

**RESOURCE ASSESSMENT AND ALLOCATION METHODOLOGY:
A STUDY OF THE PRODUCTION AND POTENTIAL OF POST
LOGGING RESIDUES**

OLAYEMI GABRIEL ADERINOYE B.Sc. Forestry (Ibadan).

In partial fulfilment of the requirements for the degree of

Master of Philosophy, University of Edinburgh,

Department of Forestry and Natural Resources.

March, 1986.



ABSTRACT

The rate at which forest resources are being depleted is now a matter of concern, with the world facing shortage in supply of wood by 2000 A.D. Recommendations for remedial actions cover a wide range of strategies, from the expansion of existing forest plantations to a fuller utilisation of available wood resources. This has resulted in studies on the uses of residues which used to be regarded as 'waste products' with most attention given to mill residues and little or none to forest residues. The allocation of the forest residue resource (which is usually left on the forest floor) has been based purely on a price theory related to the small piece size involved. However, for a resource to be properly allocated, a detailed examination of its quantity, quality and the impact arising from its alternative allocation is necessary.

This study has three main objectives. Firstly, to assess both the quantity and quality of forest residue, particularly post logging residues on a clear fell site; secondly, to develop local predictive models for residue yield; and thirdly to assess the economics of residue production, incorporating the ecological implications of residue harvesting in financial terms. The first two objectives were achieved by carrying out field works in a Borders forest while the economic analysis was based on information derived from the literature since time was limiting.

The study showed that by using simple sampling method such as a systematic grid line transect, the quantity of post logging residues can be cheaply assessed, giving an average of 57.2 and 24.4 dry tonnes per hectare of felling residues for Sitka spruce and Scots pine stands respectively. Of these, 90% are branches with the rest being tops, odd pieces and unextracted main produce. The residues are of lower quality compared with the main produce, having a higher moisture content and lower density in addition to their small sizes.

Several options for harvesting the residue, differing only in machinery used and procurement location were theoretically examined. Harvesting of residue as an extension of the current harvesting practice seemed to be the most acceptable compromise, accomodating both the conventional conversion of main produce and slash chipping. The economic implication of residue procurement, particularly the estimated costs of nutrient replacement, indicates that although residue procurement is economically viable its marginal benefits depends on the type of procurement management. It has been possible to demonstrate hypothetically that it is more profitable for forest managers or owners to undertake residue procurement than to sell residues to contractors on the basis of a price per hectare. Sensitivity analysis indicated that in some cases residue procurement by contractors is not profitable on the long term to the forest owners.

Accepting that residues left on the forest floor can help to maintain site fertility which is one way of allocating these resources, it seems likely that salvaging residues provided markets can be recognised and organised, for energy markets will be more profitable financially than the current practice of handling forest residues. This view is backed by the likelihood of a rise in energy prices.

ACKNOWLEDGEMENT

Great is Thy faithfulness oh Lord! and great is my gratitude to Him for giving me this opportunity and the grace to accomplish this study using men and women mentioned below as instruments of fulfilment.

I am grateful to my Government through the Director of Forestry, Mr. K. Aladejana, Federal Department of Forestry; all men and women both junior and senior at Federal Ministries of Agriculture, Manpower Development and Finance, and National Planning who were involved in approving my nomination for the Nigerian/UK Technical Cooperation Award and also cooperating when an extension was critically needed. I am particularly grateful to my friend Mr. J. Aderibigbe of Ministry of Internal Affairs, Lagos for giving me information on this award. The cooperate funding of my studies by both the Nigerian Government and Overseas Development Agency, UK, through the British Council was highly appreciated.

I am deeply thankful to my supervisors Dr. W.E.S. Mutch and Dr. J.F. Blyth for their efforts, love and sincere concerns for both my academic and general well being throughout my study period. My sincere thanks to all other members of staff for contributing to my happiness throughout my stay, particularly Dr. D.C. Ledger (Director of Post graduate studies) for his cooperation, Dr. C. Legg, Dr. Malcolm and Dr. J. Grace for their comments at various stages of this study.

My sincere appreciations to the following people: Mr. Inglis of International Forestry Consultancy Edinburgh, for his comments; Messers Solway, Mark Bell and Andrew Ferguson of Tweed Forest District, Scotland for granting me the permission to use their forests and their marvellous cooperation throughout the field works; Mr. R.J. Cooper of Department of Forestry and Wood Science, UCNW; Mr. J.R. Aaron of Forestry Commission, Alice Holt; Mr. S. Greig of Forestry Commission, Edinburgh and Dr. Lucy Shepard of Institute of Terrestrial Ecology, Bush-Edinburgh for sending some useful materials.

Others who deserve my appreciation include my friends within and outside the department including the following people -- Messers Alex Ogunfemi for assisting me on the field; Kweku Amfor and Raphael Mrode for proof reading this write-up; Charles Ramdass, Martin Bubala, Brian Titus for sharing my ideas and useful criticism; Drs. Bade Falade, Joe Ikuelogbon, Michael Oluwajana, David & Jane Harrison, the Pastor, Elders & Deacons of Charlotte Baptist Church, members of Friday Fellowship that used to meet in my flat, Miss Joan Campbell and others for sharing yourselves in love with me and my family. Thank you all.

Finally, I am very indebted to my wife Oluwafunmilayo Ibironke, my sons Damola and Toyosi for their understanding even when many odd hours had to be spent outside our home. My wife's participation in my field works on some occasions was very encouraging talkless of her courage to face and smile at difficulties. My mother-in-law Mama Rachel A. Malomo has been wonderfully loving, distance notwithstanding, by constant writing and prayer. God bless you all.

DEDICATION

To my most loving, hardworking and dedicated late mother, Madam AMINAT AWERO ADERINOYE who died on 1st September, 1980. I thank God always for your life and even death, for I have learnt a lot in both. I cherish your love, remember your words but miss your cares by your untimely death. Till the ressurection morning !

TABLE OF CONTENTS

CONTENTS	PAGE
ABSTRACT	(i)
ACKNOWLEDGEMENTS	(ii)
DEDICATION	(iv)
DECLARATION	(v)
CONTENTS	(vi)
LIST OF FIGURES	(ix)
LIST OF TABLES	(x)
LIST OF APPENDICES	(xi)
CHAPTER ONE Introduction	1
1.1 Definition of problems	2
1.2 Aims of the study	2
1.3 Study objectives	2
1.4 Structure of the thesis	3
1.5 Definition of terms	4
CHAPTER TWO Literature review	6
2.1 Production and handling of wood residues	6
2.2 Industrial markets	10
2.2.1 Particleboard production	10
2.2.2 Fibreboard	11
2.2.3 Pulp	12
2.3 Use of wood for energy	14
2.4 Agricultural and horticultural markets	20
2.5 Whole tree harvesting in U.K.	22
2.5.1 Nutrient removal from the crown	24
2.5.2 Nutrient losses and transformation	24
2.5.3 Physical changes in soil	26
2.6 Methodology for quantitative assessment of wood residue	27
2.7 Harvesting of forest residues	30
2.8 Summary and conclusions	31
CHAPTER THREE Methodology	34
3.1 Desk research	34

3.2	Field work	34
3.2.1	General approach	34
3.2.2	Definition of study areas	35
3.3	Field measurements	38
3.3.1	Preliminary study	39
3.3.2	The main study	40
3.3.3	Assessment of post extraction residues	42
3.4	Laboratory works	43
CHAPTER FOUR Quantitative and qualitative assessment		
	of post logging residues	45
	Results and discussion	45
4.1	Sample design	45
4.1.1	Comparision of methods	45
4.1.2	Sampling intensity	46
4.1.3	Location of individual trees	48
4.2	Residue quantity	52
4.2.1	Gross residue production	52
4.2.2	Implications of residue production	55
4.3	Residue quality	64
4.3.1	Measured physical characteristics	64
4.3.2	Tracheid length	65
4.3.3	Calorific value	69
CHAPTER FIVE Predictive models for residue production		
5.1	Choice of independent variable	73
5.2	Regression analysis	74
5.3	Graphical relationship	75
5.4	Regression equations for estimating residue	75
5.5	Reliability test for the models	85
5.6	Estimating residue production per hectare	87
CHAPTER SIX Economic consideration of residue potential		
6.1	Residue procurement	89
6.1.1	Procurement options	90
6.2	Evaluation of potential cost	
	of residue harvesting	97
6.2.1	Procurement costs	98
6.2.2	Estimates of cost of nutrient replacement	100

6.3 Potential benefits of residue harvesting	105
6.3.1 Direct financial benefit	108
6.3.2 Indirect financial benefit	113
6.4 Benefit and cost analysis of residue harvesting	113
6.4.1 Residue procurement by contract	116
6.4.2 Residue procurement by forest owners	117
6.4.3 Sensitivity analysis of residue harvesting	118
CHAPTER SEVEN Summary, conclusions and recommendations	125
7.1 Quantitative and qualitative assessment of forest residues	125
7.2 Development of predictive model	128
7.3 Economics of forest residue potential	129
7.4 Recommendations for further studies	131
7.5 General conclusions	132
REFERENCES	134
APPENDICES	150

LIST OF FIGURES

Figures		Page
1.	Fig. 4.1 Relationship between mean residue fresh weight (kg. per tree) and tree size for Scots pine	56
2.	Fig. 5.1 Scatter diagram for total above ground biomass per tree and dbh (all data)	76
3.	Fig. 5.2 Scatter diagram for total residue weight per tree and dbh (all data)	76
4.	Fig. 5.3 Scatter diagram for total residue weight per tree and dbh (SGLT data)	77
5.	Fig. 5.4 Scatter diagram for above ground biomass per tree and dbh squared (all data)	77
6.	Fig. 5.5 Scatter diagram for total residue weight per tree and dbh squared (all data)	78
7.	Fig. 5.6 Scatter diagram for total residue weight per tree and dbh squared (SGLT data)	78
8.	Fig. 5.7 Scatter diagram for above ground biomass and produce harvested per tree (all data)	79
9.	Fig. 5.8 Scatter diagram for total residue weight and produce harvested per tree (all data)	79
10.	Fig. 5.9 Scatter diagram for total residue weight and produce harvested per tree (SGLT data)	80
11.	Fig. 6.1 Light chipping machine	88
12.	Fig. 6.2 Heavy chipping machine at roadside	88
13.	Fig. 6.3 Whole tree chipping (in forest) using heavy machine	89
14.	Fig. 6.4 Whole tree chipping (in forest) by heavy machine	89
15.	Fig. 6.5 Slash chipping (in forest) by light machine	90
16.	Fig. 6.6 Whole tree chipping (at roadside) by heavy machine	90
17.	Fig. 6.7 Flow chart diagram for forest residue procurements	95

LIST OF TABLES

Tables	Page
1. Table 2.1 Retail prices for industrial energy in U.K. from 1963 to 1984	17
2. Table 4.1 Comparison of mean residue green weight (kg. per tree) obtained from whole plot and mean plot tree sampling methods	47
3. Table 4.2 Sampling intensities for estimating individual tree residue within 90% and 95% confidence limit	47
4. Table 4.3 Mean total residue weight per tree, and standard errors (SE) for three sampling techniques used in Scots pine	49
5. Table 4.4 Comparison of mean total residue weight per tree obtained by three sampling techniques used in Scots pine	49
6. Table 4.5 Gross residue production per hectare estimated by three sampling techniques used in Scots pine at Study Area 2	50
7. Table 4.6 Comparison of mean total residue per hectare obtained by three sampling techniques used in Scots pine at Study Area 2	50
8. Table 4.7 A break down of time taken to select individual sample trees for residue measurement by three sampling techniques	51
9. Table 4.8 Post conversion residue for Sitka spruce at Study Area 1 in (i) green weight (ii) dry weight	53
10. Table 4.9 Post conversion residue for Scots pine at Study Area 2 in (i) green weight (ii) dry weight	58
11. Table 4.10 Post extraction residue for Sitka Spruce in tonnes per hectare	59
12. Table 4.11 Post extraction residue for Scots pine in tonnes per hectare	59
13. Table 4.12 Percentage analysis of residue in relation to main produce harvested from Sitka spruce at Study Area 1	60
14. Table 4.13 Percentage analysis of residue in relation to main produce harvested from Scots pine at Study Area 2	61

15. Table 4.14 Percentage analysis of residue in relation to total above ground biomass for Sitka spruce and Scots pine	62
16. Table 4.15 Overall residue production for Sitka spruce (tonnes per hectare)	63
17. Table 4.16 Overall residue production for Scots pine (tonnes per hectare)	63
18. Table 4.17 Physical characteristics of main produce and residue for Scots pine	66
19. Table 4.18 Comparision of fresh moisture content of main produce and residue from Scots pine at Study Area 2	66
20. Table 4.19 Comparision of green density of main produce (merchantable stem) and residue from Scots pine	67
21. Table 4.20 Comparision of basic density of main produce (merchantable stem) and residue from Scots pine	67
22. Table 4.21 Calorific values for different parts of a tree	71
23. Table 4.22 Variation in calorific values of different types of tree assortment according to their moisture content	72
24. Table 5.1 Summary of regression statistics for residue predictive models	82
25. Table 5.2 Statistical comparision of regression equations based on dbh, dsq and pwt	84
26. Table 5.3 Comparision of trw and ttw equations derived from combined data	84
27. Table 5.4 Comparision of the predicted and actual residue weight, using models based on different variables (dbh, dsq and pwt)	86
28. Table 6.1 Basic operation matrix for residue procurement schemes	96
29. Table 6.2 Derived operation costs for residue procurement schemes	99
30. Table 6.3 Estimation of residue procurement costs per hectare	101
31. Table 6.4 Estimated conversion ratios of nutrient contribution from Scots and Corsican pines based on Wright and Will (1958)	103

32. Table 6.5	Estimated nutrient loss due to residue harvesting	104
33. Table 6.6	Estimated nutrient requirement (kg. per ha.) assuming a leaching factor of 10 (i.e 10% of soil fertiliser retention) based on Table 6.5	106
34. Table 6.7	Standard ratio and cost of fertiliser application	106
35. table 6.8	Costing of nutrient replacement due to residue harvesting	107
36. Table 6.9	Estimated costs per hectare of fertiliser applica- tion due to nutrient replacement in different Yield Classes (YC)	107
37. Table 6.10	Quantity of main produce and residue harvestable in Scots pine stand at Study Area 2	111
38. Table 6.11	Current average price for standing conifer timber from FC areas	111
39. Table 6.12	Analysis of marginal benefits according to harvesting strategies	112
40. Table 6.13	Analysis of marginal benefit for each harvesting scheme	114
41. Table 6.14	Estimated savings in site preparation and establishment	115
42. Table 6.15	Benefit and cost analysis of residue procurement undertaken by contractors, for different Yeild Classes of Scots pine	115
43. Table 6.16	Estimation of total cost of slash chipping at stump by light chipper including cost of nutrient replacement	119
44. Table 6.17	Total procurement cost of whole tree chipping at stump including cost of nutrient replacemnt	119
45. Table 6.18	Benefit and cost analysis of slash chipping at stump by light chipper	121
46. Table 6.19	Sensitivity analysis of economic potential of residue procurement for scheme 5 by contractor	121
47. Table 6.20	Sensitivity analysis of economic potential of residue procurement by forest estate owners	124

LIST OF APPENDICES

Appendices	Page
1. Appendix 3.1 Estimation of forest production	151
2. Appendix 3.2 Data collection sheet for main produce and residues	152
3. Appendix 6.1 Labour cost for different forestry skills	153
4. Appendix 6.2 Machinery operating costs	153
5. Appendix 6.3 Estimation of chipping cost by light chipper	154
6. Appendix 6.4 Estimation of chipping cost by heavy chipper	156
7. Appendix 6.5 Theoretical extraction of whole tree by tractor winching	157
8. Appendix 6.6 Estimation of cost of harvesting main produce (merchantable volume) by conventional logging and extraction methods	158
9. Appendix 6.7 Estimation of procurement costs of whole tree chipping by a light chipping machine	159
10. Appendix 6.8 Procurement cost of whole tree chipping at stump using a heavy machine	160
11. Appendix 6.9 Procurement cost of whole tree chipping at roadside using a light machine	161
12. Appendix 6.10 Procurement cost of whole tree chipping at roadside using a heavy chipping machine	162
13. Appendix 6.11 Procurement cost of post logging slash chipping at stump by a light chipping machine	163
14. Appendix 6.12 Procurement cost of post logging slash chipping at stump using a heavy machine	164
15. Appendix 6.13 Procurement cost of post logging slash chipping at roadside using a light machine	165
16. Appendix 6.14 Procurement cost of chipping post logging slash using a heavy machine	166
17. Appendix 6.15 Harvesting of stem tops and large branches by conventional method	167

CHAPTER ONE

INTRODUCTION

The current concern of foresters and wood managers all over the world is to find solutions to the imminent shortage in global supply of wood forecast for 2000 A.D. By that time, the world requirements of wood will be about 4,000 million cubic metres per annum (Keay & Hatton, 1976; FAO, 1976a). ^{Barling, 1974} The actual global demand for wood, according to Albanis (1978), could in fact be more than the projected figures because the knowledge of forest resource potential is incomplete for many countries of the world. Unfortunately, this demand cannot be met by the FAO's projected supply of 3,800 million cubic metres by the end of the century. Consequently, a deficit in supply of about 200 million cubic metres is feared.

The following measures have been suggested to meet the future wood supply :

- expansion of forest areas;
- utilisation of unused coniferous forests (in USSR, N.America) and hardwood forests (in S.America, N.America, Asia, Africa, USSR);
- preference for the establishment of fast growing plantation forests;
- improvement of silvicultural practices leading to higher forest yield;
- reduction of unwanted wood loss due to fires, pests and pathogens and climatic hazards;
- improvement of processing efficiency in wood industries and fuller utilisation of wood resource.

These should include the use of a greater proportion of both industrial and forest residues.

1.1 DEFINITION OF PROBLEMS

The contribution of forest wood residue utilisation to an alleviation of future wood shortage can be realised only if certain problems of forest wood residues are solved. These problems are:

- (i) inadequate information on the quantity and quality of residues being produced on the forest floor after conventional logging operations.
- (ii) lack of appropriate analysis to evaluate the economics of residue production and utilisation i.e.the costs and benefits of alternative strategies for residue production and use.
- (iii) lack of sufficient knowledge of potential market outlets and inadequate marketing in the existing ones.

1.2 AIMS OF THE STUDY

This study is intended to develop a methodology for dealing with specific problems of forest wood residues and their uses. The aims of the study are:

- (i) to determine the quantity and quality of post logging forest residues in order to assess their utilisation opportunities.
- (ii) to evaluate the economics of recovering and using these residues.

1.3 STUDY OBJECTIVES

To achieve these aims, the objectives of this study are briefly stated as follows :

- (i) to assess the quantity and quality of wood residues being

produced after conventional clear fell operations using a particular site and species as a case study.

- (ii) to develop and test a local prediction model for residue production based on the relationships between the quantity of main produce, diameter at breast height over bark^{of individual trees} and the residue produced.
- (iii) to investigate the economics of producing forest residues i.e. marginal costs of residue harvesting and marketing.

1.4 STRUCTURE OF THE THESIS

The structure of the thesis is as follows:

Chapter two reviews existing work on wood residue production, general quality requirements for industrial energy and other uses of wood residues. The review reveals that despite the potential of wood residues not much use has been made of them due to technical and economic reasons. Studies have concentrated more on industrial residues than on forest residues and an awareness of the potential of forest residues still needs to be developed.

Chapter three describes the various methods used for data acquisition while Chapter four deals with quantitative and qualitative assessments of forest residues. Three sampling methods were used to estimate the quantity of residue and to compare their respective precision against costs. Quality assessment included the residue type (tops, live and dead branches) according to size, basic and green density and moisture content. (Page 5).

Chapter five is concerned with development of prediction models based on allometric relationships between residue and produce harvested, on a single tree basis.

Chapter six considers the economics of residue harvesting and procurement for such markets as industrial chips and energy. Cost structures are developed based on available information for some residue harvesting and procurement options to estimate the marginal costs and revenues from any additional use of residues. (Forestry Commission, 1985; 1983; 1981; 1972).

Chapter seven discusses the overall results of the study in terms of resource assessment and allocation, considering the competitive nature of the markets that residues like any other commodity would have to face.

1.5 DEFINITION OF TERMS:

WOOD RESIDUE:

Wood residue is defined as everything that is left after man's operation of harvesting, processing and utilisation of wood and wood products (FAO, 1976b).

FOREST RESIDUES

This term generally refers to the root, stump, top, branches, leaves and needles. However, for this study, it will be limited to post logging residues above the ground only. These include stem top less than 7 cm. diameter over bark, post extraction material i.e odd pieces and main produce missed during harvesting, dead and live branches. Roots and stumps were not considered because of the impracticability of their assessment. In addition such an exercise might have deleterious effects on the regeneration of the next crop and on the level of soil nutrients.

MILL RESIDUES

All wood or bark residues produced from processing wood industries including saw mill offcuts, edgings, peeler cores, bark, saw dust, shavings etc. but not pulping liquors.

CHIPS

Small pieces into which logs or other forms of wood are cut for such purposes as the production of pulp and chip board.

FUEL WOOD

Wood in the natural condition harvested for use as a source of energy. In this category are included fuelwood from inside areas defined as "forest" and from elsewhere (farms, towns etc.) and all parts of the tree (i.e not only stem and large branches but also tops, twigs, small branches, fruit tree prunings) are included (FAO,1982).

CALORIFIC VALUE

The calorific value of a fuel is the amount of calories liberated when one unit of fuel is completely burned .

GREEN DENSITY

This is the density of freshly felled timber, calculated from green weight and green volume (Hamilton,1975).

BASIC DENSITY

This is calculated from oven dry weight and the green volume. Both green density and basic density are often expressed as specific gravity which is the ratio of weight to volume.

MOISTURE CONTENT

This is defined as the weight of the green timber less the oven dry weight expressed as percentage of the oven dry weight (Hamilton,1975).

CHAPTER TWO

LITERATURE REVIEW

2.1 PRODUCTION AND HANDLING OF WOOD RESIDUES

Wood is one of the most valuable resources that is rarely used in the form in which it grows. Right from the forest, to the processing industries, it is almost inevitable that any form of harvesting and processing normally results in leaving a proportion of the original material as waste. Such waste materials otherwise referred to as residues, can be grouped into two broad categories according to their origin, namely industrial and forest residues.

Published studies carried out on wood residue production in the U.K. are few and are also restricted to industrial residues, i.e. residues from sawmills and wood using industries. Among the few studies are the report prepared for the Forestry Commission by the Forest and Timber Consultants, Department of Forestry and Wood Science (U.C.N.W., 1974); Carruthers (1975); a leaflet published by Prince Risborough laboratory (B.R.E., 1976); Albanis (1978) and two papers published by Albanis and Cooper (1979a and 1979b).

The report by U.N.C.W. revealed that 594,000 \pm 7% tonnes of wood residues were generated by the Imported Timber Trade in 1973, of which 55% was soft wood only, 8% was hardwood only, and the remainder softwood and hardwood. Almost all of the residues (95%) produced was reported to have found useful, if not profitable outlets. During the same period the Furniture Trade generated about 300,000 tonnes of residues but more than half of this was contaminated by impurities with only 44% being used to produce heat and power.

The Building Research Establishment's note (1976) summarised the results of the above report and in addition gave an estimate of 962,000 tonnes as the

quantity of residues generated by the British home grown saw mills in 1976.

The methods of disposal of these residues were well outlined in the report published by the Department of Forestry and Wood Science, U.N.C.W. A break down of disposal methods shows that 77.7% were sold, 17.2% given away, 4.8% were either dumped and or burnt, and 0.6% used in mill boilers. For those saleable residues, it was reported that there was significant variation in the price paid for wood residues. Except where companies (usually the smaller ones) have located specialised markets, such as wood flour manufacture, agricultural uses, butchers and slaughter houses, hospitals, industrial cleanings, etc., prices seldom exceeded £4 per tonne and most were well below this price.

Five research works deal with the uses of wood residues in the U.K. These are the notes published by Princes Risborough (B.R.E., ¹⁹⁷⁵1976); a report by Timber Research and Development Association (T.R.A.D.A., 1975); Carruthers (1975); King and Smith (1974) and Albanis and Cooper (1979a; 1979b). The uses reported in these papers include particle board manufacture, agricultural and horticultural uses and energy.

All these studies were confined to mill residues and completely exclude residues from the forest floor. There is no empirical work on forest residues except some articles describing the experience of other countries such as Gott (1975); Wittering (1977); Fraser (1969). The Department of Energy contract on the utilisation of wood for energy is not ~~solely on~~ forest residues (Aitkens, ^{et al}1984).

Despite the disturbing threat to its future supply, wood still ranks high among the most wasted renewable resources. At present, the various wood harvesting techniques in most countries remove only the stem of individual trees to a point considered merchantable, usually defined by a minimum top diameter which differs from country to country. Thus merchantability of wood

is defined by markets and available technology.

According to Wittering (1977), Fraser (1980) and Mitchell (1980), that part of the tree which is usually harvested at present in Britain, i.e. the stem from just above the ground level to 7.0 cm. diameter over bark represents on average only 55% of the whole tree biomass. Thus the management and utilisation of forests has been operating within the framework of a "merchantable bole concept" (Gott, 1975). Of the 45% remaining, branches and tops account for about 22% with root and stumps the remaining 23% (Thornton, 1977). The use of a percentage ratio is very common in residue forecasting. Based on this Wittering (1977) predicted that the annual forest residue production (i.e. the branches and tops) in the U.K. by the end of the century will be about 5.5 million cubic metre. However, he doubted if more than 25% of this could be recoverable because of technological, economic and site problems e.g. mountainous terrain. Assuming there are markets for these residues, this implies that unlike mill residues a large proportion may not be economically and technically harvestable. It was also suggested that for these residues to be used, whole tree chipping as opposed to separate chipping of the residues would produce high quality chips. These would be more attractive to customers because they contain a higher proportion of wood to bark than chips from tops and branches or tops only and are also technologically easier to produce. This view embraces the concept of "whole tree utilisation".

According to Gott (1975) and King & Smith (1974), Young (1964 ;1967) advocated the use of all the material currently left as logging residues and the use of non-commercial trees and shrubs as alternative sources of raw materials for pulp mills, thus reducing pressure somewhat on forests. However, he cautioned that this concept should only be pursued in a biologically sound manner.

The components of above ground forest residue constitute what is generally referred to as logging slash. They have not proved to be of any market value in Britain to date and are usually disposed of to aid regeneration (Neustein, 1967).

Methods of disposal of forest residue are:

(i) Removal : In situ burning of slash which increases available nitrogen from the superficial layer of the soil by reducing the biological competition for nitrogen with a secondary nutritional bonus resulting from ash . Other advantages claimed are the reduction of fire hazard and more uniformity of artificial restocking (Smithers, 1964 ; Cockerell, 1966), cheaper replanting and improvement of ameliorative and tending operation. However, disadvantages of this disposal method are fewer natural seedlings e.g. in Sitka spruce, heavier deer browsing which may be deterred by slash cover (Stewart & Neustein, 1962), inferior germination and loss of nutrients in smoke (Neustein, 1962).

