Fig. 9: Good quality logs resulting from improved bucking.