(ii) In situ treatment : This involves mechanical chopping by means of a trailed and or hydraulically mounted cutting machine. Its limitations are that it can not deal with larger branch wood nor operate on sites with large protruding stones. It is also limited by slope too steep for the tractor , but stumps, provided they are cut reasonably low do not hinder it. Retention of nutrients on the site, reduction of soil surface desiccation and delay of weed re-invasion are additional advantages (Neustein, 1962)

(iii) Retention of untreated slash in situ : This has similar biological attractions to chopping but replanting through the slash is more costly. In pine stands and especially where branch wood diameters exceed 7 cm. there is an additional hazard from the building up of injurious insect population e. g. Hylobius, Hylastes and Myelophine^{at} species (Neustein, 1962).

Apart from biological considerations each of these disposal methods involves different financial cost and benefits. Up till now the much accredited contribution of forest residues to soil fertility has not been estimated in financial terms. Alternative methods of utilising at least part of forest residue also involve costs and benefits and it is important to consider when assessing residue potential, the quality of wood residue in relation to certain markets. The remaining part of this chapter will therefore deal with just that.

For the purpose of this review, the potential market outlets for forest residues can be categorised into:

- (i) industrial markets - i.e. particle board, pulp, fibre board.
- (ii) energy markets - fuelwood for heating and power generation
- (iii) agricultural and horticultural markets.

Each market requirement is reviewed with respect to wood properties in general and residue properties in particular.

2.2 INDUSTRIAL MARKETS

2.2.1 Particle board production:

The selection of tree species for particle board manufacture depends on its local availability, quality and cost. The main factors for quality consideration are wood density, moisture content, wood pH and permeability (Mitlin, 1968). Timber of higher density requires a smaller amount of adhesive because of its smaller total particle surface area, thus the higher the wood density the greater the board strength (Lyman, 1968). Timber of low density requires compensation for its lower strength by addition of more adhesive.

The effects of wood density according to Lyman (1968) and Foster (1967) centre round costs and strength of the board. Lower density timbers would involve additional cost to compensate for low strength, but they still produce

boards of superior strength because of their greater compression factors on each particle and the consequent good contact between particles (Foster, 1967).

The use of round wood and the current possibility of using forest residues raises the question of bark and its effect on particle board. Large amounts of bark from debarking have tempted some manufacturers to use it as part of the raw material mix for board production. (Moslemi, 1974)

Dost (1971), having evaluated the use of different levels of bark on particle board production found that the effect of bark fibre was adverse. He noted that modulus of rupture (MOR) and modulus of elasticity (MOE) and strength of internal bond decreased with increasing bark content. It was concluded that the deterioration of board properties as bark level increased was also attributable to other factors such as low resin and wax application to the bark fibre due to their non-uniform distribution.

Anderson *et al* (1974) investigated the properties of board manufactured from 100% bark, 25% bark, and a three layer particle board with the core made from bark. The all bark board had low bending strength with high linear expansion. The three layer particle board with bark in its core stock proved to be a board with good overall properties, while the homogenous particle board with 25% bark also produced a board with satisfactory properties.

2.2.2 Fibre board:

The main aim of fibre board industry is to convert more or less worthless or very cheap wood residues into saleable products. Softwoods are preferred but hardwoods are cheaper and easier to obtain in some countries in which case more blending is required. The final choice of species will depend on availability and economic considerations (Akers, 1966).

The properties and yield of fibre board are significantly affected by the size of chips used. Holokiz (1968), (while determining the effect of chip size on yield

and properties of fibre board) found that a reduction in chip size i.e chip length resulted in reduced yield. For example, yield from 1 cm. chips was 3.1% lower than from 2 cm. chips. The modulus of rupture increased with smaller chip size up to certain point, after which weaker boards were produced. Internal bonding increased significantly as the chip size decreased which means that fine chips could be used for making special products. (Brumbaugh, 1960).

The effect of bark on fibre board was reported by Carrol (1974). It was found that an increase in bark level in the mix caused a substantial drop in the strength of fibre board, which could be restored by increasing the proportion of phenol -formaldehyde resin binder from 0.5% to 4%. This results in increased cost of production. He concluded that though bark is undesirable in fibre board, a small proportion of it may be tolerated under more costly manufacturing conditions. ^{such as the cost due to increased resin binder.} Therefore, the economic balance is between the increased cost of adjusting the process to cope with bark (log or chip washing to remove dirt and higher adhesive content) and the cost of not including bark at all, which requires debarking and bark disposal. (Lehman 1965).

2.2.3 Pulp

Up to date, the use of softwood in pulping still dominates the world pulp industry. This is because softwoods are characterised by long fibres which leads to easy processing and the production of strong paper (F.A.O.,1973). Hardwood can also be used for certain products such as corrugated paper although a small percentage of long fibre is needed for the best results. However, the use of hardwood for pulping has the following advantages : lower flow resistance and better formation, better surface properties, good mechanical properties and rapid strength development on beating. It has the disadvantage of lower tearing strength, lower folding endurance, lower wet web strength and problems from extractives (F.A.O,1976b).

Each type of pulping has its own species preference. For instance mechanical pulping favours softwood as a raw material, instead of hardwood with its short fibre length, because the strength of ground wood pulp is inherently poor - it is used for newsprint and other printing and writing papers. Softwood and some hardwood can be used for sulphate pulps which manufacture materials suitable for packaging uses.

Wood raw materials suitable for pulp production are in the form of round wood, slab wood, pulp chips from saw mills, forest residues and saw dust. Wood is debarked, chipped and stored before use in pulping. This immediately poses two problems. Firstly, bark removal and secondly, chip deterioration during storage. Erickson (1972) tried three methods of bark separation from chips at the stage of experimentation by air floatation, liquid floatation, and compression debarking. He noted that a combined system involving steam heating of the chip with bark followed by an abrasion process has been most successful.

Chip deterioration in storage is attributed to changes taking place in the central part of the chip pile. These involve a thermogenetic reaction possibly caused by the action of parenchyma cells, biological activity of micro-organisms and chemical oxidation and hydrolysis of the cellulose component resulting in decreased moisture, high carbon dioxide and low oxygen concentration in the first days of storage. These conditions promote the activity of wood attacking micro-organisms, the action of which results in deterioration of the chip pile, usually accompanied by discoloration, losses of wood substances and reduction of pulp yield and strength (F.A.O. 1976b).

Chip deterioration in storage can be reduced by covering the pile with plastic sheet i.e anaerobic storage (Feist *et al*, 1971), water spraying of the chip piles (F.A.O. 1976b) or chemical treatment of chip pile such as the use of

Sodium N-methylid,thiocarbonate (Springer *et al*,1973)

The size of chip to be used in pulping has been investigated. Of the varying thicknesses suggested, a 3mm. chip was shown to have optimum values for delignification, yield, and physical properties for kraft pulps (Borlew & Miller, 1970). Hatton and Keay (1972) suggested 2mm chip thickness for maximum screen yield while F.A.O.- (1976b) suggested an upper limit of chip thickness of 4mm. for laboratory chips and 6 - 7 mm:for industrial chips.

2.3. USE OF WOOD FOR ENERGY

Wood is a renewable form of energy which lends itself to being used by rural or island communities where population densities are low and land may be available for tree planting.

Wood as an energy resource has the following characteristic attributes (Fraser, 1981b):

- (i) It contains no polluting impurities such as sulphur;
- (ii) It can be produced cheaply in a small quantities to meet local requirements;
- (iii) The technology for wood harvesting and conversion is simple, low cost and well proven;
- (iv) Energy can be extracted from wood after it has been used for other purposes or from residues produced during conversion processes e.g. offcuts, slabs, etc. from sawmills
- (v) The ash residues resulting from wood burning is a very low proportion of the original fuel weight (1.5 - 3.0%) and can be recycled as a fertilizer.

The potential users of wood fuel in UK can be divided into the following, in descending order of fuel used: power station, large industrial users, small commercial and institutional users, agricultural and domestic consumers.

The conventional use of wood is by direct burning (Campbell, 1979) but since the oil crisis of 1970's there has been an increase in the use of wood to supplement other fuels.

The calorific value of wood at 20% moisture content is between 3,590 to 4,610 kcalories per kilogramme, compared with 11,310 to 47,000 kcalories for natural gas, 9,565 kcalories for heating oil, 6,450 to 8,600 kcalories for coal, 6,700 kcalories for wood charcoal, and 1,670 to 2,870 kcalories for peat (Fraser, 1980).

The useful heat from wood is affected by its moisture content since some heat is required to drive off this moisture during combustion. At high moisture contents i.e above 200%, wood will not burn without an auxiliary source of heat because of the difficulty of maintaining a higher temperature in wet conditions. The calorific values of dry wood vary considerably between species depending largely on the amount of oil and resin it contains. Softwoods with their high resin content also have high calorific value.

The qualitative potential of wood residue to supplement other energy has not been fully investigated and developed. For domestic users, there is a wide range of choice of commercially available appliances which can burn wood but information on their efficiency is rare and each model has different requirements for fuel. The choice however, ranges broadly between stoves to heat individual rooms relying mainly on thermal radiation and convection, to boilers with jackets to provide heat for small bore water or central heating systems (Fraser, 1981a; 1981b; 1980).

a single stove with an output of 4 - 6 KWh., capable of heating a large room will use about 3 - 4 tonnes of dry wood annually, while a boiler with an output range between 25 - 30 KWh. will consume 10 - 15 tonnes. With these large annual requirements, maintenance, storage, and adequate supply of wood may constitute problems. Crowther & Patch (1980) noted that an approximate 1.75 tonnes of dry wood which will occupy about 4 cubic metre of space when stacked will provide the same amount of heat as a tonne of coal which occupies just about 0.75 cubic metre. An approach to solving the space problem is to reduce wood volume by compressing it into briquettes. In this form, the volume could be reduced to about one fifth of its original bulk.

For industrial and institutional users of wood energy (i.e industries and local authority schools and hospitals), there are number of large boilers which can process of space heat or steam. Most of them are supplied with self loading equipment which means that solid wood is converted into chips and stored in a hopper; this increases capital costs but reduces the running costs.

According to Fraser (1980), fluidised bed technology has in the past few years have been developed to point where a number of models are commercially which can burn wet wood. These have the advantage of handling green chips more efficiently than traditional boilers. The conventional boiler generally employs a stocker and fairly large lumps of wood in the size range of 3 - 5 cm. are preferred, compared with a fluidised bed system which requires small chips.

The third system available to large establishments in the use of wood for energy is wood gasification which may use wood or other organic matter to produce a low calorific value gas suitable for diesel generators. This has been reported to have overall efficiency between 25% and 30% so that a plant that is consuming 20 tonnes of dry wood per day will give about 1MW of electricity

Table 2.1 Retail prices for industrial energy in U.K. from 1963 to 1984

Year	Oil	Coal	Gas	Electricity
1963 ¹	1.91	2.19	6.7	16.76
1964 ¹	1.79	2.19	6.67	16.67
1965 ¹	1.67	2.19	6.61	17.43
1966 ¹	1.77	2.23	6.68	18.05
1967 ¹	2.06	2.15	6.64	18.49
1968 ¹	2.25	2.08	6.67	18.67
1969 ¹	2.22	2.11	5.85	18.86
1970 ¹	2.22	2.53	4.52	19.16
1971 ¹	3.33	3.02	3.27	21.13
1972 ¹	3.18	3.25	2.96	21.59
1973 ¹	3.11	3.4	3.07	21.68
1974 ¹	7.37	3.7	2.97	27.68
1975 ¹	9.28	6.55	4.27	36.33
1976 ¹	10.63	6.81	6.48	43.63
1977 ²	54.7	21.4	9.26	1.718
1978 ²	51.3	23.2	11.71	1.9
1979 ²	63.8	27.0	13.67	2.1
1980 ²	90.3	35.0	17.57	2.366
1981 ²	108.2	39.9	21.59	2.706
1982 ²	114.3	47.9	23.24	2.939
1983 ²	125.9	49.6	24.06	2.904
1984 ²	149.7	49.6	26.34	2.889

(1) Price in pence per therm or kWh (DOE, 1977)

(2) Price in £ per tonne (DOE, 1985)

(Fraser, 1980).

The heat values of bark are slightly higher than those reported for wood (Aaron, 1975). This appears to be affected by the amount of ash, benzene, solubles and lignin present in barks (Sproull, 1969). According to Aaron (1976), the use of bark for energy has some drawbacks. Bark has a higher ash content than other fuels (four times greater than that of wood) and its use requires specially designed furnances which involves a higher capital outlay. Bark could have significant fuel value at moisture content below 60%.

The use of wood as a major source of energy has a long traditional history and it still represents the most readily available form of domestic energy in many countries.

As the price of fossil energy rises (Table 2.1) until the recent oil slump brought about by price war, industrial firms and home owners have increased their use of wood for energy. Forest residues and currently underutilized stands are recognised as untapped resources which may contribute substantial supplies of energy in future. The assessment of the potential contribution of wood to national energy consumption has been carried out for some countries.

In the U.S.A. the potential contribution of wood to national fuel supply was assessed by MITRE Corporation for the Energy Research and Development Administration (now Department of Energy), (Anne *et al*, 1977; Howlett & Gamache, 1977a; 1977b; Salo *et al*, 1977; Inman *et al*, 1977; Bliss & Blake, 1977) and a task force separately set up by the Society of American Foresters (Doub, 1976). From these reports, energy currently obtained was estimated to be between 65 to 100 teracalories in 1979, while the potential contribution of wood to U.S. energy requirement was estimated to be about 563 teracalories. These reports covered the assessment of land capability for the establishment of energy farms, production strategies and costs, conversion processes and costs,

and the potential of wood residues.

Finland is a country with a harsh climate, long transport distances and a predominance of process type industries which have raised her per capita energy consumption to one of the highest levels in the world (Hakkila, 1982) and yet is without any indigenous fossil fuel. The only important domestic sources of energy are water, wood and peat. Hence energy management has been based on wood far longer there than in most industrialised countries.

In the early 1930's, almost 80% of the primary energy was generated from wood based fuels. As energy consumption grew and more timber was needed as raw materials for lumber, plywood and paper, Finland had to turn to fossil fuels, so that by 1978 the proportion of wood based energy had dropped to 14%, most of which was used by commercial industry (Hakkila, 1982).

In the U.K., the potential of forest biomass as a supplementary source of energy was assessed by examining single stemmed trees and the coppice from forest stands (Mitchell, 1981). The estimated potential quantity of forest residues based on percentage prediction of component parts of a tree (i.e. root, stumps, tops and branches) was 1400 kilotonnes dry weight per annum in 1977 and to be 3200 kilotonnes dry weight per annum at the end of the century. Of these quantities, only 371 kilotonnes would be recoverable in 1977 and 1,520 kilotonnes at the end of the century. These are equivalent to 163 and 670 kilotonnes of oil respectively.

The use of wood in U.K. has declined in importance because of abundant supply of coal and more recently, the North Sea oil (Fraser, 1980). However, fossil fuels seem to be rising steadily in price in real terms because of the great investment needed to extract each additional unit, (Table 2.1) with the result that interest is again focussed on potentially renewable form of energy.

Having considered the domestic and industrial potential for using wood residues in detail it should be pointed out that the choice of fuel and fuel system depends on the comparative economics of the different fuels and conversion plants that might be used. Before completing this aspect of the review it is worth mentioning that some wood processing plants and distilleries in UK are giving serious consideration to the potential contribution that green chips, possibly from forest residues, could make to their energy requirements (Greig,1985)

2.4. AGRICULTURAL AND HORTICULTURAL MARKETS

The main markets for forest residues in agriculture and horticulture are for bark and tree stakes. Bark is used for a wide range of purposes, which include mulching, potting mixture for container grown plants orchid - culture and mushroom production. According to Aaron (1985), the greatest volume of bark sold currently in UK. is for landscaping. It is also marketed for equestrian purposes and for play areas in parks and kindergartens.

2.4.1 Use of bark as mulches and soil conditioner

A mulch is any material placed on the soil surface primarily to prevent evaporative water loss or to suppress weed growth. Mulches also minimise temperature fluctuation in the plant root zone and prevent wind and water erosion of soil. They have esthetic values, encourage earth-worm populations and improve the root environment (Bollen,1969). Physical incorporation of bark or other organic matter to the benefit of the soil is termed soil conditioning. Fine textured or heavy soils are rendered more porous, which may improve aeration and drainage. This action results not only from soil dilution i.e mechanical intermixing of bark particles with soil, but also from subsequent decomposition products and humus formation, which increases aggregation or

granulation and produces an improved tilth.

For mulching, many different materials including dust, stones, papers, plastic sheeting, asphalt emulsions, bark, saw dust, straw and other crop residues can be used. An ideal mulching material should of course be safe for plants and animals, pleasant and very easy to apply, attractive, long lasting, non injurious to soil micro flora and an eventual source of soil humus. Bark has been reported to have most of these prerequisites, similar to leaves and straw (Thomas, 1969).

The size distribution of ground bark is particularly important in mulching use. There should be no excess of fines as this may cause disagreeable dust in handling and high bulk density which may be sufficient to reduce aeration and infiltration of water. Bollen (1969) recommended a screened grid ranging from 1.27cm to fines with a majority of particles greater than 0.5 cm. as generally satisfactory.

Dunns and Emery (1959) reported that when wood residues such as bark are used as soil conditioners, they improve friability and prevent crust formation as effectively as peat moss improves tilth in fine textured soil; they also increase infiltration rate, improve aeration and produce more rapid flowering. However, the amount of organic matter added to the soil must be controlled (Bollen, 1969). Excessive addition may increase aeration so much that during hot weather, soil will dry at ^{an} undesirable rate. Under wet conditions, excessive addition of organic matter increases the water holding capacity of soil which may result in water logging and development of anaerobic conditions. Other disadvantages of using bark for mulching and soil conditioning include competition with growing plants for nitrogen, increasing soil acidity and potential for production of toxic materials.

Organic mulch decomposition in soil occurs mainly at the zone of contact between the underside of ^{the} mulch and the mineral soil surface; it is usually accomplished through the action of fungi and bacteria. These microorganisms require a source of energy and nitrogen for their development. Wood residues left on soil provide carbonaceous materials needed for energy but supply little of the necessary nitrogen.

Wood residues in the soil are best composted prior to their use. One of the best methods of composting is to mix wood residues with manure or other aids to composting, and place them in a wooden box outdoors. The contents should be kept wet to aid the composting process. The advantages of composted materials over uncomposted ones are their superior water holding capacity and higher nitrogen content but their production is labour intensive (Roberts, 1968).

Other properties of mulching materials requiring some consideration are bulk density, heat capacity and reflectance. Bulk density varies with particle size and distribution, the smaller the particles the greater the bulk density (Bollen, 1969). The heat capacity of organic matter depends on its water content. Bark has a high water holding capacity several times its own weight. The colour of mulching materials is important in thermal and light reflectance. Light coloured mulch such as sawdust reflects heat which may cause sun scald of low leaves and fruit. Bark being darker than sawdust absorbs light and heat more readily and increases evaporation induced by absorbed heat (Bollen, 1969).

2.5 WHOLE TREE HARVESTING IN UK.

The concept of whole tree utilisation often raises alarm because of the fear of possible ecological repercussions of removing virtually all above ground biomass from the forest. The consequences of such action, it is claimed, are damage to soil structure, increased risk of erosion and a loss of soil nutrients

from the forest floor yet no one has translated these implications into costs.

Whole tree harvesting is the removal from site of all above ground tree parts (cf. full tree harvesting which includes the removal of stumps and roots as well) (Young, 1974). Whole tree harvesting has been regarded as an ecological threat, largely because of the obvious nutrient losses consequent on harvesting the crown which is rich in soil derived elements.

Binns (1975a) showed that at least three times as much of the major nutrients might be lost from the site with whole tree harvesting as with conventional method. Similar figures for Sitka spruce were confirmed by Miller (1978) but Carey (1980) stressed that litter nutrient stocks and atmospheric inputs may overcome the harvesting drain problems on good soils.

The particular attraction of whole tree harvesting in Britain is mainly focussed on the large weight of crown relative to stem in poor to moderate crops, probably marginally deficient in phosphorus, growing on upland sites which are expensive to harvest. Full tree harvesting methods are not likely to be adopted in U.K. as the majority of upland crops are on stony soils where roots can enclose large stones which then damage processing machinery. Furthermore many gley soils would be unacceptably damaged by pressure exerted during extraction, although some forms of stump extraction could fracture and aerate soil (Carey, 1980)

There are three important site consequences of whole tree utilisation:

- 1 Nutrient removal in the harvested crown;
- 2 Nutrient losses from the site, and transformation of nutrients due to the absence of brash carpets;
- 3 Physical changes in soil structure, aeration, and water properties which could influence rooting.

2.5.1 Nutrient removal from the crown

Studies by Binns (1975a) on the ratio of total tree nutrients to stem nutrients for Sitka spruce indicated that on average over four times as much phosphorus would be removed as with conventional harvesting; the ratio is over 5:1 for nitrogen and 2:1 for potassium and calcium. These ratios of nutrients removed by whole tree to conventional harvesting are generally lower for bigger trees and higher for smaller ones.

Binns estimated that at least 40 kg. per hectare of phosphate fertilizer would be needed to replace losses from average clearfell sitka spruce ^(i.e. of YC12) but in practice more would be needed because only a small proportion is taken up by the trees. Nutrient stocks and atmospheric input can be set against the replacement, but on the typical marginally deficient site may have to be paid for.

2.5.2 Nutrient losses and transformation

The demonstration of nutrient losses at Hubbard Brook in North America following clear fell operations has aroused considerable interest in nitrate losses to stream water (Likens & Borman, 1977). Accelerated leaching appears to be a real danger in the wet west of Britain because an intensive whole tree operation leaves the ground exposed to rainfall, with no brash cover to intercept it (Anderson, 1985). This potential danger of accelerated leaching of nitrates has not been given serious attention in the past because foresters used to think that wet acid upland soils contained predominantly ammonium rather than nitrate nitrogen. There is some evidence that on soils of this type nitrate can exceed ammonium in the root zone and the possibility of leaching is once more considered. Recently some publicity has been given to pH decreases accompanying nitrate losses from the soil, and in particular Nilsson *et al* (1982) have drawn attention to ^{the} inevitable fall in pH if cation rich foliage is removed

from the forest. In general there is not much concern about acidity per se in forest soils because there has been little or no evidence that U.K. forest trees are limited by calcium shortages. Nevertheless, large losses of calcium following clear felling might induce unforeseen changes resulting from increased metal solution and modification to decomposition processes. Gaseous denitrification is a newly perceived threat. It was assumed until recently that acid and ammonium soils with most available nitrogen present as ammonium ions would not evolve large quantities of nitrous oxide, but recent agricultural evidence casts doubts on this assumption (Anderson, 1985). It is envisaged that conditions in wet upland sites may become more strongly anaerobic near the surface after whole tree ^{harvesting} operation because of increased waterlogging following puddling and reduced interception which would increase this loss of nitrogen.

Water-logging may also influence phosphate transformation in the root zone. Many of the upland soils in U.K. are strong phosphate fixers when aerated but soil chemists believe that prolongation or intensification of anaerobic periods may convert iron and aluminium compounds into soluble forms, realising bound phosphate so that it may be leached below the rooted horizons (Anderson, 1985). Certainly the widespread phosphate deficiency on such sites suggests that this has happened in the past but the process is difficult to quantify.

Another important aspect to be considered is litter decomposition following harvesting. With conventional practice the litter is not much exposed to the sun and rain, but in the absence of an insulating carpet of brash the question arises as to whether decomposition and mineralisation will be accelerated or slowed down. According to Anderson (1985) the result of a pilot study on an upland gley soil showed a rapid flush of nutrient release following a simulated whole tree harvesting, such that 15cm. of the fermentation and humus horizons disappeared in 18 months. This is twice the amount following conventional

felling and makes one ask on which sites this occurs and which sites dry up more in summer so that there is actually less nutrient release. A rapid release following felling could be an advantage to the next crop if decomposition products remained on site, but a disaster if they were lost before the next crop forms a good system of roots. Experiments designed to measure decomposition and its products are under way at sites in Snowdonia, the Borders and N.W. Devon, using sequential measurement of litter and equipment to measure leaching, decomposition and respiration in the soil nutrients. This is aimed at investigating whether a change in micro-climate following felling causes increased or decreased decomposition.

2.5.3 Physical changes in soil

Most of Britain's productive forests are on areas with average annual rainfall of more than 1000 mm. and in many, the soils are glacial tills of heavy texture and in some cases clays derived from underlying geology. Harvesting machinery under these conditions can do a great deal of damage to the soil such as soil compaction. In contrast if they are working on a mat of brash especially spruce branches which break down rather slowly (Binns,1975a), or if they proceed through the forest on the mat of branches from the current thinnings, then the likelihood of damage is lessened.

If whole tree harvesting aggravates puddling and increases the delivery of rain water to the soil, then rooting could be affected directly. In upland gley soils, roots are not usually able to penetrate more than 25 to 30 cm. into mineral soil before being inhibited by seasonally anaerobic conditions (Anderson,1985). If this rooting depth is reduced, stability will deteriorate and any structural improvements brought about by the trees will be lost. Oxygen flux measurements are being used to determine changes in depth to the limiting level following felling (Anderson,1985).

Studies have shown that organic matter particularly decayed wood, imparts important properties to forest soils such as moisture holding capacity. However, the contribution of wood residues to soil nutrient capital takes a very long period of time to actually materialise. For example, the incorporation of soil organic materials must be considered in the long term management process. Time lags of approximately 100 to 300 years occur between the time wood is produced on a forest site and the time it becomes incorporated into soil organic matter (Harvey *et al.*, 1981).

The lag periods for incorporation of forest residues into the soil are influenced by habitat type (Harvey *et al.*, 1981). This has a major influence on time period for an ecosystem to equilibrate with wood biomass concentrated as undecayed soilsurface residue or as extensively decayed materials incorporated into the soil profile.

Resource assessment and allocation require that all factors must be considered in decision making and that wherever possible these factors should be cost analysed. For example, the pros and cons of whole tree harvesting, or conventional harvesting, should be evaluated in the light of market information, current knowledge on the ecology of the systems involved and costs of the operations.

Having highlighted the importance of wood residues, their potential and their limitations, the rest of this chapter briefly examines the various methods used for their quantitative assessment in previous studies.

2.6 METHODOLOGY FOR QUANTITATIVE ASSESSMENT OF WOOD RESIDUES

The only method of assessing the quantity of mill residues reported in this review is by questionnaire survey, usually in the form of interview or mail questionnaire (U.C.N.W., 1974; Carruthers, 1975; Albanis, 1978; Albanis & Cooper,

1979a;1979b).

The use of this method has its merits and draw-backs, which have been the subject of good deal of research and debate. Perception, attitudes and opinions which can not be inferred by observation are accessible through interviews and mail questionnaire (Cannel & Kaln, 1957; ~~Cambell & Kutona~~ 1953; Courtenay,1978; ~~Cannel & Katz, 1953~~).

The major problems of interviews stem from the inability and the unwillingness of the respondents to give correct information requested in the questionnaire either due to loss of memory or lack of interest in the survey or even both. The limitation of this method to some aspects of this study has been rendered inevitable by the nature of data collection itself. In their studies, quantitative assessment of the amount and types of residues was achievable by questioning and relying on the information given. This is not possible to acquire with forest residues without actual measurement by the researcher in the field because forest managers rarely estimate the residues left on the forest. The quantity of forest residue can be estimated for a given area by summing up the values for individual trees within the area.

Turning to forest residues, estimates of biomass have been based on a whole tree approach (Rennie, 1966). This does not relate the main forest produce to its residues which is more meaningful to a forester.

Ovington and Madgwick (1959), Baskerville (1965)^{1970; 1972} and Atwill (1966) have all compared different methods of estimating the dry weight of stands of different species. Although their methods differed, they reached the same general conclusion that, because of different proportions of leaf, branch, trunk and root materials in different tree sizes, accurate estimation of weight of trees in a stand requires a number of trees to be sampled and these should be distributed over the range of tree sizes present. A tree of average bole dimension, they

claimed is unlikely to be average in terms of other components.

Van Wazer, 1968; Noren & Oslen, 1964).
Bailey (1969) used the line intersect technique for estimating the volume of logging residues. According to this method, residue volume could be estimated from two sets of sampling lines at right angles. The only variable requiring measurement was the mean cross sectional areas of residue pieces intersected by the sampling lines. This method was particularly suitable for both tractor and cable logged areas. The line intersect method, according to Martin (1976), is both time and cost saving yet providing reliable and unbiased estimates which are little affected by species, cutting type, slope, road influence and length of residue piece. It is particularly attractive to field personnel because it requires fewer decisions and gives them greater confidence than the fixed plot method. However it is disadvantageous for small areas such as the study areas for this exercise because a very long line is needed to obtain a reasonable precision. For example, to obtain a precision of $\pm 10\%$ of mean residue volume, a length of sample line should be about 680 chains (13.68 km.) in a mechanised clearfell site. Another disadvantage of this method is that its estimate can only be related to area and type of cut but not to a single stem.

The most recent method of assessing residues is the attempt made by Rollinson (1980) using an image analysing computer to estimate crown volume of open grown trees. The method is not fully developed and its application is apparently limited to open grown trees.

The study objectives will obviously affect the methods of data collection adopted. In this study interest is beyond just quantitative assessment, it includes qualitative assessment in relation to market requirements. A full consideration of forest residues in this way will add to the body of knowledge on their market potential.

2.7 HARVESTING OF FOREST RESIDUES

The conversion of bole wood to chips has normally been a mill operation but what is relatively new is chipping on or closer to the forest and chipping a larger part of the tree.

In the beginning of the 1970's several factors led to rapid development in the use of whole tree chips particularly in North America as an industrial raw materials (F.A.O.,1976b). Prominent among these factors were :

- (i) A rapid growth in demand for chips and local shortage of fibre sources;
- (ii) Environmental concerns for wasting natural resources and concern over the slash and its treatment methods such as burning;
- (iii) The search for raw material delivered at mill at lowest cost possible;
- (iv) The advent of equipment for whole tree handling and chipping.

By the end of 1975 almost 500 mobile chippers were sold in North America of which 300 were for field chipping and others were for stationary use on terminals or for urban use. These produced both whole tree chips and chips from forest residues (FAO, 1976a).

In Scandinavia countries, there is a general shortage of bole wood raw materials in relation to consumption capacity of forest industry and furthermore, increasing areas are reaching the age when the first thinning operation is required. Alternatives to the traditional labour consuming thinning methods are needed in high cost countries. For these reasons, whole tree utilisation research projects started about 1970 and it appears that relatively more research and many trials have taken place in Scandinavia compared to North America. Major practical approaches for harvesting more forest biomass have been:

- harvesting of stump and root wood;
- harvesting of residue (slash) left after conventional logging;
- chipping of the above ground part of the tree.

At many localities the forest residue left after logging is viewed as a huge disposal problem. Different slash treatment are carried out as discussed earlier (section 2.1), one alternative being conversion to chips usable for energy. Considerable research and feasibility studies have been and are still being carried, out for example in USA and Scandinavia (Grantham, *et al.*, 1974;).

The idea of converting stem bole into chips is still being considered in Britain as previous trials did not give encouraging results (Holmes, 1976; Lofthouse, 1978). However, it is envisaged that in the light of current development in technology for chip conversion in Scandinavia (Hakkila, 1984) and the potential use of green chips as a source of energy in distilleries and mills (Greig, 1985), a reconsideration of this idea in Britain is underway.

The economic consideration of residue procurement carried out in this study made use of the machinery output guides from Finland (Hakkila, 1984) since no local data were available.

2.8 SUMMARY AND CONCLUSIONS:

Available information on the state of wood residue production in UK reveals that a large quantity of industrial wood residues is being generated by wood industries annually. Studies on the production and uses of wood residues are largely restricted to mill residues without adequate consideration being given to forest residues. Methods of acquiring information used in these studies are interviews and mail questionnaires and no detailed economic evaluation of the potential of the residues is given.

Mill residues have market values which are influenced by their proximity to markets as well as their quality in relation to particular market requirements.

For the use of wood residues for particle board production the most important quality requirements are wood density, wood acidity, permeability, moisture content, bark content, length and thickness of flakes to be produced from the residues. The factors to be considered for fibre board are size of chips and species preference, the latter again being important in pulping.

For the energy market, mill and forest residues have enjoyed a long history of traditional use for fuel. In some parts of ~~the world~~ ^{they are} the main source of energy while in others they have been replaced by technologically advanced alternative sources. Wood is then relegated to a supplementary role.

Apart from allocating mill residues to the above uses, they may be disposed of burning or by being given away free of charge. Disposal methods for forest residues are burning, chopping or no treatment at all. In spite of the apparent potential of forest residues little consideration has been given to their use, perhaps due to their quality or to fear of the environmental consequences.

The removal of mill residues does not pose any threat to management; instead it may be economically essential to make a profit if such residues are marketable. This is contrary to forest residue disposal which often raises alarm because of the apparent environmental threat. Forest residues contribute to soil nutrients but this is not instantaneous for most residue types because it takes long periods for the decomposition of woody materials to take place. The current thinking in U.K. is that the most feared ecological effect of whole tree harvesting is not nutrient drain as such but soil compaction especially on gleyed soils. This may be overcome by using brash as a carpet during harvesting operations.

This study will therefore pay specific attention to forest residues, their quantitative and qualitative assessment coupled with economic assessment of their potential for particular markets. Thus, this study will quantify the types of residues usually available, i.e. both post conversion (which includes branches and tops) and post extraction residues (unextracted main produce and odd pieces). The quality factors such as density, moisture content, calorific value and tracheid of both the main produce and residues will be investigated, in order to see whether or not there is a significant difference between their values. The quantitative assessment of forest residue in this study has been based on the hypothesis that post logging residue excluding stumps can be estimated for a given area by summing up the values for individual trees within the area. These values can be expressed in terms of weight or volume.

The possibility of predicting the quantity of post logging residue by regression equation will be looked into with aim of finding the best predictor variables out of dbh, dbh squared (dsq) and produce weight (pwt). This will be based on the framework of biomass model already reviewed.

Finally, the consequences of harvesting residues already highlighted earlier will be considered. In this respect, the potential of site nutrient depletion will be estimated for an hypothetical situation, which will be translated into financial costs assuming all the nutrients removed from the site as a result of residue harvesting will be replaced by artificial fertilisers such as urea, rock phosphate and muriate of potash. The cost of procuring the residues as well as the potential value of the residue will also be put into consideration in the known benefit - cost analysis that follows.

CHAPTER THREE

METHODOLOGY

Both primary and secondary data were used to realise the objectives of the study. Secondary data had to be relied upon for some aspects of the study because of lack of time, finance and manpower to cope with deriving them primarily. The methods of study divide into the following three stages :-

- (i) desk research
- (ii) field work
- (iii) laboratory work.

3.1 DESK RESEARCH

This stage involved the collection of data from secondary sources i.e. those that have been collected previously and reported by someone other than the present researcher. As far as this study is concerned, preliminary information indicated the available data could not supply all of the required information. However, acquiring all the appropriate data would be too costly and time consuming to carry out every component part of the study. Therefore the experience and findings reported elsewhere have been modified and used with care to supplement the information collected and such sources are duly acknowledged.

3.2 FIELD WORK

3.2.1 General approach

It was initially planned that this study be carried out in randomly selected forests in South Scotland, covering different species, rates of growth, types of topography and harvesting techniques in order to relate residue production to each of these factors. This proved impracticable within the constraints of

accessibility, time and manpower available so the study was limited in scope to two species at two different sites.

Accessibility: The field work did not start until early autumn 1984 and ended in early spring, 1985. During this period, particularly the spring time, wet weather prevented regular logging operations and detailed residue assessment from taking place at the chosen site.

Manpower: The initial part of the study was undertaken single handed. The detailed measurements involved were rather cumbersome without field assistance, thus a longer time was spent on measuring the required number of trees.

Forest operation schedule: Since the success of the study depended on the cooperation received from the Forestry Commission, the decisions on study site and species had to be taken to suit their felling programme.

Sampling in the forest:

This stage of the study was concerned with collection of data from the forests for the quantitative and qualitative assessment of post logging residues. Ideally the best method of acquiring data about forests is to undertake a measurement of the whole population possessing the attributes under investigation. In practice, this is only practicable where the population is both small and readily accessible (Jeffers, 1969). Hence, there was a need for sampling. The forest wood residue assessment was carried out in three phases namely a preliminary pilot exercise, the main study of post conversion residues and the assessment of post extraction residues (together termed 'post logging' residues). These phases are described in Section 3.3.

3.2.2 Definition of study areas:

This study was carried out in the Elibank and Glentress blocks of the Forestry Commission's Lothian and Tweed Forest District, Scotland.

Elibank Forest

A pilot exercise was conducted between September and October 1984 in Compartment 52. The compartment is about 380m. above the sea level and the soil is an imperfectly drained fine loamy brown earth, the terrain having an even roughness and very steep slope (Forestry Commission, 1971).

The crop was an even aged mixed stand of Sitka spruce and Scots pine (*Pinus sylvestris* L.) (*Picea sitchensis* (Bong.) Carr.) planted in 1952. The stand had received no silvicultural treatment so that the spruce had suppressed the pine resulting in irregular spacing due to high mortality of the latter. Because of the lack of thinning the stocking was high with an average of 26 trees per 0.01 ha. plot. The whole area was being clear felled, the produce being sorted into sawlog, pallet and chipwood lengths for extraction by forwarder.

Glentress forest:

The main study was carried out in compartment 1025E which is about 320 metres above the sea level. The soils comprise freely drained coarse loamy and fine loamy brown earths and podzols and the terrain has an even roughness with moderate slope (Forestry Commission, 1971).

The crop was pure Scots pine planted in 1933 which, unlike the Elibank stand, had been thinned and brashed. The area was clearfelled soon after measurement took place, with conversion at the stump into the same produce as in Elibank. The expected proportions of produce harvested were 28% saw log, 42% pallet logs and 30% chipwood lengths.

3.2.3 Choice of sampling methods:

When preparing a sampling scheme the following points should be considered:

- (i) stratification of the area,

- (ii) allocation of sample unit by stratum area,
- (iii) use of systematic or random sampling units,
- (iv) the required number of sampling units to give a desired level of precision,
- (v) size and shape of the sampling units.

Area subdivision becomes necessary only if the population to be sampled has high variability. The greater the population variability the higher the sampling cost. Stratification of the population was necessary at the study site at Elibank forest, based on diameter at breast height. It was not necessary in the Glentress forest site in the uniform stand of Scots pine. Thus stratified random sampling was used for the pilot study, ^{because of size and species variability of the crops} while three main sampling techniques were used in ^{the} main study. The pilot exercise indicated no significant difference between the mean values of total residue weight per tree obtained from sample plots and plot mean trees. Therefore individual tree measurements were used in the main study.

Three techniques were used to locate the trees for measurement in the main study area : a systematic grid line transect, a systematic plot mean tree approach and a random plot mean tree approach. This was done to test the effect of sampling technique on the assessment of forest residues by comparing their estimates per hectare in terms of precision and cost in time. A comparative study was considered necessary because one of the main problems of estimating forest residues is that the exercise has proved to be too cumbersome and unappealing to foresters. The first two sampling methods used were systematic and the third random in principle. The statistical difference between the two centres around ^{the} element of randomisation, which is lacking in systematic sampling but is always assumed in the test of significance

and estimation of confidence limits. In random sampling the element of sample unit, randomisation is always present because selection of plot is based on the theory of equal probability of selection (Jeffers,1960; Husch, et al,1982; Freese,1962). This means that each sample unit has an equal chance of being selected, thus consistency eliminates bias and enhancing the possibility of estimating precision. However systematic sampling is frequently used in practice and can give a more representative sample (Bitterlich,1984).

Apart from the difference in statistical principle, the method used can be divided into either fixed area plots and non-fixed area plots e.g. the grid line transect. In the case of fixed area plots, the selection of the most suitable plot shape and size is a factor which may influence considerably the precision of the surveys. In this study, circular plots of 0.01 ha. were chosen since this was considered an appropriate size for the range of crop types envisaged.

A circular plot has the advantage of minimum perimeter per unit area and small size has the advantage of statistical efficiency, which is increased by decreasing the size of sampling unit and increasing the number of units measured in a population (Jeffers,1960; Freese,1962; Husch,1971 & Hamilton,1975).

3.3 FIELD MEASUREMENTS

The measurements taken in the field in order to achieve the first two objectives (Section 1.3) were the produce volume, tree size (i.e. diameter at breast height over bark) and weight of branches and stem tops. The weight of the produce was obtained indirectly by taking discs to determine density.

Weight measurement is a useful means of quantifying produce for sale i.e. where payment is made in terms of price per tonne. It is becoming an important method for measuring forest produce although mainly confined to bulk supply

of small round wood (Hamilton,1975). Weight may be obtained indirectly from known volume and density.

The use of weight for quantifying residues in this study was considered appropriate because it is very suitable for the small sized residues being investigated. One drawback is that variability in timber density could result in less reliable data if some measurements are of volume converted to weight.

The green weight (GWT) of branches and stem tops of trees was measured in the field and oven dry weight (OWT) was determined in the laboratory from sample material.

3.3.1 Preliminary study:

This was carried out at Elibank forest block with the following aims:

- (i) To assess the practicability and adequacy of the proposed methods,
- (ii) To identify potential field constraints and tackle them before the commencement of the main study.
- (iii) To determine the optimum sampling schemes for forest residue estimation to a desired precision.
- (iv) To identify further improvements, if any, that could be made to make the study a success.

Ten circular plots of 0.01 ha. each were laid down randomly within Compartment 52. Eight sample trees were chosen to cover the dbh distribution because the unusually high stocking density made it impracticable to measure all the trees in each plot.

All trees within the plots were marked by spraying for ease of recognition and their diameter at breast height over bark (dbh) was measured with a diameter tape. Measurements were taken to the nearest 1 cm (rounded down diameter class) and recorded on the data collection sheet (Appendix 3.1).

Each sample tree was felled by a chainsaw operator who also did the snedding and conversion into main produce pieces according to standard logging and safety conventions. These pieces were of varying diameter but were all of standard lengths i.e. 4.9 - 5.1 metres for sawlogs, 2.5 metres for pallet logs and 2.0 metres for chip wood logs. Length and mid diameter of the main produce pieces were measured for volume calculation according to Huber's formula (Husch et al, 1982).

Measurement of the residue was limited to branches, stem tops and the foliage. The stump was not considered because of the observed high standard of felling convention that did not allow any significant proportion of the merchantable stem as stump.

A 10 kg. weighing balance was suspended on a strong rope fastened to two standing trees. The branches on each whorl ^{were} bundled together and the stem tops were in turn hooked to the balance and their weights recorded to the nearest 0.1 kg. on data sheet (Appendix 3.2).

3.3.2 The main study

Experience gained from the preliminary study showed that the method used was cumbersome and time consuming and therefore unsuitable as a means of qualitative assessment needed to achieve the first two objectives (Section 1.3). Three sampling techniques were therefore compared as mentioned in section 3.2.3 and these are described fully in the following sections. They differ from each other only in the methods of selecting the sample tree, while the same measurements were carried out on all sample trees.

Data were collected from a total of 353 trees measured by using each of the following sampling techniques:

(i) Systematic Grid Line Transect (SGLT)

A square grid of approximately 30m. x 30m. was laid out over the area by pacing with the aid of a compass, the base line being chosen carefully to maximise the number of grid points in the stand. The trees selected as sample trees were those which lay closest to a grid point irrespective of their size ; grid points less than 2m. from the stand boundary were rejected to minimise edge effects.

Every tree selected was marked with blue tape, labelled and its breast height diameter measured and recorded on data collection sheet A3 (Appendix 3). In all, 33 trees were selected for sampling and the time spent on locating the trees as well as measuring the dbh was recorded.

(ii) Systematic Plot Mean Tree (SPMT)

This involved laying out 0.01 ha. circular plots at every grid point, using the grid transect tree i.e trees already tagged with blue tapes, as the centre of each plot. The dbh of every tree within the plot was measured and recorded. The quadratic mean dbh was calculated in the field on a pocket calculator and the tree with or closest to this figure was selected and marked as the plot mean tree. Thirty one plot mean trees were selected out of 240 sample trees measured and all the plot mean trees were tagged with red tape and labelled for easy identification with code numbers. The time spent on this exercise was recorded.

(iii) Random Plot Mean Tree Approach (RPMT)

This differed from (ii) above by the way in which the plot centres were located. Random numbers (from standard tables) were chosen between 1 to 29 for both x and y coordinates of each grid square before going into the stand ; this will enhance more efficient randomisation (Jeffers, 1960). Plot centres were located by pacing with the aid of a compass from the grid points marked by the blue band^{ed} trees. Sample plots were laid out and measured as in the systematic

plot mean tree approach. Once the plot mean trees had been identified they were tagged with white tape.

Data collection:

All sample trees regardless of the method of selection, were felled and converted by a Forestry Commission operator as in the pilot study. The quality and quantity of the branches, were recorded under two categories, dead and live branches (Bunce, 1968 ; Whittaker & Woodwell,1968) and each category was sorted out into the following size classes:

Class1 less than 3.0 cm. base diameter

Class2 3.1 to 5.0 cm. base diameter

Class3 5.1 to 7.0 cm. base diameter

Class4 greater than 7.0cm.base diameter

The range of size class was chosen arbitrarily, with a view to providing information which could later be related to harvesting. The number of branches belonging to each of the above classes was counted and recorded in record sheet A4 (Appendix 3.2). Representative branches were picked randomly from each class for weighing, using the 10 kg. weighing balance as before. The stem tops were also weighed in the same way.

Samples of branches from each category and class together with discs cut from the lower part of the stem as well as ^{the} stem top were collected and wrapped in foil paper to prevent loss of moisture, put in black cellophane bags and brought to the laboratory for further quality assessment.

Time study was conducted on the conversion of the stem top and large branches which otherwise would have been left as residues to give an indication of the extra time that would be spent converting these residues.

3.3.3 Assessment of post extraction residue:

The aim of this was to quantify the main produce and the odd pieces left after a normal extraction from the site to the road side. Odd pieces comprise sound woody material of at least 5cm diameter and 0.5m long. The practice of bench felling and stacking of the produce in strips alternating with brash strips to aid extraction often means that some main produce is also not extracted. The produce from both study sites was not extracted until five months after felling, and the length of this period may have some effect on the quantity of converted produce left on site.

At both Elibank and Glentress study areas, rectangular plots 10m. wide and of varying length were laid out, systematically after the produce had been extracted. The lengths and mid diameters of the odd pieces and left overs from the main produce were measured and recorded (Appendix 3C). The dry weight of these was indirectly calculated from their volume and density, discs being taken back to the laboratory for density determination.

3.4 LABORATORY WORK

The aim of this aspect was to assess the residue with respect to certain properties which are important for assessing its market potential, namely moisture content, green density and basic density ^(as defined on page 5). In order to determine moisture content of the stem wood from the main produce, stem top and branches, discs of 1.5 cm. thickness were cut from these component parts and oven dried to a constant weight at 103^o C. The samples were weighed every 24 hours until there was no difference in at least three consecutive weightings. Three diameter and thickness measurements were recorded in order to estimate volume. Using the fresh weight recorded in the field the moisture content was determined, using the formula :

$$MC=(W-w)/w \times 100 \text{ (Hamilton, 1975) ;}$$

where MC is the % Moisture Content, W is the green weight, and w is the oven dry weight. Densities were calculated from the relationship between volumes and weights. Conversion ratio which is the ratio of green weight to oven dry weight, was used for converting the fresh weight to dry weight.

Tracheid length and dirt content were not considered for empirical measurements because of lack of time. A brief review of the relevant conclusions from past work on variation of fibre length is presented in chapter four. Also, standard figures on calorific values for the component parts of both species covered in this study were obtained from the literature.

CHAPTER FOUR

QUANTITATIVE AND QUALITATIVE ASSESSMENT OF POST LOGGING RESIDUES

RESULTS AND DISCUSSION

This chapter opens with a discussion of the sampling techniques (3.2.2) used in assessing the quantity of post logging residue, particularly the number and choice of the individual sample trees, with the aim of finding ^{the} most suitable techniques in terms of precision and costs. The quantity of residues are presented both in green and dry weight per hectare and are divided into two broad categories, namely the post conversion and post extraction residues. Finally, the quality of various types of residues namely tops, live and dead branches are assessed in terms of moisture content, green and basic density, with supplementary information obtained from published data on calorific value and fibre length.

4.1 SAMPLE DESIGN

The results presented in this chapter are from both study areas (3.2.2).

4.1.1 Comparison of methods:

Because of the high stocking at Elibank (2,600 stems per hectare resulting in an average of 26 trees per 0.01 ha plot) it was necessary to find a solution to this excessive number of stems to be sampled per plot. A comparison of residue weight obtained from whole plot data and plot mean tree data was carried out for the 10 sample plots, using paired t-tests to check whether the difference between the two methods was statistically significant.

Although all the values of mean tree residues obtained from whole plot data are higher than those using the plot mean tree, the differences are not significant at 95% level of probability (Table 4.1). This result confirms the

findings of the previous workers (Atwill,1966; Madgwick,1969; Rennie,1966) that the plot mean tree method underestimates the variables being measured since the mean tree is not necessarily average in terms of other components. The main advantage of the plot mean tree method is that it is much quicker, reducing the sampling time by a factor dependent on the number of trees in the sample plot since only one tree is measured per plot. Thus, the plot mean tree method was adopted inspite of the fact that it slightly underestimates residue quantity.

4.1.2 Sampling Intensity:

The number of sample trees required to estimate mean tree residue weight at two suitable levels of precision was computed for pure and mixed stands (Table 4.2). Sampling intensity is influenced by stand variability. Since there was no information on the variability within the stand the preliminary exercise using 10 sample plots was undertaken to estimate an appropriate sample size determined by the following formula:

$$N = \frac{CV^2 t^2}{A^2}$$

where N is the sample size, CV, the coefficient of variation in percentage, t the student's t-value and A the desired level of precision expressed in terms of confidence limit as percent of the mean. This preliminary exercise was used to give a rough guide for the number of trees to be sampled in both pure and a mixed stands.

Two things are shown to have an effect on the sampling intensities (Table 4.2), first the nature of the stand i.e. whether pure or mixed and secondly the level of precision desired. More samples are required in mixed stands than in a pure stand. Also the higher the precision required the higher number of trees to be sampled. The cost of sampling trees for the purpose of quantifying total

Table 4.1 Comparison of mean residue green weight (kg. per tree) obtained from whole plot and mean plot tree sampling methods.

Residue type	Plot average value	Mean plot tree value	Calculated t value	t(p=0.05)	Level of sig.
Stem tops	5.3	5.2	0.078	1.994	n.s
Live branches	46.2	37.4	0.750	1.994	n.s
Total	51.6	42.6	0.727	1.994	n.s

n.s means not significant at 95% level of probability

Table 4.2 Sampling intensities for estimating individual trees* residue within 90% and 95% confidence limits

Stand	Estimated nos. of trees required:	
	90% CL.	95% CL.
Mixed Sitka spruce & Scots pine	149	595
Mixed (Sitka spruce only)	55	219
Pure Scots pine	19	76

* Average of all sample plot trees for the mixed stand in Study Area 1

mean basal area tree for Scots pine sample plots in Study Area 2

CL Confidence limit

residue per tree with 95% confidence limit (CL) is about four times that of sampling with 90% CL regardless of the nature of the stand. Also, in this case, sampling a mixed stand requires three times more samples than for a pure stand. These points were taken into consideration in the main study where sampling at 90% CL was considered satisfactory since it was carried out in pure stand of Scots pine.

4.1.3 Location of Individual Sample Tree:

Three sampling techniques were used in the Scots pine stand to locate individual trees namely : systematic grid line transect, systematic plot mean tree and random plot mean tree (3.3.2). The quantities of tops and branches per tree estimated by each sampling technique are presented in Table 4.3. These values were compared by t-test (Table 4.4) and there was no statistically significant ^{difference} between them.

In order to determine the quantity of residue per hectare using the three sampling techniques, the number of trees per hectare was computed. For the systematic grid line transect this was estimated by using the distance between the sample tree and its third nearest neighbour while for the two plot mean tree techniques stocking was obtained from the number of trees per plot.

The mean total residue per hectare by the systematic plot mean tree technique gave the highest value while the lowest value per hectare was given by the systematic grid line transect technique (Table 4.5). When the mean values were compared using the paired t-test there was no statistically significant ^{difference} between them (Tables 4.5 & 4.6).

Since the mean values for these techniques were not statistically significant they were then evaluated using the time factor (which is related to cost) as the only criterion for this purpose. A breakdown of the time taken to select individual sample trees for residue measurement is given in Table 4.7. The total

Table 4.3 Mean total residue weights per tree, and standard errors (S.E.) for three sampling techniques used in Scots pine

Sampling technique	No. of trees sampled	mrw (kg.)	S.E. (kg.)
SGLT	31	62.5	5.63
SPMT	31	65.6	4.59
RPMT	21	64.7	5.18

mrw - mean total residue weight per tree (kg. green weight)

SGLT - systematic grid line transect

SPMT - systematic plot mean tree

RPMT - random plot mean tree

Table 4.4 Comparison of mean total residue weights per tree obtained by three sampling techniques in Scots pine

Techniques compared	actual t value	t (p=95%)	remarks
SGLT & SPMT	0.409	2.000	n.s.
SGLT & RPMT	0.276	2.011	n.s.
SPMT & RPMT	0.124	2.011	n.s.

Table 4.5 Gross residue production per hectare estimated by three sampling techniques in Scots pine at Study Area 2

Sampling technique	mrw	N	GRW
Systematic grid line transect	62.5	666	41.7
Systematic plot mean tree	65.6	728	47.8
Random plot mean tree	64.7	686	44.9

mrw _ mean total residue weight per tree (kg., green weight)

N _ estimated number of stems per hectare

GRW _ gross residue weight per hectare (tonnes, green weight)

Table 4.6 Comparison of mean total residue per hectare obtained by three sampling techniques in Scots pine at Study Area 2

Techniques compared	Calculated t	t (p=95%.)	Remarks
SGLT & SPMT	1.364	2.000	n.s
SGLT & RPMT	0.642	2.011	n.s
SPMT & RPMT	0.607	2.011	n.s

SGLT _ systematic grid line transect

SPMT _ systematic plot mean tree

RPMT _ random plot mean tree

Table 4.7 A breakdown of time taken to select individual sample trees
for residue measurement by three sampling techniques
Times to the nearest 0.1 minute

Sampling technique	T1	T2	T3	T4	TOTAL
Systematic grid line transect	0.8	n.a	1.2	n.a	2.0
Systematic plot mean tree	0.8	6.2	n.a	5.4	12.5
Random plot mean tree	2.4	6.2	n.a	5.5	14.0

- T1 - average time taken to locate either plot centre or grid point tree
excluding laying out of the grid which was common to all three techniques
- T2 - average time spent to lay out plot and measure dbh of all plot trees
- T3 - average time taken to identify and measure the third nearest tree
- T4 - average time taken to identify plot mean tree (tree with mean basal area)



sampling time per tree was least for the systematic grid line transect and highest for the random plot mean tree technique. This is because in the former, the selection of ^{the} sample tree is predetermined while in the latter three times more ^{than} ~~the time~~ ^{on the former} was spent on locating plot centres (T1) using random coordinates from each grid point.

In order to quantify forest residues the choice of sample trees must be simple, precise and economical as the detailed measurement of each tree is time consuming. Any of the three techniques used is adequate, providing similar levels of precision, but the systematic grid line transect is the cheapest. In addition it is relatively easy to apply, for example in difficult sites such as the mixed stand of Sitka spruce and Scots pine which could not be penetrated easily because it was not brashed. The more difficult the study site is, the more necessary it is to simplify working methods.

4.2 RESIDUE QUANTITY

4.2.1 Gross residue production:

In order to present the results the residue produced after clear felling is categorised into post conversion and post extraction residues. The tops and branches, which are the materials usually left after a felled stand has been converted into appropriate produce, constitute the post conversion residues. Materials intended for extraction but left behind and odd pieces that could not be harvested because of their form (e.g. bent sections of stem) make up the post extraction residues.

The average quantity of post conversion residues per tree was obtained and used for estimating the amount produced per hectare (Tables 4.8 and 4.9). In both species studied, the branches produced over 90% of the post conversion residues on a clear felled site, the remainder being the stem tops less than

Table 4.8 Post conversion residue for Sitka spruce at Study Area 1 :

(i) green weight and (ii) dry weight

Residue type		mrw	S.E	Rt.	Rha.	GRW
Tops	(i)	5.32	0.319	1.30 - 13.20	3.38 - 34.32	13.84
	(ii)	2.02	0.121	0.49 - 5.02	1.27 - 13.05	5.25
Branches	(i)	46.21	4.621	4.29 - 186.21	11.54 - 483.60	120.15
	(ii)	17.56	1.756	1.63 - 70.76	4.24 - 183.98	45.66
Total	(i)	51.50	4.937	5.58 - 199.42	14.58 - 518.50	133.97
	(ii)	19.58	1.877	2.12 - 75.78	5.54 - 197.03	50.91

Number of trees per hectare is 2,600

mrw _ mean total residue weight in kg. per tree derived from plot

Rt. _ range of total residue weight } average tree values.

Rha. _ range of total residue in tonnes per hectare

GRW _ gross residue weight in tonnes per hectare

7 cm in diameter. The range of post conversion residue produced per tree shows a clear positive relationship with tree size i.e. as tree size increases the quantity of residue increases (fig. 1).

The total production of post extraction residue ranges from 1.83 to 9.91 dry tonnes per hectare for Sitka spruce (Table 4.10) and from 1.13 to 15.66 tonnes per hectare for Scots pine (Table 4.11). The quantity of converted but unextracted material is a significant proportion (about 50%) of the total post extraction residue in the Sitka spruce but this drops to about 20% in the Scots pine. The probable reason for the high value of this residue type at Elibank forest is that extraction of the main produce to roadside is not fully efficient. This is particularly so where trees are felled, converted and stacked by one person (chainsaw operator) and are later extracted by another person (forwarder operator).

Tables 4.12 and 4.13 relate the different residues to the main produce for both Sitka spruce and Scots pine. In both cases the percentages of their post conversion residue are greater than that of post extraction residue but in particular, this is higher in Sitka spruce (28%) than in Scots pine (24%). The percentage of post-extraction residue (4%) is several times more in Sitka spruce than in Scots pine (1.4%). Unextracted main produce constituted 2% of ^{the} main produce in Sitka spruce and 0.4% in Scots pine. Given the overall percentage of residue compared with harvested main produce, material currently termed as 'waste' can no longer be ignored as the cost of production particularly labour and machinery increases.

The converted but unextracted material represents a twofold financial loss to the forest manager in market value lost and payments made for its felling and conversion. From observation in the field, this material was most often covered by brash with some parts being partially exposed. The remainder of the post

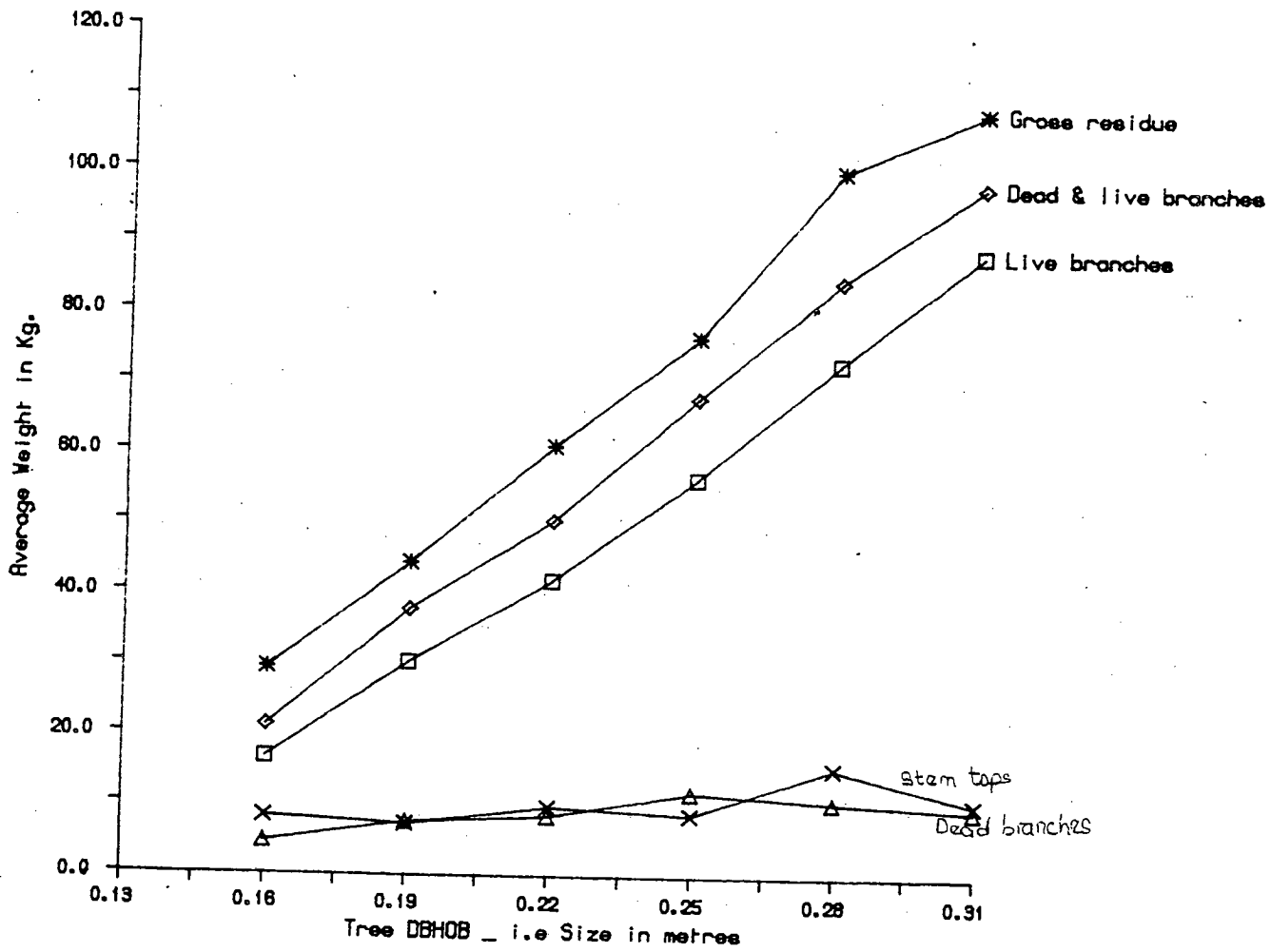


Fig 4.1 Relationship between mean residue fresh weight (kg. per tree) and tree size for Scots pine.

extraction residue comprises odd pieces which represents a potential financial loss if they could be utilised.

An overview of gross production which represents the amount of fibre material available from the above ground parts of a tree (excluding the main produce) shows that the production of post conversion and post extraction ^{residues} are 21% and 3% respectively for Sitka spruce; 21% and 1% for Scots pine (Table 4.14). This indicates that the gross production of residues depends mainly on the branches and tops (Tables 4.12 & 4.13).

4.2.2 Implications of residue productions:

The quantity and type of residue (type being related to quality as discussed in section 4.3) varies with tree size (fig.1). As tree size increases, the gross production and the quality of residues (particularly the live branches) increases i.e. bigger trees produce a higher quantity of better quality branches and have good potential for marketable residue production.

It is important to note that this study deals with both the quantity and type of forest residue. Both (the quantity and types of residue) have an impact on reforestation techniques, aesthetics, environmental quality (e.g. nutrient distribution), wildlife habitat, stand management and fire hazard. Various forms of residue provide materials for the development and function of forest soils, Harvey *et al* (1981). Organic matter provides either the environment or the energy source for a variety of microorganisms which are central for continued site productivity. Of the many organic materials added to forest soils during a stand rotation, the woody component is in many respect the most important Harvey *et al* (1981). To protect the productive potential of forest soils,

a continuous supply of organic material must be provided. Substantial increases in utilisation intensity, extremely hot wildfire or excessive site preparation could reduce stand productivity particularly on cold or dry sites.

On the other hand, excessive volumes of forest residue can result in significant management problems, creating a fire hazard, inhibiting wildlife use, detracting from aesthetic quality, interfering with regeneration, and requiring costly disposal treatments.

Given the above relationships, a measure of residue production is important in the broad context of forest management. However, the impression given to the author by woodland manager in the study areas as to why residues are left behind to decay and decompose is not primarily to improve soil fertility but that they are of unmarketable size.

The gross quantity of residue per unit area is likely ^{to be} greater for clear fell logging than for thinning because the former involves a larger number. The expression of gross residue per unit land area is valuable for production forecasting, economic assessment and evaluating residue management alternatives such as equipment requirements, for example, and the cost of handling and transporting residue. This is dealt with in chapter six. Overall residue production for both study sites is summarised in Tables 4.14 and 4.15.

Table 4.9 Post conversion residues for Scots pine at Study Area 2 :

(i) green weight and (ii) oven dry weight

Residue type		mrw	S.E	Rt.	Rha.	GRW
Tops	(i)	8.24	0.578	1.0 - 28.80	0.68 - 20.10	6.44
	(ii)	3.38	0.237	0.41 - 11.89	0.28 - 8.24	2.65
Branches	(i)	48.79	2.928	8.08 - 170.89	5.61 - 118.43	33.82
	(ii)	29.76	1.786	4.93 - 104.24	3.42 - 72.24	20.28
Total	(i)	57.03	3.506	9.08 - 199.69	6.29 - 138.53	40.28
	(ii)	33.14	2.023	5.34 - 116.13	3.70 - 80.48	23.28

mrw _ mean total residue weight in kg. per tree derived from plot

Rt. _ range of total residue weight } plot mean tree values.

Rha. _ range of total residue in tonnes per hectare

GRW - gross residue weight in tonnes per hectare

N - stocking per hectare (666 trees per hectare)

Table 4.10 Post extraction residue for Sitka spruce in
tonnes per hectare

Residue type	Green weight in tonnes/ha.			Dry weight in tonnes/ha.		
	Mean	SE	Range	Mean	SE	Range
Unextracted MP	8.79	0.703	3.92-12.08	3.34	0.267	1.49-4.59
Odd pieces	7.71	0.539	0.89-14.00	2.93	0.205	0.34-5.32
Total	16.5	1.22	4.8-26.08	6.27	0.472	1.83-9.91

Table 4.11 Post extraction residue for Scots pine in tonnes per hectare

Residue type	Green weight in tonnes/ha.			Dry weight in tonnes/ha.		
	Mean	SE	Range	Mean	SE	Range
Unextracted MP	0.44	0.081	0.26- 0.73	0.21	0.039	0.12- 0.35
Odd pieces	1.83	0.142	1.85-30.38	0.87	0.068	1.01-15.31
Total	2.27	0.223	2.11-31.11	1.08	0.117	1.13 15.66

MP - Main produce

Table 4.12 Percentage analysis of residue in relation to main produce harvested from Sitka spruce at Study Area 1

Material	Weight as % of merchantable bole i.e. to 7 cm. minimum top diameter over bark	
	Weight in dry tonnes/ha.	%
Main produce (MP)	182.0	
(i) Post conversion		
Tops	5.3	3
Branches	45.7	25
Total (i)	51.0	28
(ii) Post extraction		
Odd pieces	2.9	2
Unextracted MP	3.3	2
Total (ii)	6.2	4
Overall total (i) + (ii)	57.2	32

Table 4.13 Percentage analysis of residue in relation to main produce harvested from Scots pine at Study Area 2

Material	Weight as % of merchantable bole i.e. to 7 cm. minimum top diameter over bark	
	Weight in dry tonnes/ha.	%
Main produce (MP)	79.8	
(i) Post conversion		
Tops	2.65	3
Branches	20.28	25
Total (i)	22.93	28
(ii) Post extraction		
Odd pieces	0.9	1
Unextracted MP	0.2	0.4
Total (ii)	1.1	1.4
Overall total (i) + (ii)	23.2	29.4

Table 4.14 Percentage analysis of residue in relation to total
above ground biomass for Sitka spruce & Scots pine

Residue	Wt.in tonnes/ha.	Total biomass*	%
Sitka spruce			
Post conversion	51.0	239.3	21
Post extraction	6.3	239.3	3
Total	57.3		24
Scots pine			
Post conversion	22.1	103.0	21
Post extraction	1.1	103.0	<1
Total	23.2		22

* Above ground biomass (i.e. produce + residue) in tonnes/ha.

Table 4.15 Overall residue production for Sitka spruce (tonnes per hectare)

Residue type	GREEN WEIGHT (tonnes/ha.)			DRY WEIGHT (tonnes/ha.)		
	Mean	SE	Range	Mean	SE	Range
Post conversion	133.97	12.836	14.51-518.49	50.91	4.878	5.54-197.03
Post extraction	16.5	1.247	4.82- 26.08	6.27	0.474	1.83- 9.91
Total	150.47	14.083	19.33-544.57	57.18	5.352	7.37-206.94

Table 4.16 Overall residue production for Scots pine (tonnes per hectare)

Residue type	GREEN WEIGHT (tonnes/ha.)			DRY WEIGHT (tonnes/ha.)		
	Mean	SE	Range	Mean	SE	Range
Post conversion	40.28	3.5	6.29-138.53	23.28	2.023	5.34-116.13
Post extraction	2.27	0.194	0.62- 8.75	1.08	0.107	0.29- 4.16
Total	42.55	3.694	6.91-147.28	24.36	2.13	5.63-120.29

4.3 RESIDUE QUALITY

The qualitative assessment of forest residue is necessary for marketing purposes; there is a general belief that size is the most limiting factor against residue ^{marketability} (Higginbotham, 1979). The aim of the qualitative assessment was to find out whether or not the materials left behind are qualitatively different from those removed for sale, apart from their size.

In this analysis which is restricted to Scots pine in Study Area 2, the characteristics considered include those that were determined directly - moisture content, green and basic density and those which were obtained from published data - calorific value and fibre length. Each of these are treated separately.

4.3.1 Measured physical characteristics:

There is variation in the physical characteristics within a tree particularly between the main produce (i.e. the merchantable stem wood) and the residue types (i.e. tops, live and dead branches) (Table 4.17). Generally the fresh moisture content and green density are highest for stem tops compared with the main produce and branches but the reverse is true for basic density. This is because of the juvenile nature of the wood being formed at the top of trees. The fresh moisture content of live branches is twice that of dead branches.

The mean values obtained for each of these characteristics were compared by t-test at 95% level of probability (tables 4.18, 4.19 and 4.20). Although the moisture content of the main produce is higher than that of the live branches, the difference is not significant whereas the moisture content for stem wood is significantly different from that of the tops and dead branches (Table 4.18). The differences in green density between the main produce, tops and live branches are very slight and not significant. It is only the 'green density' of the dead

branches that is lowest due to their low moisture content (Table 4.19).

Since the green density of a tree is affected by its moisture content (Hamilton, 1975), the basic density^(page 5) is a better indicator of the amount of biomass obtainable from a given residue type. The values obtained for^{the} basic density of the main produce and^{for} the different residue types are very close except for the stem top. This becomes more obvious in a t-test which shows a highly significant difference in mean basic density between main produce and stem top (Table 4.17). Thus, although the stem top is a probable material to be considered for sale, particularly if the branches are smaller in size than the tops, it is of lower quality than branches in terms of moisture content and basic density.

4.3.2 Tracheid length:

The measurement of tracheid length for different types of post logging residue could not be made because of time. However many investigations have been carried out on the variation of tracheid length within a tree. This brief presentation is a summary of relevant parts of comprehensive reviews on the subject written by Dinwoodie (1961) and Spurr *et al* (1954).

Sanio started the pioneer work on this subject and his findings were later referred to as laws by Bailey and Shepard (1915). These laws formed the basis for subsequent discussion. Of the four laws, two are very relevant to this study and these were quoted in the English translation:

1. "The final size of the tracheids in the stem increases from the bottom towards the top; at a definite height it reaches a maximum and then decreases towards the crown"
2. "The final size of tracheids in the branches is less than in the stem but depends upon the latter in that those branches which arise at such a stem

Table 4.17 Physical characteristics of main produce and residues for Scots pine

Type	Fresh moisture content(%)	Green density (gm./cc.)	Basic density (gm./cc.)	CF
Main produce	112 ± 4.5	0.88 ± 0.042	0.42 ± 0.021	0.48
Stem top	144 ± 4.3	0.89 ± 0.024	0.36 ± 0.009	0.41
Live branches	101 ± 2.9	0.84 ± 0.016	0.42 ± 0.006	0.51
Dead branches	50 ± 6.2	0.66 ± 0.026	0.44 ± 0.001	0.70

mean values ± standard error (S.E)

CF _ conversion factor from green weight to dry weight

Table 4.18 Comparison of fresh moisture content of main produce and residue Scots pine at Study Area 2

Type compared	Moisture content (%)				
	MP	residue	t value	t(p=95%)	remark
Produce & top	112	144	4.902	2.038	0.1%
Produce & live branches	112	101	1.502	1.974	n.s
Produce & dead branches	112	50	5.600	2.011	0.1%

MP - main produce

n.s _ not significant at 95% probability level

Table 4.19 Comparision of green density of main produce
(merchantable stem) and residues from Scots pine

Types compared	Actual t*-value	t(p=95%)	Remarks
Produce & tops	0.231	2.038	n.s.
Produce & live branches	1.052	1.974	n.s.
Produce & dead branches	4.722	2.011	1%

* based on mean values in Table 4.14

Table 4.20 Comparision of basic density of main produce
(merchantable stem) and residues from Scots pine

Type compared	Actual t*-value	t(p=95%)	Remarks
Produce & tops	2.837	2.038	1%
Produce & live branches	1.947	1.974	n.s.
Produce & dead branches	1.061	2.011	n.s.

* based on mean values in Table 4.14

height that the stem tracheids are larger, themselves have larger cells than those branches which arise at a stem height where the cell size is less".

The relationship between tracheid length and height can be studied from two different perspectives. These correspond with two vertical sequences of rings in the tree i.e either a single ring is followed upwards or rings at fixed number from the centre be traced upwards (Dinwoodie,1961).

The tracheid length within a growth ring increases upwards for a certain distance before decreasing progressively to the top of the tree. The average length at the top of each ring is generally less than those at ground level.

Sanio first put forward this relationship between tracheid length and the height of each growth sheath for Scots pine (*Pinus sylvestris* L.). According to him, the position of maximum tracheid length is related to that part of the trunk where colour and texture of bark change from being relatively thick and greyish brown to a yellowish brown bark. This pattern of tracheid length variation has been verified by many workers for a wide range of species e.g. Hartig (1892) for *Picea abies* (L.) Karst. ; Bertog (1895) for *Abies alba* (Mill.) and *Picea abies*; Omeis (1895) for *Pinus sylvestris* ; Bailey and Shepard (1915) for *Pinus palustris* (Lind. & Gord.) , *Pinus strobus* (L.) and *Abies concolor* (Lind. & Gord.) ; and Mork (1928; Schultze-Dewitz, 1959) also for *Picea abies*.

A number of workers have recorded the percentage height at which tracheid length is maximal in each growth ring. Among them is Halender (1953) who recorded that in *Pinus sylvestris* and *Picea abies*, the maximum cell length occurs between 15% and 40% height from the ground.

With regard to variation in tracheid length in different tree components, the few investigations carried out to determine the relative length of cells in branches and roots compared with the trunk showed that fibres from branches are shorter than those of the trunk; Sanio (1872), Baranitzky (1901), Hata (1949), Gleaton & Saydah (1956).

Sanio (1872) found that although branch fibres were shorter than the stem fibres, both increased from the pith outwards and from the base of the branch outwards for a certain distance. This was confirmed by Baranitzky (1901), who in addition demonstrated that the average length of fibres on the upper side of branches in each annual ring except the first was greater than ^{on} the lower side where the compression wood was formed.

Since the forest residue is made of up branches and tops, the evidence from this brief review shows that they are of lower quality for pulp markets due to a shorter fibre length when compared with main produce cut from the stem.

4.3.3 Calorific value:

The calorific values measured in mega joules per kilogram oven dry weight (MJ/Kg.) according to Olofsson (1975) vary for different parts of a tree (Table 4.21). This variation follows a general pattern regardless of tree species. The order of increase is from wood to needles (Hakkila, 1978). This implies that calorific values of the forest are higher than that of the main produce (stem wood). However, the difference is not much and probably due to ^{the} resin content of bark and needles. Calorific values for different parts of a tree decrease with increasing moisture content regardless of specie (Table 4.22).

The investigation carried out on the moisture content, green and basic densities of different component parts of a tree indicates that these factors also limit their marketability. From this qualitative assessment, it is evident that residues with the exception of dry branches possess higher values of moisture content and lower values of basic density than the main produce. Consideration of fibre length and calorific values suggests that residues have different potential uses: for example, due to their shorter fibre length branches will not be able to compete with main produce for pulpwood whereas for fuel they may be more useful. Whatever the quantity and quality of forest residues,

information on these aspects will assist in a better allocation of forest resources.

Table 4.21 Calorific values for different parts of a tree

Tree part	*Calorific values in MJ per KG.	
	PINES	SPRUCE
Stem wood	19.3	18.8
Stem bark	19.8	18.7
Branches (excluding foliage)	20.5	19.8
Needles	21.1	20.0

* values at oven dry

Source : Olofsson, 1975

Table 4.22 Variation in calorific values of different parts of ^atree according to their moisture content

Material	Basic Calorific values in MJ/KG at MC (%)				
	density				
	KG./CU.M.	0	20	40	60
PINES					
Unbarked stem wood	390	7511	7274	6876	6680
Whole tree chips	385	7542	7307	6916	6129
Residue chips (excl. needles)	405	8246	7999	7586	6723
Residue chips (incl. needles)	395	8113	7872	7470	6628
SPRUCE					
Unbarked stem wood	380	7260	7034	6646	5871
Whole tree chips	400	7676	7432	7024	6208
Residue chips (excl. needles)	465	9161	8877	8403	7454
Residue chips (incl. needles)	425	8242	8164	7731	6864

Source : Hakkila, 1978

CHAPTER FIVE

PREDICTIVE MODELS FOR RESIDUE PRODUCTION

This chapter examines the use of such variables as the diameter at breast height (dbh) and the quantity of the main produce (pwt) for predicting the quantity of post logging forest residue (i.e. gross quantity of dead and live branches and tops) per tree. Its main objective is to determine a simple yet precise way of developing prediction equations for residue biomass which are:

- (i) to be simple to use and
- (ii) to be compatible with a system of stand residue prediction.

Two main criteria were considered when evaluating the equations. Firstly, the sampling technique used to collect the data which was by systematic grid line transect (SGLT), systematic plot mean tree (SPMT) and random plot mean tree (RPMT) as described in section 3.2.2. Secondly, the predictive ability of the independent variables used which were diameter at breast height (dbh), dbh squared (dsq) and produce weight (pwt).

5.1 CHOICE OF INDEPENDENT VARIABLE

It is well known that tree or stand biomass may be expressed as a simple exponential or power function of individual tree or stand mean tree diameter. Many studies on dry matter production were based on the weight of a tree (or trees) of mean dimension multiplied by the number of trees per unit area (Bujan, 1981; Ovington, 1957; ~~Orman & Will, 1960~~; Stanek & State, 1978; and Alemdag, 1979; 1982; Alemdag & Horton, 1981). Most of these considered the whole tree biomass and in a few cases broadleaf crown biomass (Atwill, 1966), usually expressed as a function of diameter or diameter and

height. In this study, prediction of residue was based on tree diameter and in addition, the quantity of main produce since both are parameters which woodland managers are used to. The aim of the study was to derive simple linear models which do not require sophisticated computation.

5.2 REGRESSION ANALYSES

The procedure for the above ground biomass modelling based on regression analysis was modified for residue prediction. The idea was to work within the frame work of biomass prediction, using tree diameter ^(Ker, 1980) and produce weight as predictor variables since biomass is insensitive to tree height (Crow, 1978; Green & Grigal, 1978). However, the use of produce weight (which is a function of density and volume) has automatically included the tree height in the computation.

Data for the residue produced after a clear fell operation of the Scots pine stand in Glentress forest were converted values to oven dry weight. The conversion ratios obtained for different types of post logging residues in chapter four (Table 4.17) ^{Page 66)} were used. The total oven dry weight of the tops, dead and live branches constituted the total residue weight (trw) expressed in kg. per tree. The produce weight (pwt) was obtained indirectly from the relationship between green volume and basic density. The total tree weight (ttw) i.e. the above ground biomass, is the sum of pwt and trw. Both the ttw and trw were used as dependent variables and each regressed on dbh, dsq and pwt in the subsequent regression analyses. These were carried out with the aid of standard computer packages.

5.3 GRAPHICAL RELATIONSHIP

The first step in the analysis was a graphical investigation of the relationship between the dependent and independent variables. This was carried out by plotting scatter diagrams as follows:-

- (i) Figure 5.1 ttw vs. dbh (all data)
- (ii) Figure 5.2 trw vs. dbh (all data)
- (iii) Figure 5.3 trw vs. dbh (SGLT data only)
- (iv) Figure 5.4 ttw vs. dsq (all data)
- (v) Figure 5.5 trw vs. dsq (all data)
- (vi) Figure 5.6 trw vs. dsq (SGLT data)
- (vii) Figure 5.7 ttw vs. pwt (all data)
- (viii) Figure 5.8 trw vs. pwt (all data)
- (ix) Figure 5.9 trw vs. pwt (SGLT data only)

(N.B. SGLT data were assessed separately because this sampling technique was found to be most cost effective (section 4.2)). Figures 5.1 and 5.4 were plotted for comparison with the results of previous work. In terms of pattern and closeness of points they agree with results obtained by Whittaker & Woodwell (1968), Bunce (1968). However the scatter diagrams for trw and dbh (Figure 5.2), trw and dsq (Figure 5.5) and trw and pwt (Figure 5.8), although similar in pattern and spread with each other show greater scattering than those for ttw and the independent variables (Figures 5.1, 5.4 and 5.7). Thus, a greater error is likely when estimating residue weight than total tree weight.

5.4 REGRESSION EQUATIONS FOR ESTIMATING TOTAL RESIDUE WEIGHT

Since the data used for these analyses were collected by three different sampling techniques, separate regression analyses were carried out for each independent variable (dbh, dsq and pwt) for each sampling technique.

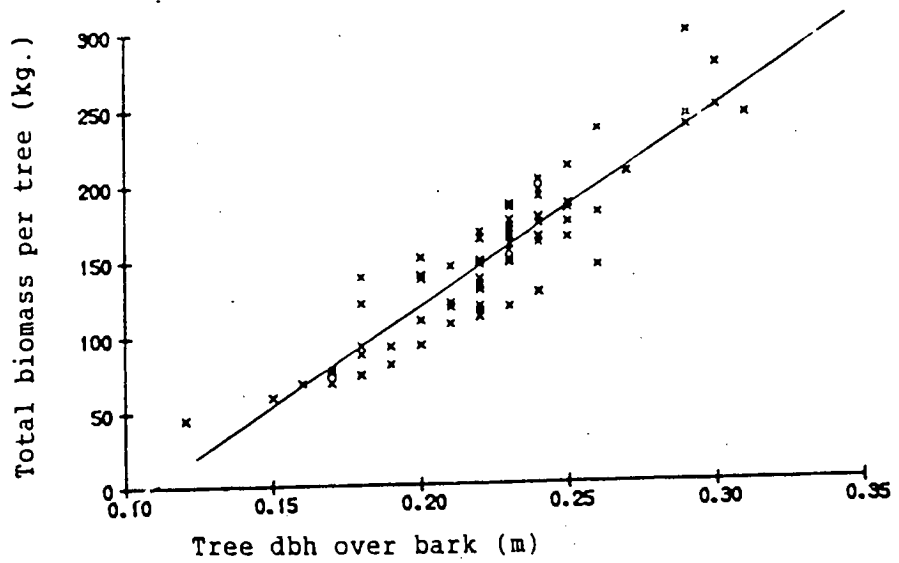


Fig. 5.1 Scatter diagram for total above ground biomass per tree and dbh (all data).

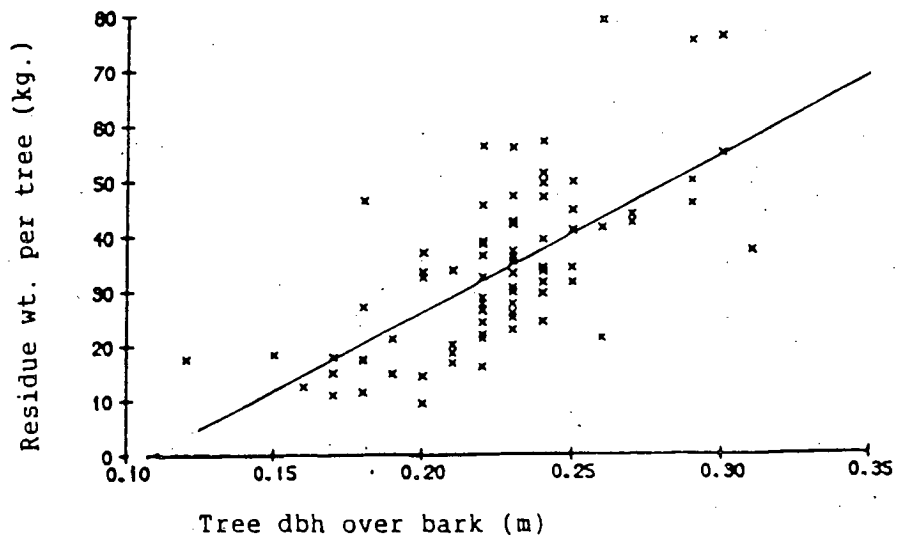


Fig. 5.2 Scatter diagram for total residue weight per tree and dbh (all data)

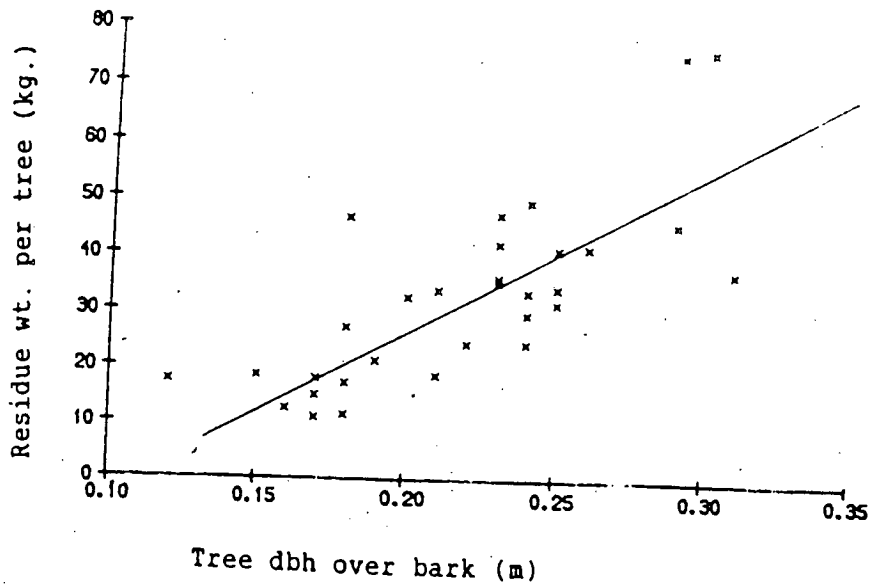


Fig. 5.3 Scatter diagram for total residue weight per tree and dbh (SGLT data).

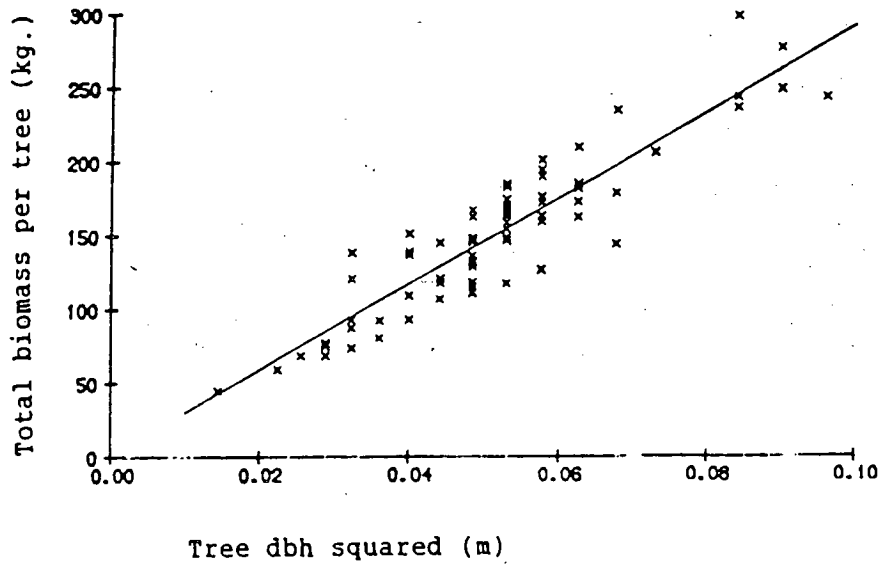


Fig. 5.4 Scatter diagram for above ground biomass per tree and dbh squared (all data).

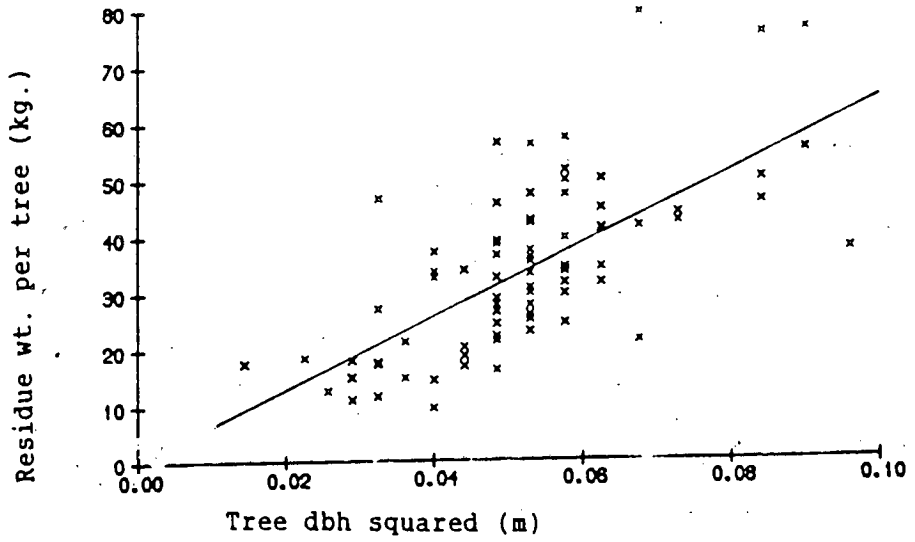


Fig. 5.5 Scatter diagram for total residue weight per tree and dbh squared (all data).

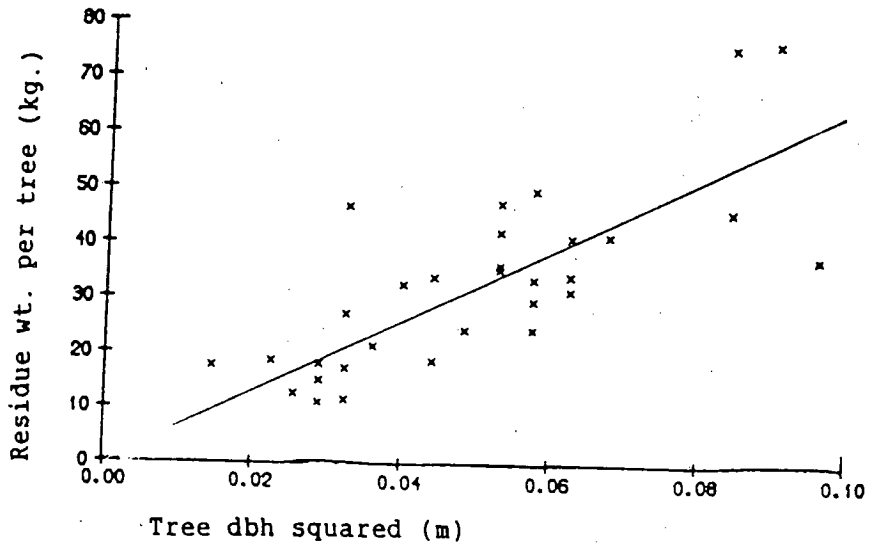


Fig. 5.6 Scatter diagram for total residue weight per tree and dbh squared (SGLT data).

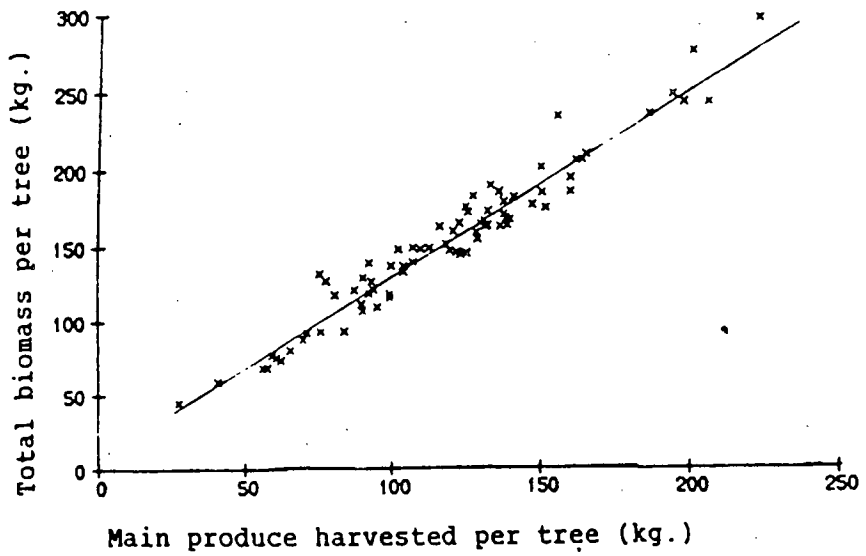


Fig. 5.7 Scatter diagram for above ground biomass
produce harvested per tree (all data).

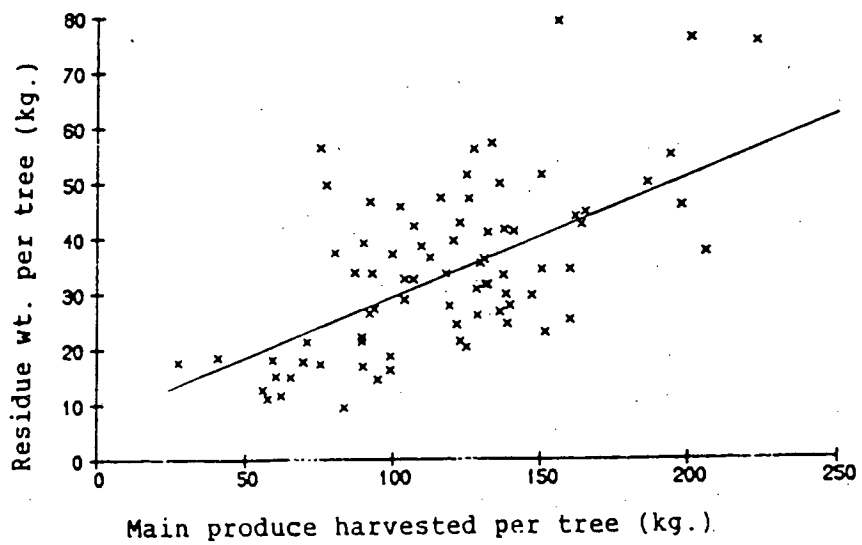


Fig. 5.8 Scatter diagram for residue weight and
produce harvested per tree (all data).

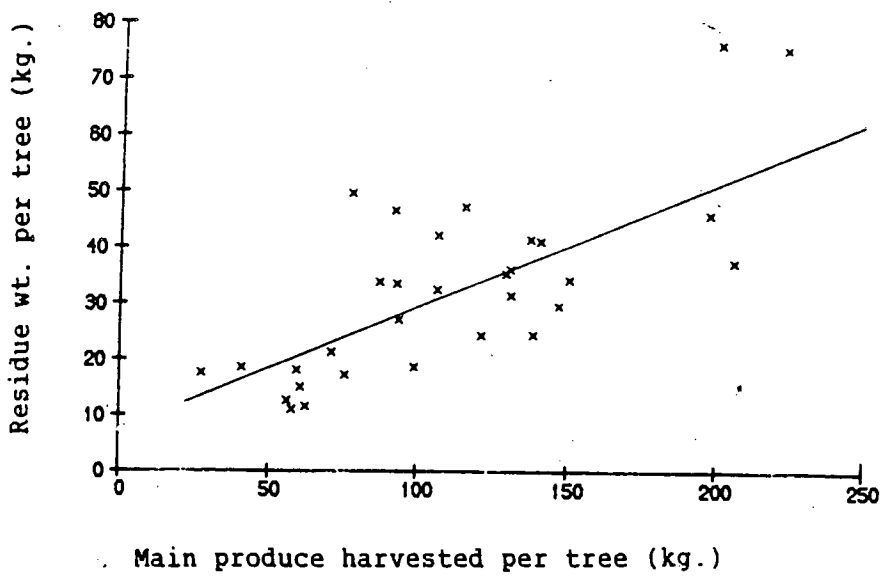


Fig. 5.9 Scatter diagram for total residue weight and produce harvested per tree (SGLT data).

There were two reasons for this. Firstly, to find out which sampling technique would produce the best regression equation from its data. Secondly, to establish which independent variables are reliable for predicting residue production..

(i) Analysis of different sampling techniques

Regression equations for all three independent variables using data were derived from the three sampling techniques (Equations 1-9, Table 5.1). Comparison of these equations according to the three sampling techniques used to collect their data (equations:1-3, 4-6, 6-9) shows that no equation is remarkably better than the others in terms of Standard Error of the Estimate (SEE) but there are differences in their R^2 and F ratio, with those based on systematic grid line transect being persistently best of all (Equations 1,4 & 7). When the calculated F ratio is greater than the tabulated, it might imply that the evidence for the relationship between the dependent variable trw and independent variable is strong. However, F.ratio and SEE are dependent on sample size in addition to closeness of points to the line. In the random plot mean tree technique, fewer trees were sampled because of the method of locating the sample trees (section 3.3.2) which constrained the selection of sampling tree to limited area. This constraint notwithstanding, it is likely that the SGLT will be better than any of the other methods used. Since the main objective is to find out which technique is best for residue predictive modelling R^2 is a better indicator than either F.ratio or SEE. The use of grid line transect technique for data collection in residue assessment, apart from being cheap is also the best of the three techniques considered.

(ii) Analysis of different independent variables

In addition to the above, it was considered desirable to find out which variable gave the best prediction model. Equation 4 based on dbh squared

Table 5.1 Summary of regression statistics for residue predictive models

EN.	ST	EQUATION	SEE	R	F	DF
1	1	trw= -24 + 262dbh	10.94	0.56	36.99	1 & 30 **
2	2	trw= -58 + 403dbh	11.55	0.45	23.64	1 & 30 **
3	3	trw= -18 + 228dbh	11.25	0.11	2.48	1 & 20 n.s
4	1	trw= 3 + 599dsq	10.99	0.57	39.15	1 & 30 **
5	2	trw= 11 + 845dsq	11.64	0.44	22.85	1 & 30 **
6	3	trw= 10 + 451dsq	11.27	0.11	2.40	1 & 20 n.s
7	1	trw= 6 + 0.24pwt	10.99	0.56	36.34	1 & 30 **
8	2	trw= 4 + 0.24pwt	13.37	0.26	10.28	1 & 30 **
9	3	trw= 27 + 0.05pwt	11.87	0.01	0.27	1 & 20 n.s

EN _ Equation number

ST _ Sampling Technique 1 = systematic grid line transect

2 = systematic plot mean tree

3 = random plot mean tree

SEE _ standard error of the estimate of slope

R _ coefficient of multiple correlation

F _ calculated F.ratio

DF _ degree of freedom

Levels of significance: * 5%

** 1%

n.s. not sig. at 5%

gives the overall best values of both R^2 . When produce weight (pwt) was considered for equations 1, 4 and 7 (SGLT), the values of their R^2 are very close, but for 2,5 and 8; and 3, 6 and 9, these values are lowest for equations based on pwt. The reason for this is uncertain from this study. However, it can be suggested that the 'cutting habit' of the chainsaw operator not strictly adhering to 7 cm minimum diameter might be a cause.

A further analysis was carried out to determine whether the equations for each independent variable were statistically different from each other or not. This is necessary first to ascertain if data from the three techniques can be combined to form an overall equation and secondly to see if the data based on one technique can be used for testing the reliability of a model developed from data collected by another technique.

A summary of statistical tests for these equations using both the CHI square and ANOVA is presented in Table 5.2. The following comparisons were made: comparison based on dbh (Equations 1-3), dsq (Equations 4-6) and pwt (Equations 7-9). There was no statistical difference between these equations hence further analysis above was carried out using combined data from all the three techniques.

The summary of statistics for this combined data is given in Table 5.3. Equations for trw (10, 12 & 14) were compared with equations for ttw each regressed on dbh, dsq and pwt (Equations 11, 13 & 15). In terms of R^2 and SEE, the use of dsq is marginally superior to both dbh and pwt. But the strength of the relationships obtained in ttw equations (11, 13 and 15) is greater than trw equations (10, 12 and 14). This shows that these variables (dbh, dbhsquared and pwt) are more strongly related to total above ground biomass than to just the residues. When the values of R^2 obtained from the residue prediction equations based on SGLT technique (Table 5.1) are compared

Table 5.2 Statistical comparison of regression equations based on dbh, dsq and pwt

Equations compared	Calculated value	Degrees of freedom	Tabulated value (p=.05)	Remark
1 -3 (i)	0.085	1,2	4.61	n.s.
(ii)	1.275	2,80	3.13	n.s.
4 -6 (i)	0.018	1,2	4.61	n.s.
(ii)	1.002	2,80	3.13	n.s.
7 -9 (i)	1.12	1,2	4.61	n.s.
(ii)	1.5	2,80	3.13	n.s.

(i) Bartlett's test for homogeneity of variance (CHISQ)

(ii) Analysis of covariance between regressions.

Table 5.3 Comparison of trw and ttw equations derived from combined data

No.	Equation	SEE	R ²	F.Ratio
10	trw= 31.9 + 285dbh.	11.19	0.65	60.38
11	ttw=141.5 + 1302dbh.	21.22	0.81	352.24
12	trw= 0.12 + 641dsq	11.1	0.66	62.69
13	ttw= 1.19 + 2903dsq.	20.92	0.82	305.0
14	trw= 7.52 + 0.22pwt.	12.09	0.58	40.02
15	ttw= 7.52 + 1.22pwt.	12.09	0.93	1253.36

trw _ total residue weight (kg. dry wt.)

ttw _ total tree weight (i.e main produce plus total residue) per tree

with those equations based on combined data from the three sampling techniques, these values are greater for the latter (equations 10, 12 & 14, Table 5.3) than for the former (equations 1-9, Table 5.1). However the cost of such data collection (which is three times the sample size of SGLT data) is triple the cost of data collection by any of the ^{other} three techniques and can not be sufficiently justified. Hence, the use of a systematic grid line transect technique to collect limited data (31 cases in this study) is sufficient to develop a predictive model that will estimate the quantity of total residue per tree based on dbh squared.

5.5 RELIABILITY TEST FOR THE MODELS:

In order to check how reliable each of these three variables are in the development of a residue prediction model, the equations developed from SGLT data (equations 1,4 & 7) were used to predict trw from 'raw data' derived from SGLT sample plots. The actual total residue weight per tree (trwa), predicted total residue weight based on dbh of individual tree (p1trw), predicted total residue weight based on dsq of individual tree (p2trw) and predicted total residue weight based on pwt (p3trw) were compared by analysis of variance (ANOVA).

None of the predicted mean values (p1trw, p2trw and p3trw) was shown to be significantly different from the actual total residue weight, nor from each other (Table 5.4). The accuracy of an estimating system is also important; it is measured by the magnitude of bias. Bias was computed as the average of differences between actual and predicted values of residue weight. For this study, bias is expressed as:

% Difference = $\frac{(trwa - ptrw)}{trwa} \times 100\%$ where trwa is the average actual total residue weight per tree and ptrw is the average predicted total residue weight

Table 5.4 Comparison of the predicted and actual residue weight, using model based on different variables (dbh, dsq and pwt)

	TRWA	P1TRW	P2TRW	P3TRW
Mean	34.437	35.764	34.762	35.76
%*	-	3.85	0.94	3.84

* % Difference (bias) = $\frac{\text{TRWA} - \text{P1TRW}}{\text{TRWA}} \times 100$

TRWA

according to the independent variables (dbh, dsq and pwt) used in the equations.

Although no significant difference exists between mean values of total residue predicted. The bias of the predicted value is least for P2TRW which is based on dsq (Table 5.4). This might suggest that a model based on dsq predicts values closest to the actual values hence the most reliable independent variable.

5.6 ESTIMATING RESIDUE PRODUCTION PER HECTARE

Equation 4 represents the best model for estimating total residue produced by individual trees i.e. $trw = 3 + 599dsq$

If N is the number of trees per hectare (i.e. stand stocking), total residue weight per hectare TRW can be estimated as:

$$TRW = trw \times N$$

$$TRW = N \times (3 + 599dsq)$$

In the previous chapter (Table 4.5), N for systematic grid line transect technique is 666 trees per hectare and average trw per tree using dsq (Table 5.4) is 34 kg. dry weight, then

$$TRW = (666 \times 34) \text{ kg. dry weight per hectare}$$

$$= 23,150 \text{ kg. dry weight per hectare}$$

$$= 23.2 \text{ dry tonnes per hectare (cf 23.28 dry tonnes per hectare in}$$

Table 4.9 which is the actual quantity of residue).

An increasing amount of time, money and other resources is being devoted to investigations of forest biomass and to their implication to forest management. There is an urgent need to test and appraise sampling procedure for a variety of species and situations, since frequently the number of trees that can be examined is severely limited and guidance is needed if the most appropriate

sampling technique is to be used.

From this study, a partial solution has been provided with conclusions on which sampling procedure and tree parameter should be used to develop a simple predictive model. The use of SGLT is best compared with SMPT and RPMT because it is cheapest. The predictor variable that gave the best model was dbh squared. Although this model is a local one, it can form a basis for regional model for residue prediction by enlarging the sampling to cover wider ranges of site differences.

CHAPTER SIX

ECONOMIC CONSIDERATION OF RESIDUE POTENTIAL

This chapter begins with a background description of the various residue procurement strategies, based mainly on experience in Finland. It assesses the potential costs of residue harvesting including procurement and nutrient replacement in hypothetical situations. The potential benefits of harvesting residues which include savings in site preparation and silvicultural operations, as well as revenue from sales of residues, are also assessed in order to carry out benefit - cost analysis. The benefit - cost ratios calculated indicates the economic feasibility of these strategies in the U.K. These ratios are further subjected to sensitivity analysis in order to test the effect of changes in various economic factors of production and sale of residues.

6.1 RESIDUE PROCUREMENT

As mentioned earlier (section 2.7), the procurement of forest residues is not normally practised on a commercial scale in Britain. There is potential for it, particularly in-forest wood chipping, both as an extension to existing harvesting practice and as an alternative harvesting system. However, there are signs that the potential of forest residues may at last be realised; Fibroply Ltd. of Inverness have recently agreed in a contract with Tormore Distilleries to supply their energy requirements by utilising brash and tops from local forests, using a Bruks 800 CT chipping unit similar to that illustrated in Figure 6.5 (Forestry & British Timber, 1985). Also, there are other large saw mills and distilleries that have completed technical and feasibility studies on the use of green chips from the forest particularly in England and Wales (Greig, 1985).

6.1.1 Procurement Options

Three broad options for harvesting forest wood residue were examined, all of which are currently being practised in Finland (Hakkila,1984) and Sweden (Olsson, 1984) with some currently being tried in the U.K.

Residue can be procured by :

(i) Whole tree chipping - This involves the chipping of all the above ground parts of a tree including the merchantable parts. Chips produced contain proportionally less bark than chips from tops and branches.

(ii) Conventional harvesting and chipping of slash - In this case, the main produce is harvested by traditional logging practices while the post logging residues, mainly the tops and branches with or without the needles are chipped. Due to the smaller sizes of branches and tops, the chips produced are likely to be smaller with a greater bark content since the bark - wood ratio increases with decrease in stem size.

(iii) Conventional conversion of top and larger branches - This option is an extension of the current harvesting practice where the minimum top diameter of 7.0 cm. is reduced to 3.0 cm. Any material between 7 and 3 cm. diameter is crosscut into 1 m or 1.5 m short wood. In addition to harvesting of the tops, large branches equal or greater than 3.0 cm. would also be included for harvesting.

Each of these options is achievable by at least two strategies based on chipping location. In-forest chipping can be done at stump or at a roadside depot (Figures 6.1 & 6.2). Each chipping strategy can be done with a range of machinery, i.e. light, medium or heavy chippers made available by recent technological advancement (Hakkila,1984). However two main categories of chipping machinery were considered in this chapter. These are light and heavy machines (M/C) because they serve as the current technological extremes.

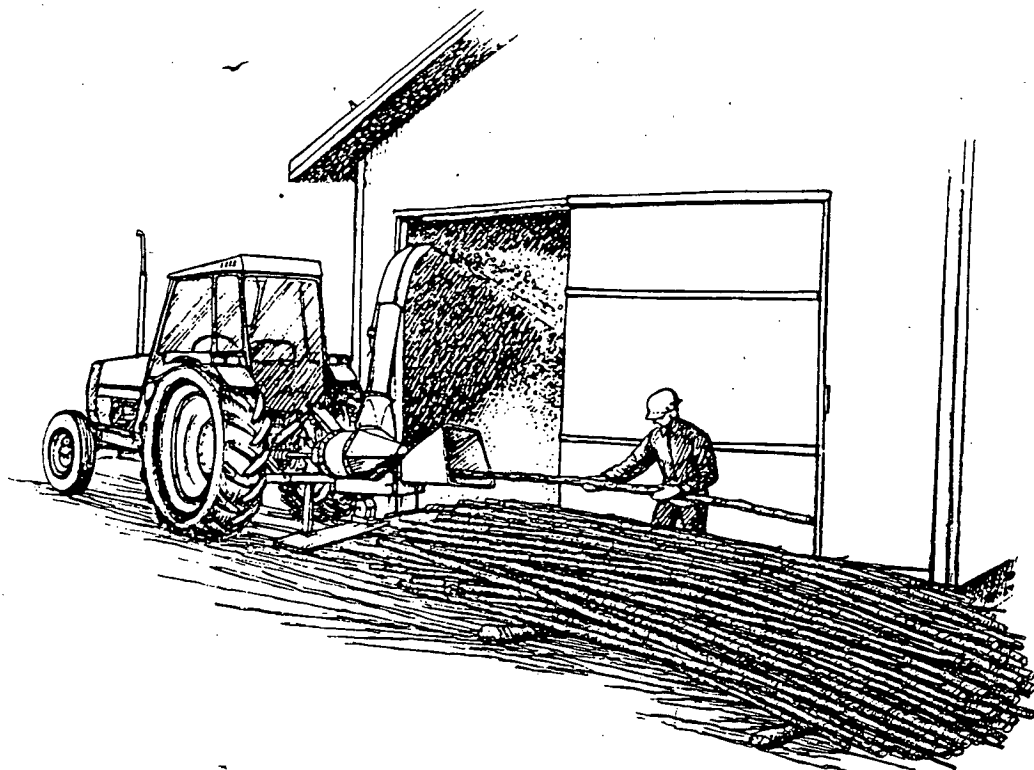


Fig.6.1 Light chipping machine*

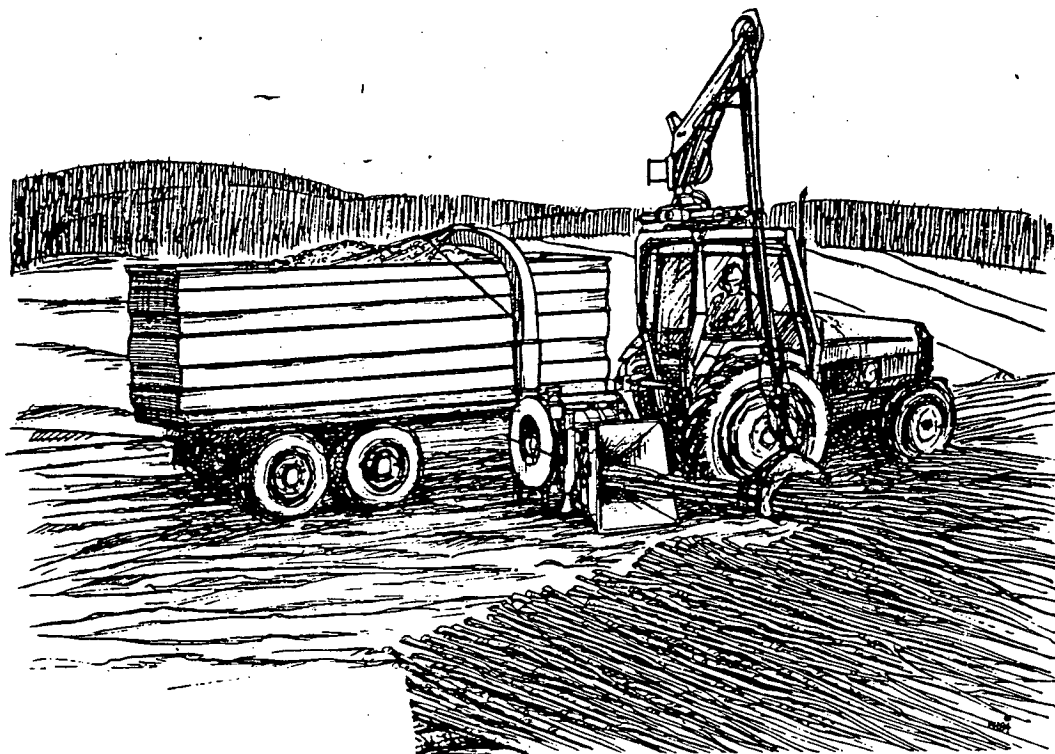


Fig.6.2 Heavy chipping at roadside*

* Source Hakkila, 1984.

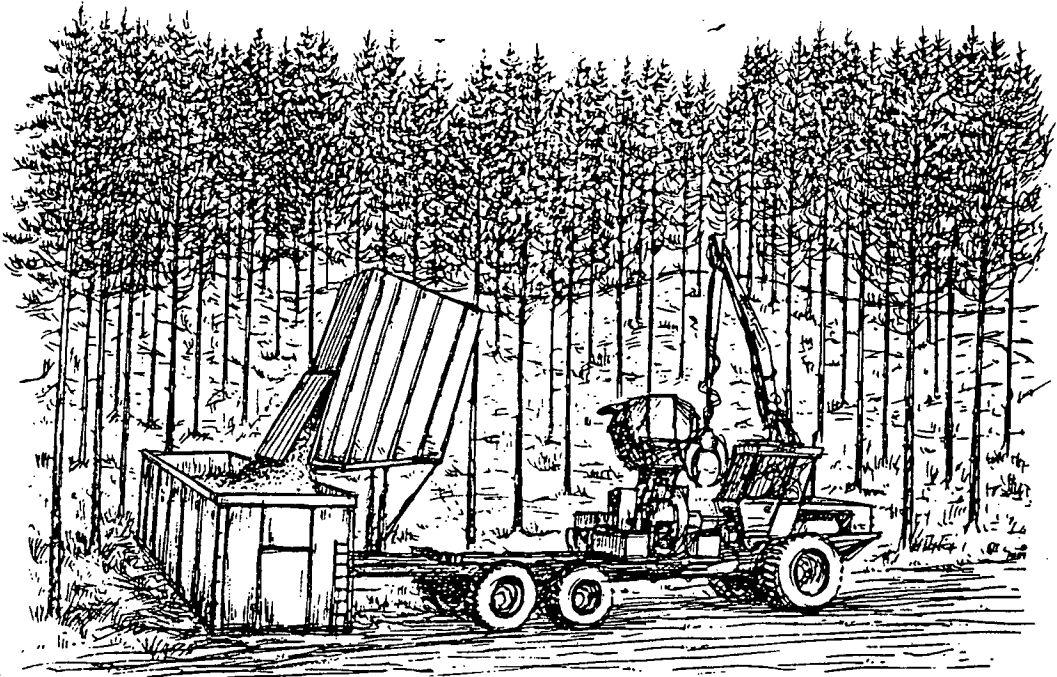


Fig.6.3 Whole tree chipping (in forest) using heavy machine*

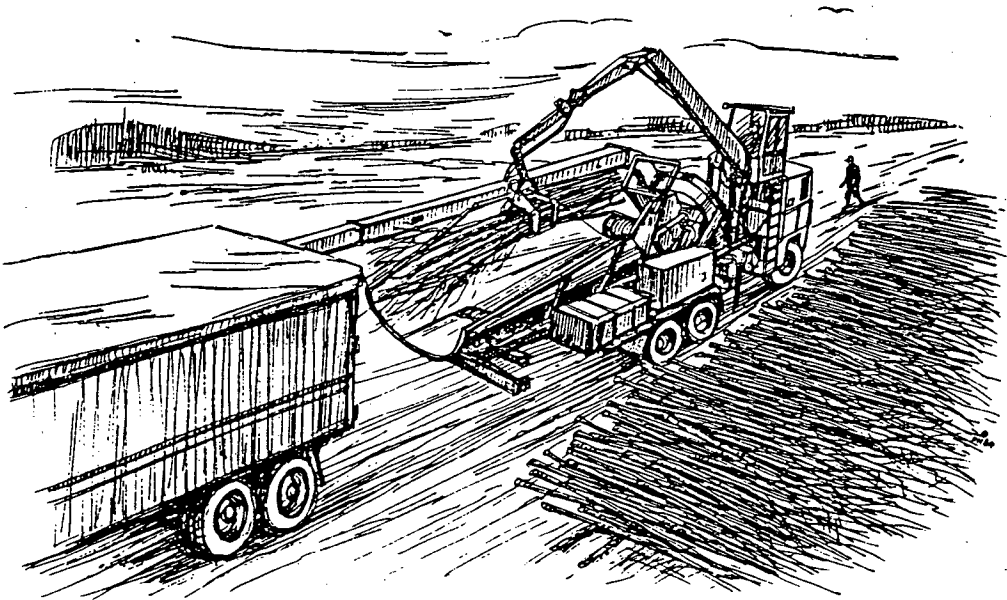


Fig.6.4 Whole tree chipping (in forest) by heavy machine*

* Source Hakkila, 1984.

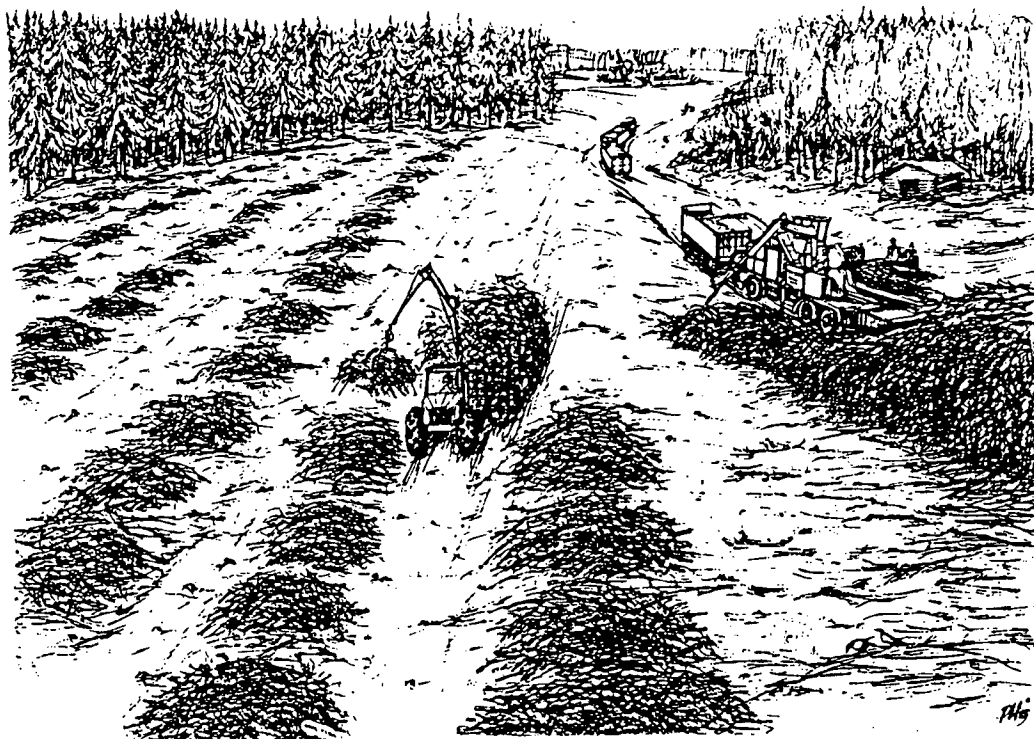


Fig.6.5 Slash chipping (in forest) by light machine*

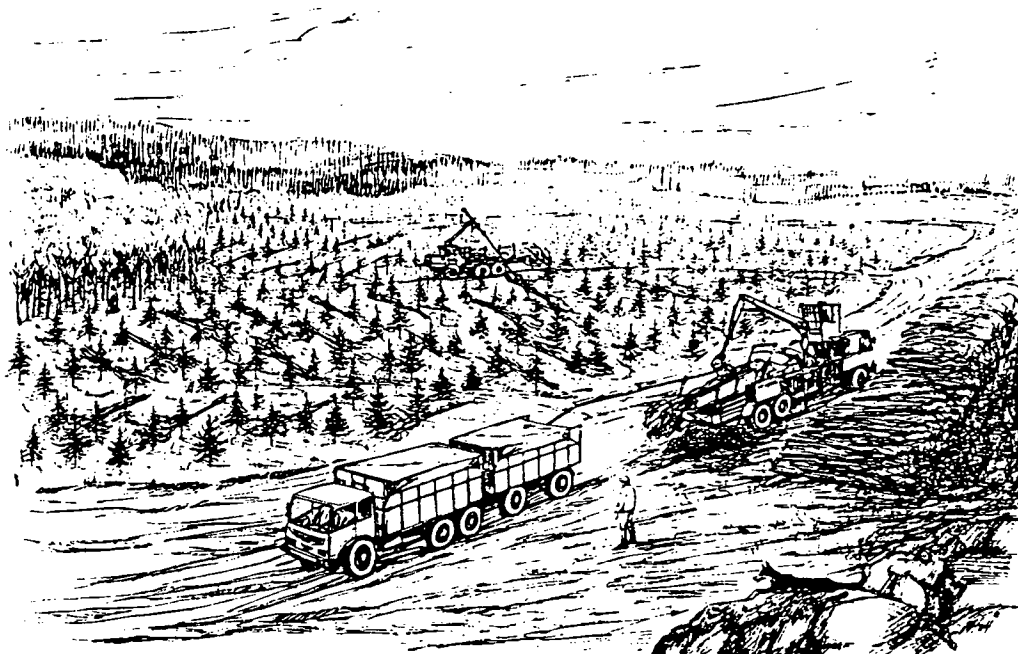


Fig.6.6 Whole tree chipping (at roadside) by heavy machine*

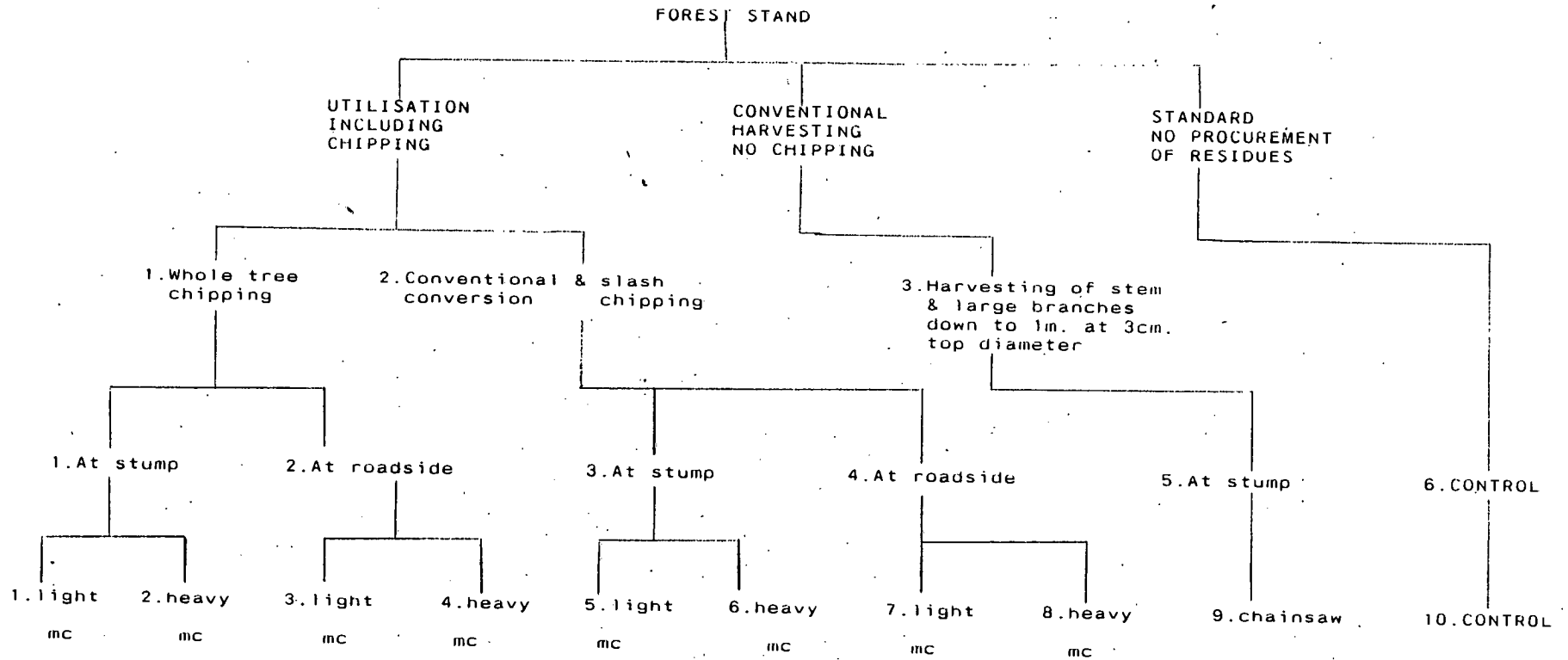
* Source Hakkila, 1984.

Thus at the bottom of the chart (Figure 6.7) there are nine harvesting schemes namely :

1. Whole tree chipping at stump by light chipping machine
2. Whole tree chipping at stump by heavy chipping machine
3. Whole tree chipping at roadside using light chipping machine
4. Whole tree chipping at roadside using heavy chipping machine
5. Chipping of post logging slash at stump by light chipping machine
6. Chipping of post logging slash at stump by heavy chipping machine
7. Conventional conversion of main produce and chipping of post logging slash at roadside by light chipping machine
8. Conventional conversion of main produce and chipping of post logging slash at roadside by heavy chipping machine
9. Conventional (i.e. chainsaw) harvesting of stem tops and any large branches to 3.0 cm. at stump.
10. CONTROL i.e. No procurement of residue - which is the standard practice whereby only the currently merchantable parts of the tree are harvested by conventional shortwood logging methods to minimum top diameter of 7.0 cm. while the residues (i.e. tops and branches) are left behind on the forest floor.

Essentially, seven phases (Table 6.1) can be recognised in the residue procurement options and each of the nine procurement schemes contains between four to six phases. These phases are briefly outlined as follows :

1. Felling of trees - This is assumed to be done by chainsaw and is applicable to all of the nine alternative schemes irrespective of chipping location.
2. Chipping - This is carried out by either of the two machinery categories and is applicable to all schemes except number 9 where procurement



mc - machine

Fig.6.7 Flow chart diagram for forest residue procurements

Thus at the bottom of the chart (Figure 6.7) there are nine harvesting schemes namely :

1. Whole tree chipping at stump by light chipping machine
2. Whole tree chipping at stump by heavy chipping machine
3. Whole tree chipping at roadside using light chipping machine
4. Whole tree chipping at roadside using heavy chipping machine
5. Chipping of post logging slash at stump by light chipping machine
6. Chipping of post logging slash at stump by heavy chipping machine
7. Conventional conversion of main produce and chipping of post logging slash at roadside by light chipping machine
8. Conventional conversion of main produce and chipping of post logging slash at roadside by heavy chipping machine
9. Conventional (i.e. chainsaw) harvesting of stem tops and any large branches to 3.0 cm. at stump.
10. CONTROL i.e. No procurement of residue - which is the standard practice whereby only the currently merchantable parts of the tree are harvested by conventional shortwood logging methods to minimum top diameter of 7.0 cm. while the residues (i.e. tops and branches) are left behind on the forest floor.

Table 6.1 Basic operation matrix for residue procurement schemes

Operational phases	Alternative harvesting schemes*									
	1	2	3	4	5	6	7	8	9	10
1. Chainsaw felling	x	x	x	x	x	x	x	x	x	x
2. Chipping	x	x	x	x	x	x	x	x	-	-
3. Loading & haulage chips/shortwood to roadside	x	x	-	-	x	x	-	-	x	-
4. Extraction of whole tree to roadside	-	-	x	x	-	-	x	x	-	-
5. Supervision	x	x	x	x	x	x	x	x	x	x
6. Conversion of main produce	-	-	-	-	x	x	x	x	x	x
7. Extraction of main produce to roadside	-	-	-	-	x	x	-	-	x	x

* Alternative procurement schemes as in text

x applicable

- not applicable

is carried out as an extension of the current practice and the control.

3. Loading and haulage of chips (or small roundwood 3 - 7 cm. diameter from scheme 9) to roadside.
4. Extraction of whole tree to roadside by tractor skidding
5. Supervision
6. Conversion of main produce (at stump or roadside)
7. Extraction of main produce to roadside.

Eight of the nine procurement schemes involve chipping. The chipping machine is likely to be used in number of different situations especially if purchased by contractors or a large estate. The machine is therefore required to be versatile in use and economic to operate on a range of materials. With few trials of residue procurement in the U.K., the basic operation flow diagrams (Appendices 6.14 and 6.15) were derived from Finnish literature (Hakkila,1984) to cover the essential procurement phases. The standard times for estimating machinery performance in each of the alternative harvesting schemes were built up by synthesising available standard times for each phase of the operation according to standard workstudy procedure (Wittering,1977).

6.2 EVALUATION OF POTENTIAL COSTS OF RESIDUE HARVESTING

Of the three major threats posed by intensive harvesting (section 2.7), the biological consequences notably the potential nutrient depletion seem to be of greatest concern. In order to give a balanced evaluation of the potential economic feasibility of producing residues it is necessary to evaluate the potential nutrient drain, translate this into financial cost, and add this to the procurement cost.

For the purpose of this study potential costs of nutrient depletion and residue procurement were derived from published works (Ovington,1957; Wright

and Will, 1958; Miller *et al* 1980; Hakkila,1984).

6.2.1 Procurement Costs

Each of the nine possible schemes for procuring forest residue (Figure 6.1) was evaluated. The economic evaluation involved both machinery and labour costs; these were assessed for each scheme with stated assumptions (Appendices 6.1 - 6.13). This assessment is for a hypothetical situation which assumes a relatively flat land area with easy access for the machinery, although costs are expected to be affected by slope. Brief descriptions of the machinery costed are also given in the appendices: only two machines considered representative of light and heavy categories respectively were used in developing costs, which were based mainly on current output performance (Hakkila,1984) together with some equivalent operational elements under British condition (Forestry Commission,1978). The estimated standard times produced by this synthesis (Wittering,1977) were used together with the U.K. Forestry Commission wage rates for different forest skills. Conditions in the two countries are not precisely the same in both physical and ergonomic terms but their possible differences are catered for in the sensitivity analyses found later in this chapter.

The derived operational costs are summarised in Table 6.2. There are two striking observations from this table regarding the component and total procurement costs. Both the chipping location (i.e. at stump or at roadside) and the type of machinery used influence the component and total costs. It is generally more costly to produce chips, whether from whole tree or slash, at roadside than at stump. This implies that, except in steep terrain which creates difficulties for machinery, chipping at stump should be encouraged. A breakdown of the cost of haulage shows that it is cheaper (Appendices 6.7 & 6.9) to haul chips from stump than to skid or haul whole trees to roadside (or

Table 6.2 Derived operation costs for residue procurement schemes

Procurement schemes	Costs in £ per m ³		
	Labour	Machinery	Total
1	9.23	1.58	10.81
2	3.54	2.42	5.96
3	11.95	3.30	15.25
4	6.21	3.98	10.19
5	3.98	0.99	4.28
6	1.85	3.77	5.62
7	4.41	1.77	6.18
8	2.25	2.99	5.24
9	9.41	2.84	12.25
10	4.49	8.78	13.27

10 - Conventional harvesting practice serving as CONTROL

depot) for chipping. The type of machinery also affects the cost of producing chips. Considering whole tree chipping, for two broad approaches; whole tree chipping (schemes 1 - 4) and slash chipping (schemes 5 - 8), the machinery cost per unit volume is higher for heavy machinery than for light machinery but the total costs are generally higher for light machinery than for heavy machinery. This is because light machinery is labour intensive; the higher the machinery costs the lower the labour costs. This is responsible for the high cost of procurement (£1589 per ha.) in scheme 3

In order to compare the cost of residue procurement by the nine harvesting schemes the cost of whole tree harvesting (above ground biomass) per hectare was estimated (Table 6.3). This, less the cost of harvesting the main produce, gives the cost of harvesting the residues. The cost of residue harvesting varies from -(£839) per hectare to £429 per hectare, the negative value simply means that the cost of whole tree harvesting for scheme 2 is less than the cost of conventional logging i.e. a saving of £839 per hectare is estimated.

6.2.2 Estimate of Costs of Nutrient Replacement

Nutrients replacement

Soil nutrients are always present in solutions and consist of macro - and micro - elements. Discussion on soil nutrient depletion usually centres round the amount of elemental nitrogen (N), phosphorus (P) and potassium (K) removed. Although other elements such as magnesium, calcium, copper, iron and zinc are important, it is the first three (N,P,K) that constitute essential elements. Sources of nutrients include aerosol input (Miller et al, 1980) and decomposing litter.

Data on the nutrient contribution of different tree parts in Scots pine are hard to come by and laboratory determination for this study was not possible due to limited time and resources. Reliance has had to be made on published

1. Whole tree chipping at stump by light chipping machine
2. Whole tree chipping at stump by heavy chipping machine
3. Whole tree chipping at roadside using light chipping machine
4. Whole tree chipping at roadside using heavy chipping machine
5. Chipping of post logging slash at stump by light chipping machine
6. Chipping of post logging slash at stump by heavy chipping machine
7. Conventional conversion of main produce and chipping of post logging slash at roadside by light chipping machine
8. Conventional conversion of main produce and chipping of post logging slash at roadside by heavy chipping machine
9. Conventional (i.e. chainsaw) harvesting of stem tops and any large branches to 3.0 cm. at stump.

Table 6.3 Estimates of residue procurement costs per hectare

Harvesting scheme	Procurement cost £ha.		
	whole tree harvesting	conventional harvesting	residue harvesting
1	2825	2396	429
2	1557	2396	(839)
3	3985	2396	1589
4	2663	2396	267
5	2636	2396	240
6	2712	2396	316
7	2743	2396	347
8	2690	2396	294
9	3084	2396	668

N.B. () saving instead of cost.

Calculation of 'whole tree' harvesting costs

Schemes 1-4: whole tree value^{ha} = Total procurement cost in Table 6.2

x whole tree volume^{ha}.

Schemes 5-8: Total procurement cost^{m³} x quantity of residue^{ha}.

+ cost of harvesting the main produce^{ha}.

data (as mentioned in section 3.2.2) in order to produce an estimate of nutrient contribution from post logging residues.

Different figures for nutrient contribution from stem wood, branches and needles were given by Ovington (1957), Wright and Will (1958). These were examined together with the figures given by Miller et al (1980) on nutrient loss in a Corsican pine stand due to different harvesting policies in the Moray Firth part of Scotland. Figures given by Ovington for Scots pine could not be used directly in this study because they generally refer to the forest canopy. Besides, they were derived from a contrasting ecological area in Thetford forest in south east England, quite unlike the study area in Scotland.

From Wright and Will's work (1958) based in Scotland, conversion factors were established for different elements from comparable studies on nutrient contribution from tops, branches and foliage both Scots and Corsican pines. The summary of this is contained in Table 6.4. Both species were growing on the same site and were of the same age. These conversion factors were used to estimate the nutrient drain due to whole tree harvesting in Scots pine from the figures given for Corsican pine by Miller et al (1980) - see Table 6.5 (and appendix 6.16)

If it is assumed that the whole nutrient content of branches, tops and foliage is taken away when they are harvested, it is necessary to consider the cost of their replacement by applying fertiliser. This viewpoint is taken regardless of the fact that other sources such as aerosols contribute to soil nutrients and that different sites have a varying capacity to sustain nutrient requirements and yield.

The response of different soils to fertiliser application varies (Fox and Kamprath, 1971; Malcolm et al, 1977; Malcolm and Cuttle, 1983a; 1983b). In the case of fertiliser replacing lost nutrient from intensive harvesting, more than the

Table 6.4 Estimated conversion ratios of nutrient contribution from Scots and Corsican pines based on Wright & Will (1958)

Weight in Kg.per ha.

Species	Age(yrs.)	N	P	K
Scots pine	18	151.2	16.6	115.6
Corsican pine	18	80.6	12.0	49.3
Ratio of SP/CP		1.9	1.4	2.3
Scots pine (SP)	28	224.0	25.0	128.8
Corsican pine (CP)	28	101.9	13.7	79.5
Ratio of SP/CP		2.2	1.8	1.6
Average Ratio (approx.)		2.1	1.6	2.0

Table 6.5 Estimated nutrient loss due to residue harvesting

Species	Elements	Yield Class					
		in Kg./ha.					
		6	8	10	12	14	16
Corsican pine*	N	1.72	2.39	3.14	4.10	5.22	7.03
	P	0.17	0.23	0.32	0.39	0.46	0.58
	K	1.20	1.71	2.35	2.63	3.34	3.67
Scots pine+	N	3.61	5.02	6.59	8.61	10.96	14.76
	P	0.27	0.37	0.51	0.62	0.74	0.93
	K	2.40	3.42	4.50	5.26	6.68	7.34

* Estimated from data based on the works of Miller et al(1979) Appendix 6.

+ Estimates based on conversion ratio derived from Table 6.4

actual quantity of nutrient loss would have to be applied because of leaching, erosion and immobilization of some elements after fertiliser application (Malcolm & Cuttle, 1983a; Anderson, 1985). The capability of soil to retain nutrients from applied fertiliser varies with soil type as the individual soil nutrient requirement does. It is believed that deep peat in the U.K. represents an extreme case requiring more fertiliser application especially in the early or seedling stage of various conifer species i.e. year 0 - 12 (McIntosh, 1981).

In this study it is assumed that at least ten times the quantity of nutrient removed by residue harvesting would be required to replace the nutrient loss. This figure presupposes that nutrient retention of some peat soils is so poor that only one - tenth of the applied fertiliser is retained and made available to the trees, i.e. it assumes the worst site conditions likely to be found. Accurate figures for leaching and other losses are not available for this exercise and the above assumptions will not be valid for good sites. Estimates of nutrient requirements in Table 6.6 are computed on this basis to allow cost - benefit analyses of the harvesting options to be carried out.

Three types of fertiliser are considered for nutrient replacement (Table 6.7), with their respective available quantities of elemental N,P,K and their current costs. These three were chosen because they are popular choices of fertiliser applied in Britain (Binns, 1975b). Table 6.8 shows how the costs of nutrient replacement are estimated. In practice, it is unlikely that the quantity of fertiliser required would increase with increasing Yield Class because the soil nutrient potential is greater on better sites.

6.3 POTENTIAL BENEFITS OF RESIDUE HARVESTING

The evaluation of benefits according to this study considers both direct and indirect financial benefits. This assumes firstly that there is a market for

Table 6.6 Estimated nutrient requirement (kg./ha.) assuming a leaching factor of 10 (i.e. 10% soil fertiliser retention) based on Table 6.5

Element (kg./ha.)	Yield Class					
	6	8	10	12	14	16
N	36.1	50.2	65.9	86.1	109.6	147.6
P	2.7	3.7	5.1	6.2	7.4	9.3
K	24.0	34.2	45.0	52.6	66.0	73.4

Table 6.7 Standard rates and costs of fertiliser application

Fertiliser type	Quantity/ha. (kg.)	Element/ha. (kg.)	Cost*/ha. (\$)	
			Actual	Approximate
Urea	350	150 of N	76.68	77
Rock phosphate	450	60 of P	58.21	58
Muriate of potash	200	100 of K	86.87	87

* Average cost (including fertiliser) for aerial application in Great Britain, 1985. Forestry Commission (pers. comm.).

Table 6.8 Costing of nutrient replacement due to residue harvesting.

Element	Costing Formula
N	$N\text{-cost} = \text{Nr.}/150 \times \text{Urea cost per ha.}$
P	$P\text{-cost} = \text{Pr.}/60 \times \text{Rock phosphate cost/ha.}$
K	$K\text{-cost} = \text{Kr.}/100 \times \text{Potash cost per ha.}$
NPK	$\text{NPK-cost} = \text{N-cost} + \text{P-cost} + \text{K-cost}$

Nr, Pr, Kr nutrient requirements (kg/ha.) r as estimated in Table 6.6
 fertiliser costs (£/ha.) as estimated in Table 6.7

Table 6.9 Estimated costs per hectare of fertiliser application due to nutrient replacement in different Yield Classes.

Yield Class	N-cost	P-cost	K-cost	NPK-cost
6	18.53	2.61	20.88	42.02
8	25.77	3.58	29.75	59.10
10	33.83	4.93	39.15	77.91
12	44.20	5.99	45.76	95.95
14	56.26	7.15	57.42	120.83
16	75.77	8.99	63.86	148.62

cost in £ per ha.

residue produced (which is currently at an early stage of development in ^{the} U.K.) and secondly that the potential market for residue produced is evaluated with reference to the fuelwood price.

6.3.1 Direct Financial Benefits

Estimation of the potential direct financial benefits of harvesting and procuring forest residue requires a knowledge of the quantity available and its market value. The quantity of available residue will be affected by such factors as site quality, harvesting practice and accessibility. Given that the amount of different types of residue available per hectare is as shown in Table 6.10, the potential financial benefit for all residue types is estimated assuming a fixed price relative to the market price for fuel wood. This is because none of these products is in large commercial production in the U.K. yet. Hence their prices are derived hypothetically for the estimation of the marginal benefits as follows:

Assumptions:

1. Whole tree chips attract 10% more than the current price paid for fuel wood. The price of fuel wood is currently £16 per tonne. Thus 1 tonne of whole tree chips costs £17.60p at the forest gate.
2. Chips from slash (i.e. tops and branches) attract 10% less than the current price paid for fuel wood. The forest gate price per tonne of slash chips is taken to be £14.40p
3. Short wood from harvesting scheme 9 (i.e. tops and large branches of any length between 1 and 2 m. with a minimum top diameter of 3 cm.) is worth the same price as fuel wood i.e. £16 per tonne.

Evaluation of financial returns from sales of main produce, whole tree and slash chips can now be carried out as follows:

(i) Produce value per hectare (produce from conventional logging)

Harvestable volume of main produce per hectare (V_p) = 205.22 m² (Table 6.10)

Average price for main produce (P_a) = £9.63 per m³ (Table 6.11)

$$\begin{aligned} \text{Produce value per hectare (Pha.)} &= V_p \times P_a & (1) \\ &= £205.22 \times 9.63 \text{ per hectare} \\ &= £1,977 \text{ (approx.)} \end{aligned}$$

(ii) Whole tree value per hectare (i.e. the potential value from to whole tree chipping excluding stumps and roots).

Quantity of whole tree (Q_w) = 226.15 tonnes per ha. (Table 6.10)

Potential price of whole tree chips (P_w) = £17.60 per tonne.

Potential value per hectare of whole tree chips (P_{vw})

$$\begin{aligned} &= Q_w \times P_w & (2) \\ &= £226.15 \times 17.60 \text{ per ha.} \\ &= £3,980 \end{aligned}$$

Additional benefit per ha. due to whole tree chipping (MBw)

$$MB_w = P_{vw} - P_v \quad (3)$$

$$MB_w = (Q_w \times P_w) - (V_p \times P_a) \quad (4)$$

$$= £3,980 - £1,977$$

$$= £2,003$$

(iii) Value of slash per hectare

Quantity of slash per hectare (Q_s) = 45.56 tonnes (Table 6.10)

Potential price of slash per tonne (P_s) = £14.4

Potential value of slash per ha. (P_{vs}) = $Q_s \times P_s$ (5)

Additional benefit due to slash chipping (MBs) = $P_s \times Q_s$ (6)

$$=45.56 \times 14.4$$

$$=£656 \text{ per ha.}$$

(iv) Value of tops and large branches per hectare

Quantity of tops and large branches per ha. (Qtb)

$$=6.64 \text{ tonnes (Table 6.10)}$$

Potential price of short wood (assumption3)(Ptb)

$$=£16.0 \text{ per tonne}$$

Potential value of short wood (PVtb) $=Qtb \times Ptb$ (8)

Additionally benefit due to harvesting of tops and large branches (MBvt)

$$=PVtb =Qtb \times Ptb \quad (9)$$

$$=£6.64 \times 16 \text{ per ha.}$$

$$=£106$$

The nine harvesting schemes outlined in section 6.1 can be summarised into three main strategies namely whole tree harvesting by complete chipping; whole tree harvesting by combined conventional harvesting of main produce and conventional chipping of slash; and harvesting without chipping but including produce down to 3 cm. top diameter. The marginal benefit which is the additional benefit per unit of extra volume of residue harvested, is given for each strategy as shown in Table 6.12.

The extra potential benefit due to residue harvesting depends on the harvesting strategies adopted to procure the residues. Considering the three main strategies for harvesting residues (Table 6.12), the extra direct financial benefit is greatest for whole tree chipping. However, benefits can not be adequately compared exclusive of procurement costs. A summary of financial benefit less direct cost of production provides a better form of comparison of alternative schemes. Table 6.13 provides such a comparison. This shows that

Table 6.10 Quantity of main produce and residue harvestable per hectare
for Scots pine in Study Area 2.

Type	Fresh wt.(tonnes/ha.)	Dry wt.(tonnes/ha.)	Vol.*
Live branches	32.00	16.33	31.33
Dead branches	6.92	4.85	10.48
Tops	6.64	2.71	7.55
Total Residue	45.56	23.89	56.14
Main produce	180.59	86.19	205.22
Whole tree +	226.15	133.97	261.36

* green volume in cubic metres per hectare

+ excluding roots and stumps.

Table 6.11 Current average price for standing conifer timber from FC. areas.

Average tree size (m/3)	Average price m/3 (£) for Great Britain
Up to 0.074	3.095
Over 0.424	16.172
Mean 0.249	9.634

Source: Timber Grower, April 1985.

Table 6.12 Analysis of marginal benefits according to harvesting strategies.

Harvesting strategies	Extra benefit £ per ha.	Extra vol m ³ per ha.	Marginal benefit* £ per ha.
Whole tree chipping	2003	56.00	35.78
Conventional+slash chipping	656	56.00	11.71
Conventional harvestin down to 3 cm. top diameter	106	7.55	13.25

_ benefits in £ per ha. or * per cu.m.

vol. in cubic metre per ha.

scheme 2 is the most cost effective and hence the most economical. The negative cost implies there is a saving of £839 if whole tree chipping by heavy chipper is used. On the other hand, it is not economical to harvest residue by scheme 9 because it is labour intensive. The potential extra benefit is a negative value (-£582) meaning that it is less economical than the conventional harvesting.

The cost - benefit analysis which follows the next section considers one other scheme (with the second lowest procurement cost - Table 6.3) namely scheme 5. This is the conventional harvesting of the main crop and chipping of slash at stump by light chipper. This could be easily acceptable because it does not conflict with the traditional method of harvesting the merchantable volume.

6.3.2 Indirect Financial Benefit

The piles of branches, tops and odd pieces increase the cost of site preparation depending on the amount of residue left on site. If residues are harvested, it has been found to reduce the costs of site preparation i.e. operations such as ground preparation, ploughing, planting and beating up. Estimates of these potential savings have been worked out by the Forestry Commission, the results being summarised in Table 6.14 (Greig,1985). From the present deliberation between the Forestry Commission and prospective buyers of forest residues the offer made by the latter is in the range of £25 to £30 per hectare for whatever quantity of residue removed (Greig,1985).

6.4 BENEFIT AND COST ANALYSIS

An overall cost-benefit analysis is made, to include all the known costs and benefits of harvesting residues. Known costs include those due to nutrient depletion and procurement while benefits are both direct and indirect (6.3).

1. Whole tree chipping at stump by light chipping machine
2. Whole tree chipping at stump by heavy chipping machine
3. Whole tree chipping at roadside using light chipping machine
4. Whole tree chipping at roadside using heavy chipping machine
5. Chipping of post logging slash at stump by light chipping machine
6. Chipping of post logging slash at stump by heavy chipping machine
7. Conventional conversion of main produce and chipping of post logging slash at roadside by light chipping machine
8. Conventional conversion of main produce and chipping of post logging slash at roadside by heavy chipping machine
9. Conventional (i.e. chainsaw) harvesting of stem tops and any large branches to 3.0 cm. at stump.

Table 6.13 Analysis of marginal benefit for each to harvesting schemes.

Harvesting scheme	Extra B £/ha. ¹	Extra C £/ha.	Margin £/ha.	Residue Vol. m ³ /ha. ²	Marginal B £/m ³
1	2003	429	1574	56.00	28.1
2	2003	(839)	2842	56.00	51.1
3	2003	1589	414	56.00	7.4
4	2003	267	1736	56.00	31.0
5	656	240	416	56.0	7.4
6	656	316	340	56.00	6.1
7	656	347	309	56.00	5.5
8	656	294	362	56.00	6.5
9	106	688	(582)	7.55	(13.3)

¹ Table 6.3

² Table 6.10

B benefit

C cost

() negative values from Table 6.3

Table 6.14 Estimated savings in site preparation and establishment.

Savings	£/ha.
Ground preparation excluding ploughing	33
Ploughing	7
Planting	50
Beating up	50
Total	140

Source: Greig (1985)

Table 6.15 Benefit and cost analysis of residue procurement undertaken by contractor for different Yield Classes of Scots pine.

Yield Class	Benefit(B) £/ha.	Costs* (C) £/ha.	B/C ratio
6	165	42	3.93
8	165	59	2.80
10	165	78	2.12
12	165	96	1.72
14	165	121	1.36
16	165	149	1.11

* Cost of NPK fertilisers from Table 6.9

This section addresses itself to evaluating the overall economic feasibility of residue potential. This is approached in two ways. Firstly, the residue harvesting is undertaken by contractor or an organised buyer other than forest owners themselves. In this case residue is priced on area basis. Thus, the price per hectare is between £20 to £30 regardless of the quantity of material removed. The second approach involves a situation whereby the forest owner, whether private or public, directly undertakes procurement of residue. This involves a direct sale of residue at the forest gate. Each of these two approaches is subjected to evaluation for different Yield Classes by assessing their economic implications as follows:

6.4.1 Residue Procurement by Contract

The concern here is not the benefit to the contractor but to the forest manager selling the residues. The only known cost (estimated) involved in this case is that likely to be incurred by the forest manager in replacing the nutrients removed as a result of residue harvesting. At present, other costs due to soil compaction and possibly hydrological effects can be ignored because they are not taken into consideration for conventional mechanised harvesting. Secondly, they are difficult to quantify, requiring long term studies of the effects of whole tree harvesting on both the physical and hydrological aspects of the site. The cost due to nutrient replacement differs for different Yield Classes (YC). The higher the site nutrient potential the higher the quantity of residue removed, thus the higher is the nutrient drain due to nutrient removal. Although the soils of sites with a higher Yield Class may have greater nutrient resources and the potential to maintain present rates of tree growth, this hypothetical assessment simply considers the replacement of nutrient drain.

Since under the current arrangements prospective buyers pay on area basis, it is perfectly in order to assume constant financial benefit per hectare. Thus ,

while the benefit per hectare under this approach remains constant (i.e. savings in ground preparation and subsequent silvicultural operation; and revenue per hectare), the cost of replacing nutrient losses increases with the Yield Class (YC) as shown in Table 6.15. Given the assumptions stated, the potential for residue procurement is economically viable since the benefit - cost ratios are all greater than unity. However, there is a decreasing trend of benefit - cost ratio with increasing Yield Class, indicating that the economic feasibility becomes marginal at YC 16. In theory, this implies that in order to compensate for nutrient depletion as a result of residue harvesting, the management pays a little less than overall potential benefits. However in practice a YC 16 site has a better nutrient support for the crop than in lower YC site. A better test of the potential economic feasibility (considering several uncertainties) is given in the latter part of this chapter (6.4.3).

6.4.2 Residue Procurement by Forest Owners

In this approach, with the procurement of forest residues undertaken as an extension of harvesting by the forest owner, the costs and benefits involved are slightly different. Costs include a hypothetically constant procurement cost, but because of the varying cost of fertiliser application the total increases with YC (Table 6.16). Table 6.17 shows a negative cost of procurement by whole tree chipping (heavy chipper at stump). Since this is cheaper than conventional harvesting, and there is still a substantial net benefit after subtracting the cost of nutrient replacement. If a market exists for whole tree chips it is potentially more profitable harvesting the timber in this form than as round wood for the pulp markets. However, for quality reasons, pulp manufacturers prefer traditional pulpwood to chips from whole tree chipping because it is technically easier to process pulp wood than to process chips with bark.

Analysis of costs and benefits of residue harvesting was carried out on slash chipping at stump. A production venture is considered economically feasible if the benefit - cost ratio is equal to or greater than unity (Gittinger,1983). The results (Table 6.18) for different YC indicate the potential economic feasibility of residue procurement. The benefit - cost ratio decreases with increasing YC but not so steeply as when residue procurement is undertaken by contractor (Table 6.15).

6.4.3 Sensitivity Analysis of Residue Procurement

In any hypothetical economic analysis of this type incorporating a number of assumptions, there is a need to check what happens if these assumptions do not hold. The application of sensitivity analysis (Gittinger,1982; Alan,1981) involves testing how sensitive the estimated economic feasibilities are to possible changes in benefit-cost assumptions. It is a means of drawing attention to the central reality of investment analysis since projections and expectations are inevitably subject to a high degree of uncertainty. In this section, the application of sensitivity analysis aims to cater for the range of conditions described in the following eight assumptions the first four relate to contractor purchase and the second set of four relate to forest owner:.

ASSUMPTIONS:

- I. Benefit is 15% less than estimated: e.g the forest owner decides to give away the residue free of charge to the contractor. In this case total benefits are only the savings in site preparation (estimated at £140 per hectare).

- II. Marginal increase in benefits, assuming that the price paid for residue is increased by £25 to £30 per hectare. Such an increase might be due to ^q/_k better

Table 6.16 Estimates of total cost of slash chipping at stump by
light chipper including cost of nutrient replacement

Yield Class	Fertiliser (NPK) 1	Procurement 2.	Total
6	42	240	282
8	59	240	299
10	78	240	318
12	96	240	336
14	121	240	361
16	149	240	389

1. Derived from Table 6.9

2. Derived from Table 6.3

All costs in £ per ha.

Table 6.17 Total procurement cost of whole tree chipping at
stump, including cost of nutrient replacement.

Yield Class	Fertiliser (NPK) 1.	Procurement 2.	Total
6	42	(839)	(797)
8	59	(839)	(780)
10	78	(839)	(761)
12	96	(839)	(743)
14	121	(839)	(718)
16	149	(839)	(690)

1. Derived from Table 6.9

2. Derived from Table 6.3

() negative value of costs implying savings.

bargain between ^{the} residue producer and user or to an increase in demand for residue due to technological awareness of residue uses. Thus, the gross benefit is benefit is £170 per hectare.

III. Benefits from savings in site preparation and silvicultural operation are reduced by 25% (i.e. from £140 to £105) but the price paid for hectare remained the same. Gross benefit per hectare is £130 (21% less than £165).

IV. Assuming the required fertiliser costs 50% more than estimated in extremely bad sites e.g. deep peat, the cost of nutrient replacement will be increased.

V. A 30% increase in machinery operating costs which might be due to any of the following possibilities: (a) rise in total machinery ^{costs} (b) fall in machine output level due to its inability to perform at the same level as in Finland where it has been on a large scale use, or lack experience and skill by its driver. (c) changes in foreign exchange rate (e.g. weakness ~~of~~ strength of Sterling) which increases capital cost. Thus the estimated operating cost rises from £0.99 per m³ in Table 6.2 to £1.49 per m³. This directly increases the corresponding harvesting cost for the above ground volume from £4.28 per m³ to £4.78 per m³ and the residue harvesting cost per hectare (Table 6.3) from £240 to £268.

VI. A 30% fall in the price paid for each slash chips per tonne (i.e. from £14.4 to £10.8 per tonne at forest gate). This will reduce the extra revenue on sales from £656 per hectare to £459 per hectare.

VII. A 40% increase in fertiliser requirement for each Yield Class will result in

Table 6.18 Benefit-cost analysis of slash chipping at stump by light chipper.

Yield Class	Benefits (B) £/ha.	Costs (C) £/ha.	B/C Ratio
6	796	282	2.82
8	796	299	2.66
10	796	317	2.51
12	796	335	2.38
14	796	360	2.21
16	796	388	2.05

* Estimated benefits due to residue harvesting by forest owners:

Extra revenue from residue sales (6.2.1) =£656 per ha.

Savings in site preparation & silvicultural operation (6.3.1)
=£140 per ha.

Overall benefits (slash chipping) =£796 per ha.

Table 6.19 Sensitivity analysis of economic potential
of residue procurement for scheme 5 by contractor.
B/C Ratios for range of assumptions I to ~~IV~~

Yield Class	Standard	I	II	III	IV
6	3.93	3.33	4.05	3.09	1.96
8	2.80	2.37	2.88	2.20	1.39
10	2.12	1.79	2.18	1.67	1.06
12	1.72	1.46	1.77	1.35	0.86
14	1.36	1.16	1.42	1.07	0.68
16	1.11	0.94	1.14	0.87	0.55

a corresponding increase in cost of nutrient replacement due to residue harvesting

VIII. A drop of 50% in the estimated savings from both the site preparation and silvicultural operations (i.e. from £140 per hectare to £70 per hectare). This brings down the total potential benefit by 9% from £796 to £726 while the overall cost remains the same.

First to be considered is a situation where an outside body such as a contractor undertakes the residue procurement and secondly where procurement is by the forest owner. The benefit - cost ratios obtained by making hypothetical changes in factors of production and procurement are detailed in Tables 6.19 and 6.20 respectively. A consideration of the two approaches shows that the economic feasibility is sensitive to a number of changes in costs and benefit.

In the first approach (residue procured by contractors who pay by area rather than quantity harvested) the economic potential becomes critically sensitive especially in the higher Yield Classes. Where the benefit-cost ratio is less than unity the procurement of residue is not economically profitable to the forest owner. This is particularly true of assumption IV which implies that the economic potential for residue is sensitive to major changes in nutrient replacement especially on sites where large amount of fertiliser will be needed to compensate for nutrient depletion. Under those conditions residue harvesting is economically disadvantageous to forest owners. Thus, such arrangements (which are currently being considered by Forestry Commission - Greig, 1985) are likely to be economically detrimental especially in sites with high yield. It is more profitable for the forest owner to bargain on a quantity basis, or even allow the residue to replace soil nutrients than to harvest them

for procurement on a area basis.

In the second approach, which involves the forest owner offering residues for sale the benefit-cost ratio also shows a progressive decrease with Yield Class (Table 6.20). Despite this, it is apparent that within the stated conditions V to VIII, residue procurement by forest owners is economically feasible even if its price falls 30% below the current value for fuel wood.

These analyses have to some extent shown that the potential of forest residues can be realised if the markets develop. Care must be taken by ^{the}residue procuring body on the choice of harvesting strategy and machinery as these influence procurement costs substantially, and consequently affect the benefit - cost ratios. Regardless of the procurement management (whether by contractor or forest owner), the potential economic viability of the exercise decreases in theory with increasing site potential (i.e. higher YC). It is reasonable to assume this particularly in costing site nutrient depletion due to residue harvesting until further work is done on the ability of the site to regain more nutrients from both its decomposing materials and aerosol. However, it is more critical under contractor than under forest owner, when both cases were subjected to sensitivity analysis (Tables 6.19 and 6.20). Forest residues occur because they can not be handled economically, so there is a need to reduce their costs of harvesting in order to utilise them. Residue procurement costs are influenced by size of the material, skidding distance, haulage distance, chipping location, slope of the site and species. The most important of these factors is likely to be the size of residue pieces but the effects of each need further investigation so as to decide on residue optimisation.

Table 6.20 Sensitivity analysis of economic potential of residue procurement by forest estate owners

B/C Ratio for a range of assumptions

Yield Class	Standard	V	VI	VII	VIII
6	2.82	2.57	2.12	2.66	2.57
8	2.66	2.48	2.00	2.46	2.43
10	2.51	2.30	1.89	2.28	2.29
12	2.38	2.19	1.79	2.13	2.17
14	2.21	2.05	1.66	1.95	2.01
16	2.05	1.91	1.54	1.77	1.87

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of this study according to each of the objectives. The techniques used to achieve each of the objectives as well as the main results are briefly discussed and recommendations for further studies are suggested.

7.1 QUANTITATIVE AND QUALITATIVE ASSESSMENT OF FOREST RESIDUE

The first objective was to assess both the quantity and quality of post logging clear felling residues using a particular site and crop as a case study. This is considered as an important step towards a better, i.e. more economic, allocation of the forest residue resource which until now has received little attention or economic analysis. The assessment started with a pilot study to determine appropriate methodology followed by a main study at Elibank and Glentress forests respectively. The main study involved the use of three sampling procedures utilising systematic plot mean tree, systematic grid line tree and random plot trees. Each was used to estimate the quantity of residue per hectare, differing only in the way the sample trees were chosen.

Qualitative assessment included the sorting of forest residue into types i.e. post-conversion residue (which includes tops and branches) and post extraction residue which consisted of unharvested main produce and odd pieces. Laboratory investigations were conducted on the green density, basic density and moisture content of these residue types and their values compared with those of main produce harvested. Reference was made to published information on both calorific value and

fibre length in different parts of a tree.

In the pilot study on Sitka spruce, the quantity of residue produced per hectare averaged 57.2 dry tonnes which is 32% of the main produce harvested (Table 4.12) and 24% of the above ground biomass (Table 4.14). These consisted of post conversion residues (28% of main produce; 21% of total above ground biomass) and post extraction residues which is (4% and 3% of main produce and total above ground biomass respectively). It was observed on the field that the losses were largely caused by the excessive quantity of branches due to the no-thinning regime. Although other factors could also account for this (such as the experience and skill of both the chain saw operator and the tractor driver) the quantity of the unextracted material from unthinned spruce should be a matter of concern for forest management.

For the Scots pine stand of yield class 8 at Glentress forest the quantity of logging residue averaged 24 dry tonnes per hectare which is 28% of the main produce harvested (Table 4.12) and 21% of the above total biomass (Table 4.13). Of this amount 27% is post conversion while 1% is post extraction residue. The study further revealed that the post conversion residue consisted of 87% branches and 13% tops and the post extraction residue (8% of material greater than 7cm top diameter) comprised of 47% odd pieces and 53% unextracted main produce. The unextracted main produce again represented 4% of the total main produce cut.

Of greatest concern is the quantity of main produce being left unextracted. This represents two financial losses to the management which are the procurement cost and the potential revenue foregone.

Qualitative assessment was carried out on residue materials from the pine site and revealed that the moisture content of tops is higher than that of live branches, and least for dead branches. When compared with the moisture content of ^{the} main produce the values for tops and dead branches are significantly different. As for green density, there are no significant differences between the values for main produce and residues (except for the dead branches which have ^a lower value due to their lower moisture content). Basic density, which is a better indicator of biomass, varies for the different residue types being least for tops. Although the stem tops may be more marketable than small branches they are of lower quality in terms of moisture content and basic density.

Literature surveys regarding tracheid length and calorific value revealed that the tracheid lengths of both tops and branches ~~or~~ shorter than for the older (i.e. matured) conventional produce. The differences in calorific value of different parts of trees are very slight. Wood with bark has a higher value probably due to extraneous substances present in the bark. Calorific value is inversely related to moisture content.

When considering the allocation of forest residue resources to different markets price has generally been accepted as the major controlling factor, and this is largely determined by piece size and overall quantity. This study has shown that in addition to size some quality parameters such as moisture content, density, fibre length and calorific value can influence residue utilisation. For example, the increased bark to wood ratio of tops and branches debar the use of this material for pulp and favours its allocation in the energy market.

7.2 DEVELOPMENT OF PREDICTIVE MODEL

The second objective of the study was the development and testing of local predictive models for residue yield. This was achieved using regression analysis to develop simple linear models for predicting residue quantity based on either tree diameter at breast height (dbh), dbh squared (dsq) or main produce weight harvested (pwt) as independent variables. Three sampling procedures were used and tests were carried out by comparing predicted and actual values to determine which predictor variable and sampling procedure produced the best model in terms of precision bias and cost.

Results obtained from these shows that any of the independent variables (dbh, dsq, or pwt) could satisfactorily predict the quantity of post conversion residues. The transformed function (dsq) was found to be a marginally more precise predictor variable than dbh or pwt. With regard to the selection of sample trees a systematic grid line transect has advantages over the other sampling procedures employed. Apart from its cheapness and simplicity, it also produced models with least standard error and relatively high coefficient of determination.

This study has shown that local stand predictive models for residue prediction on clearfell sites can be developed based on as few as thirty trees chosen by a systematic grid line transect technique. This could form the basis for wider forest or regional models which would take into account differences in site potential and crop type. This would enable managers to be aware of the quantity of what is currently regarded as 'waste' and to decide on its market potential.

7.3 ECONOMICS OF FOREST RESIDUE POTENTIAL

The third objective of this study was the economic assessment of residue production. This was carried out on a hypothetical framework because the material under discussion is not yet being produced on a commercial scale in the U.K. This section is subdivided into three parts, namely the evaluation of three harvesting options, the estimation of revenue under two management approaches, and the economic analysis of residue procurement. Data obtained in the field on residue quantity were used along with other relevant data derived from the literature. For example, procurement costs were based on synthesised standard times derived from Finnish data and UK Forestry Commission workstudy practice. The economic analysis necessitated some assumptions on potential residue value, and economics of residue procurement and indirect costs and benefits such as ecological implications.

Three broad options for harvesting forest residue considered are whole tree chipping; conventional harvesting plus chipping of slash; and conventional harvesting plus partial conversion of tops and larger branches. Strategies for achieving these options are based on both chipping location (at stump or roadside) and machinery type (light or heavy). It was shown that the second option i.e. conventional conversion plus chipping of slash at stump using light chipping machinery is both cost effective and likely to be accepted as a less risky modification to the existing harvesting convention. However, the most cost effective scheme is whole tree chipping at stump by heavy chipper but this is unlikely to be practicable unless a substantial continuing market develops for whole tree chips.

The ecological implication of intensive residue harvesting which is of greatest concern to forest resource management is the nutrient drain from forest sites. Estimates of potential nutrient depletion in this study show that although the loss is substantial (and varies with site potential) it does not seem to be too serious when translated into financial terms. Since the figures used in costing are only estimates, this finding should be reviewed as real costs become available. However, this study suggests that the consequences of harvesting forest residues may not be as ecologically and economically gloomy as some people would have us believe.

Two approaches to the management of residue procurement were considered, i.e. forest owner and contractor working. Benefit - cost analysis of residue procurement on different sites favoured procurement by forest owners rather than by contractors. However, if contract harvesting is necessary, negotiations based on the quantity rather than area is likely to be more profitable.

Sensitivity analysis carried out for the economic potential of residue harvesting under the two procurement managements showed that the viability of the exercise becomes critical at higher Yield Class^{es} but this critical condition was worse in ^{the} contract situation than in ^{the} forest owner's. At both critical situations it is ^{the} forest owner who has to bear the cost of nutrient replacement, this presupposes that sites with high yield potential are not capable of recovering from such nutrient drain.

Before concluding this economic assessment it is instructive to compare this study with that conducted by Albanis (1978) on mill residue. His survey showed that 85% of mill residues from home grown sawmills in England and Wales are being sold, two-thirds going to chipmills,

pulpmills, contractors and others. By comparison, ^{the} market for forest residues is not yet developed on a large scale. Secondly, the unsold quantity of residues (representing about 16% in 1978) is dumped or burnt. This implies that disposal of mill residues is compulsory and requires special equipment which involves cost. Again by comparison, the forest residue can be left to rot down except where it is excessive and impedes further silvicultural operations from taking place. The marketability of mill residue is due to its proven quality although there is still preference by purchasers for ^{particular} species and residue types. Finally, the disposal of mill residue does not pose any threat to the sawmilling industry, unlike the forest residues which has some ecological implications apart from its limitation.

7.4 RECOMMENDATIONS FOR FURTHER STUDY

The limited resources available for this study have highlighted the following recommendations for further study:

1. Detailed quantitative and qualitative investigation of residue production as related to site, species, silviculture, management regime and harvesting technique.
2. Development of regional predictive models that accomodate different species, sites, and management methods.
3. Research into the ecological and economic implications of residue harvesting on various species and site combinations. This would take into account different nutrient ^{requirements} and decomposition processes at each site in order to estimate the financial implications.
4. Research on the marketing of forest residues, with particular attention paid to the energy market and studies that emphasise competition with

other types of energy . Two aspects of this research should be the contribution of bio-energy from forest residues to economically depressed areas in the U.K. and the export of such technology to other parts of the world.

7.5 GENERAL CONCLUSIONS

Even though this study has not fully exhausted the issues associated with the potential of residues and their allocation to appropriate markets, it has highlighted the awareness of their resource potential in the light of current technological development. Thus, the following can be concluded from this study:

1. A simple and suitably precise technique for assessing the quantity of forest residue based on systematic sampling can be adopted to suit a particular working site. A systematic grid line transect technique has been found to be the cheapest, simplest yet most precise sampling procedure, compared with both random plot mean tree and systematic plot mean tree techniques.
2. Large amounts of material which if harvested could possibly alleviate the problem of global wood shortage are being left on forest floors as underutilised resources. This study revealed an average residue weight of 57.2 and 24.4 dry tonnes per hectare for clear-felled stands of Sitka spruce (unthinned) and Scots pine respectively. In both cases over 90% of these residues are branches, the rest being tops, odd pieces and unextracted produce.
3. The quantity of branches and tops left after felling and and extraction can be predicted using dbh, dsq (diameter squared) or produce weight (pwt). However, dsq is marginally the best predictor of residue quantity

out of the three, for a local predictive model using the grid line transect sampling technique.

4. Qualitative properties of these residues which make them less desirable for industrial uses such as pulp and board manufacturing are not restricted to piece size. Apart from size, their quality in terms of moisture content, and density is generally poorer than that of main produce. The tracheid length of tops and branches is shorter than that of merchantable boles while calorific value ^{of wood without bark is lower than} wood with bark.
5. There are several options for harvesting residue depending on machinery and procurement location (either roadside or stump). The lighter the machinery the more labour intensive it becomes and the costlier the whole operation. It was found that chipping at stump by a light chipping machine and haulage of chips to roadside is cheaper than chipping with the same machine at roadside. In view of the current opposition to intensive harvesting, conventional harvesting plus chipping of slash could be an acceptable compromise between non-harvesting of residue and intensive harvesting.
6. The economic implication of residue procurement from the hypothetical situations considered indicated more benefits than losses. Against the costs of nutrient depletion and subsequent replacement can be set the potential double benefits of savings in restocking costs and direct revenue from residue sales. The magnitude of these benefits depends on the type of procurement; it is more profitable for forest owners to procure residue by themselves, assuming there are markets, than to engage contractors, except where the terms of bargaining is on quantity rather than an area basis.
7. Sensitivity analysis relating to each of the factors mentioned in

section 6.4.3 has shown that the residue procurement is viable, with benefit - cost ratios generally greater than 1. However, residue procurement by contract is sensitive to increased costs of fertiliser application, and may become unprofitable to ^{the} forest owner who have to pay for nutrient replacement.

Salvaging forest wood residue has more promising potential in both financial and ecological terms especially if their market outlet is increased, recognised and organised. With a generally increasing trend of rise in the price of other sources of energy the allocation of forest residue into energy markets seems promising in the U.K., either for local consumption in rural areas or even as export in modified forms.

REFERENCES

- AARON, J.R. 1985 Pers. Comm. Potential uses of forest residues. Forestry Commission, Alice Holt Lodge Wrecclesham, Farham. Surrey.
- AARON, J.R. 1976 United Kingdom experience in the use of bark. Paper presented at the symposium on extending the use of wood residue. Bucharest, Romania.
- AARON, J.R. 1975 The use of wood as fuel. *Timber Grower* 55 : 30-31
- AITKENS W.S. & PARTNERS; and INTERNATIONAL FORESTRY CONSULTANCY 1984. Wood utilisation system. Combustion strategies. Reports prepared for Energy Technology Support Unit. Department of Energy, U.K. AERE, Harvel.
- AKERS, L.A. 1966. Particle board and Hard board. Pergamon Press, London.
- ALAN, J.B. 1981 Business decision making. Crom Helm London pp 192-211
- ALBANIS, K. 1978 An economic analysis of current and future markets for wood residue. Unpublished Ph.D thesis UCNW.
- ALBANIS, K. and COOPER, J.R. 1979a Residue production by home grown sawmills in England and Wales. *Forestry and British Timber* 8 (1): 20-22
- ALBANIS, K. and COOPER, J.R. 1979b Industrial uses of wood residues in Britain. *Forestry and British Timber* 8 (2):44-45
- ALEMDAG, I.S. 1982 Aboveground dry matter of Jack pine, Black spruce, White spruce and Balsam fir trees at two localities in Ontario. *The Forestry Chronicle*. 58 (1):26 - 30
- ALEMDAG, I.S. and HORTON K.W. 1981 Single tree biomass equation of trembling aspen, large tooth aspen and white birch in Ontario. *The Forestry Chronicle* 57 (4):69-173
- ANDERSON, A.B; WONG, A. and KING-TSEUN WU, 1974 Utilisation of fir bark in particle board. *Forest Product Journal* 1 : 51-54

- ANDERSON M. 1985 The impact of whole tree harvesting in British Forestry. *Journal of Forestry*. LXXIX (1): 33 - 39
- ANNE, S.F. , ROBERT, E.I. & DAVID, J.S. 1979 Energy farms for the future. *Journal of Forestry*. 79 (6):358 - 361
- ATWILL, P.W. 1966 A method for estimating crown height in Eucalyptus, and some implications of relationship between crown weight and stem diameter. *Ecology* 47 (5): 795-804
- BAILEY, G.R. 1969 An evaluation of the line intersect method of assessing logging residues. Information Rep. VP-X-23, Can. Dep. Fish. and Forest, Forestry Product Lab., Vancouver, B.C.
- BAILEY, I.W. and SHEPHERD, H.B. 1915 'Sanio's laws for the variation in size of coniferous tracheids'. *Bot. Gaz.* ix :66 - 71
- BARANTZKY, J. 1901. 'Ueber die unsachen welche die Richtung der Aeste der Baum- und straucharten bedingen'. *Flora*, lxxxix: 138 - 239
- BARLING, L. 1974. World paper and pulp shortage forecast. *Timber Grower*. 52 :36-38
- BASKERVILLE, G.L. 1965. Estimation of tree components and total standing crop in conifer stand. *Ecology* 46 :867-869
- BASKERVILLE, G.L. 1970. A simplified method of sampling logging. *The Forestry Chronicle*. 46 (3):288-294.
- BASKERVILLE, G.L. 1972. Use of logarithmic regression in estimation of plant biomass. *Can. J. For. Res.* 1:49-53.
- BERTO, H. 1895. 'Untersuchungen über den Wuchs und das Holz der Beisstana and und Fichte' *Forstl. Naturw z.* iv 97 - 112, 117 - 216.
- BIJAN, P. 1981. Choosing regression models for predictions. *The Forestry Chronicle*. 57 (5):229-232.

- BINNS, W.O. 1975a. Whole tree utilization -consequences for soil and environment experience and opinion in Britain. Proc. Konk. SK2. Elmia 72 Jonkoping Sweden.
- BINNS, W.O. 1975b. Fertilisers in the forest, a guide to materials. Forestry Commission leaflet 63. LONDON H.M.S.O.
- BITTERLICH, W. 1984. The relascope idea. Relative measurement in forestry. Commonwealth Agricultural Bureaux. Printed by Page Bros (Norwich) Ltd. Norfolk.
- BLISS, C. and BLAKE, D.O. 1977. Silvicultural biomass farms. Vol V: Conversion process and costs. National Technical Information service. (Rep. MITRE-TR-7347-V2/LL,136p) Springfield,Va.
- BORLEW, P.B. and MILLER, R.L. 1970. Chip thickness. A critical dimension in Kraft pulping. Tappi 53(11):2107-2116.
- BOLLEN, W.B. 1969 Properties of tree bark in relation to their agricultural utilisation. USDA Forest Service Research Paper PNN-77,1969. PACIFIC NORTHWEST Forest and Range Experiment Stations USDA. Portland, Oregon.
- B.R.E. Information, 1975. Measuring waste of building materials. Building Research Establishment. B.R.E. 34.
- B.R.E. Information, 1976. Wood residue utilisation, Princes Risborough Laboratory.
- BRUMBAUGH, J. 1960 Effect of flake dimension on properties of particle board. Forest Product Journal. 10 (5): 243 - 246
- BUNCE, R.H. 1968. Biomass and production of tree in mixed deciduous woodland: I.Girth and height as parameters for the estimation of tree dry weight. Journal of Ecology 56(1) :759 - 775.
- CAMPBELL, J. 1979. Wood energy. Forestry and British timber. 8 (2):38 -

- CAMBELL, A.A. and G. KATONA, G. 1953. The sample survey: A technique for social science research pp.15-55. In Festinger, L and D. Katz (Editors). Research method in Behavioral Sciences. Stapple Press, London.
- CANNELL, C.F. and KATZ, R. L. 1953. The collection of data by interviewing pp.327-380. In Festinger,L. and D. Katz (Editors). Research Methods in Behavioural Sciences. Stapple Press. London.
- CAREY, M.L. 1980. Whole tree harvesting in Sitka spruce. Possibilities and implications. Irish Forestry, 37 :48-63.
- CARROL, M.N. 1974. Effect of bark on the manufacture of particle boards and fibre boards. Informations Report, Western Forest Product Laboratory, Canada No. VP X-126
- CARRUTHERS, J. 1975. Availability and consumption of saw milling residues. Paper submitted to the symposium on modernisation of the saw milling industries. Geneva 1975.
- COURTENAY, G. 1978. Questionnaire construction. pp.27-54. In Hoinville,g., Jowell,R. and Associates. Survey Research Practice. Heinmann Educational Books. London.
- CROW, T.R. 1978. Common regressions to estimate tree biomass in tropical stands. For. Sci. 24 (1):110 - 114
- CROWTHER, R.E. and PATCH, D. 1980. How much wood for stove? Research information Note 54/80 SILS. Forestry Commission Research Station. Alice Holt Lodge, Surrey, U.K..
- DALLIMORE, W. & JACKSON, A.B. 1954. A Handbook of Coniferae including Ginhgoaceae. Third Edition. Edward Arnold (Publishers) Ltd. London.

- DEPARTMENT OF ENERGY, U.K. 1985. Digest of United Kingdom energy statistics , London HMSO.
- DEPARTMENT OF ENERGY, U.K. 1977. Digest of United Kingdom energy statistics (1977), London HMSO 120pp
- DINWOODIE, J. M. 1961. Tracheid and fibre length in timber. A review of literature. Forestry XXXIV : 125 - 144
- DOST, W.A. 1971. Redwood bark fiber in particle board. Forest Product Journal, 24 (1) :51-54.
- DOUB, R.L. 1976. Forest biomass as energy source. Study Report on a task force of the Society of American Foresters. Washington,D.C.
- DUNNS, S. & EMERY, J.O. 1959. Wood waste in composts. Forest Products Journal (9) 8:277 - 281
- ERICKSON, J. R. 1972 The status of methods for debarking wood chips. Tappi 55 (8): 1216 - 1220.
- F.A.O. 1973. A guide for planning pulp and paper enterprises.
- F.A.O 1976a. Wood chips. Production, handling transport. Rome.
- F.A.O. 1976b. Classification, definition and properties of wood residues. Paper prepared by the ECE/FAO Timber division at symposium on the extending the use of wood residues, Bucharest (Romania) 1976.
- FEIST, W.C., SPRINGER, E.L. & HAJNY, G. J. 1971. Storing wood chips at elevated temperatures- effect of abeali pre-treatment. Tappi 57(8): 112-114.
- FORESTRY COMMISSION, U.K. 1985. Harvesting mechnery statistics- FY 83/84 Harvesting Note 7. Unpublished.
- FORESTRY COMMISSION, U.K. 1983. Output guide- Extraction of semlogs and pulp wood by Valmet 10-tonne class forwarder. Section

XXII No. G14.

FORESTRY COMMISSION, U.K. 1981. Provisional standard time table thinning and clearing: Pine Larches and Douglas fir shortwood working. Section XVIII No.42

FORESTRY COMMISSION, U.K. 1978. Standard times for clearfelling Scots and Corsican pines. Section XVIII No. 33

FORESTRY COMMISSION, U.K. 1972. Standard times for extraction by Massey Ferguson MF.135 fitted with hydratongs. Section XXII No.24

FORESTRY COMMISSION, U.K. 1971. Terrain Classification Map of Forestry Commission forests in Scotland. FC. Record 114 LONDON HMSO.

FORESTRY AND BRITISH TIMBER, 1985. Current prices of Forestry Commission timbers. Forestry and British Timber 14 (6):8

FOSTER, N.G. 1967. Species variation. Proceeding of first symposium on particle board. Washington. ed. T. MALONEY.

FOX, R.L. and KAMPRATH, E. J. 1971. Adsorption and leaching of P in acid organic soils and high organic matter sand. Soil Sci. Amer. Proc. 35:154 - 156

FRASER, A.I. 1969. Some investigations of the relative development of crown, stem and root of trees on shallow peat soil in Britain. Suo. : 291 - 298.

FRASER, A.I. 1980. Wood as a source of energy for rural and Island communities. In Energy for rural and Island Communities, Ed. J. Twidell, Pergamon; Oxford.

FRASER, A.I. 1981a Wood as a source of energy for rural and Island communities. A paper presented at 'Energy for Rural and

Island Communities Conference held in Inverness. Organised by the Energy Study Units and the Dept. of Applied Physics, University of Strathclyde, Glasgow.

FRASER, A.I. 1981b The use of wood for industrial and domestic energy in rural areas of Britain and the transfer of wood energy technology to developing countries. Paper presented at the 'Energy for Rural and Island Communities' held in Inverness. September 1981, Organised by the Energy Studies Unit and the Dept. of Applied Physics, University of Strathclyde, Glasgow.

FREESE, F. 1962 Elementary forest sampling. Agricultural Handbook No.232. U.S. Department of Agriculture, Forest Service pp.9

FREESE, F. 1980 Elementary statistical methods for foresters. Agricultural Handbook No.317. U.S. Department of Agriculture. Forest Service.

GITTINGER, J.P. 1982. Economic analysis of agricultural projects 2nd Ed. Completely revised and Expanded. Published for the Economic Development Institute of the World Bank. The Johns Hopkins University Press. Baltimore and London.

GLEATON, E.A. and SAYDAH, L. 1956. 'Fiber dimension and paper making properties of various portion of a tree. Tappi xxxix (2):157A - 158A

GOCKERELL, E.C. 1966. Plantations on burned versus unburned areas. J. of Forestry. 64 (6):392 - 394

GRANTHEM, J.B; ESTEP, E.M.; PIEROVICH, J.M.; TARKON, H.; & ADAM, T.C
1974 Energy and raw material potentials of wood residues in the Pacific Coast states - a summary of a preliminary

- feasibility investigation. USDA Forest Service General Technical Report PNW-18.
- GREEN, D.C & GRIGAL, D.F. 1980 Nutrient accumulation in Jackpine stand on Deep and Shallow soil over Bedrock. *Forestry Science* 26(2):325 - 353
- GREIG, S. 1985 Pers. comm. Forestry Commission, Edinburgh.
- GOTT, A.M. 1975 Complete tree utilisation- Application in the U.K. Paper presented at 10th International Forestry students symposium. Department of Forestry and Wood Science. University College of North Wales, Bangor.
- HAKKILA, P. 1978. Harvesting small-sized wood. *Folia Forestalia* 342
- HAKKILA, P. 1980. Harvesting fuel chips with the Pallari swath harvester *Folia forestalia* 418
- HAKKILA, P. 1982. Utilisation of wood for energy in Finland. A report for OECF. 1982. Unpublished.
- HAKKILA, P. 1984. Forest chips as fuel for heating plants in Finland. *Folia Forestalia* 586
- HAMILTON, G. J. 1975 Forest mensuration handbook. Forest Commission Booklet No.39 LONDON HMSO.
- HARVEY, A.E., M.J. LARSEN, and JURQEUSEN, M. F. 1981. Rate of woody incorporation into Northern Rocky Mountain Forest Soils. USDA. For. Serv. Information. Forest and Range Experiment Station. Research paper INT-282
- HARTIG, R. 1892. 'Die Verschiedenheiten in der Qualität und im anatomischen Bau des Fichtenholzes.' *Forstl. Naturw. Z.* i.209. (Not seen, reviewed by Schultze-Dewitz, 1959).
- HATA, K. 1949. 'Studies on the pulp of Akamatsu (*Pinus densiflora* Sieb et

- Zucc). I. On the Length, Diameter and Length - diameter ratio of tracheid in Akamatsu wood.' Kawaga - Ken.Agric. Coll. Tech. Bull.i. 1-35. (Not seen. Abstracted in For. Abs. xiv.629).
- HATTON, J.V. and KEAY, J. L. 1975. The effect of bark on wood pulp, yield and quality on the economics of pulp production. Canadian Forestry Service. Western Forest Products Laboratory. Information report VR-X-126.
- HELANDER, A.B. 1933 'Variation in tracheid length of pine and spruce'. Found. For. Prod. Res. Finland. Publ. NO.14 . (English Summary).
- HIGGINBOTHAM, P. 1979, Possible solutions to small wood harvesting. Forestry and British Timber.18 (10):40-43.
- HOLMES, G.D. 1976. Whole tree marketing 1976 Annual Conference on 'The Developing World of Wood's Institute of Wood Science.
- HOLKIZ, H. 1968. Effect of chip size on wood fibre pulp and properties of fibreboard. Appila, 21 (6):196-206.
- HOWLETT, K. and GAMACHE, A. 1977a. Silvicultural biomass farms, Vol II.The biomass potential of short-rotation farms . National Technical Information Service. (Rep. MITRE-TR-7347-V2/LL,136p). Springfield, Va
- HOWLETT, K. and A. GAMACHE, A.. 1977b. Silvicultural biomass Farms . Vol VI: Forest and Mill Residues as potential sources of biomass. National Technical Information Service (Rep. MITRE-TR-7347-V6/LL 123 p). Springfield, Va.
- HUSCH, B., MILLER,C.I. and BEERS, T. W. 1982 . Forest mensuration 3rd edition. Ronald Press Co. New York.

- HUSCH, B. 1971. Planning a forest inventory. Food and Agriculture Organisation of United Nations.
- INMAN, R.E; D.J. SALO & MCGURK, B. J. 1977. Silvicultural biomass farms. Vol.iv: Site specific production studies and cost analyses. National Technical Information Service. (Rep.MITRE-TR-7347-V4/LL 158P) Springfield, Va.
- JEFFERS, J. N. R. 1960 Experimental design and analysis in forest research. (International Union of Forest Research Organisation) Stockholm, 1960.
- KEAY, J.L & J.V. HATTON, 1975. The implication of full forest utilisation on world wide supply by year 2000. Pulp & Paper International. 17 (6):49 - 52.
- KER, M.F. 1980 Tree biomass equations for seven species in southwestern Brunswick. Canadian Forest Service. Marit. For. Res. Centre Fredericton, New Brunswick, Inf. Rep. M-X-114.
- KING, N.J. & SMITH, C. A. 1974 Problems of wood waste. Forestry and Home Grown Timber, 3 (1): 46-48
- LEHMANN, W.F. 1965. Improved particleboard through better resin efficiency. Forest Product Journal. 15 (4): 243 - 246
- LYMAN, F.C. 1968. Factors influencing the properties of wood chip board. Particle Board Manufacturing and Application, ed. by L.Mitlin. Published by Pressmedia.
- LIKENS, G.E. & BORMAN, F. H. 1977 Biogeochemistry of a forested ecosystem Springer Verlag.
- LOFTHOUSE 1978. Whole tree chipping in the forest. Northern Region Work Study Team Report No.59 to Conservator, harvesting and marketing Division Ref. No. 040/77/6

- MALCOLM, D.C. and . CUTTLE, S. P. 1983a. The application of fertiliser to drain peat 1. Nutrient losses in drainage. *Forestry* 56 (2):155 - 173
- MALCOLM, D.C. and CUTTLE, S. P. 1983b. The application of fertiliser to drained peat 2. Uptake by vegetation and residual distribution. *Forestry* 56 (2):177 - 185
- MALCOLM, D.C., BRADBURY, I.K. & FREEZAILLAH, B.C.Y. 1977 The loss of nutrients from peat in an artificial system in the field. *Forest Ecol. & Mangt* . 1:109 - 118.
- MARTIN, A.J. 1976. Suitability of the line intersect method for sampling logging residues. USDA For.Serv. Research Paper NE 339 1976 . Forest Service, USDA. Northeastern Forest Experiment Station.
- MARTIN, R.J. 1984. Personal communication. SWOAC Edinburgh. U.K.
- McINTOSH, R.1981. Fertiliser treatment of Sitka spruce in the establishment phase in upland Britain. *Scottish Forestry* 35 (1):3 - 13
- MILLER, H.G. 1978. The nutrient budgets of even aged forests. pp 221 - 256. In *The Ecology of Even aged Plantation*,(ed.) D.Ford, D.Malcom, J.Atterson, I.U.F.R.O; Edinburgh.
- MILLER, H.G; MILLER, J.D & COOPER, J. M.1980. Biomass and nutrient accumulation at different growth rates in thinned plantations of Corsican pine. *Forestry* 53 (1):23 - 39.
- MITCHEL, C.P. 1981. Forest biomass for energy in Britain. *ARBOR* 7 (1) : 5 - 9
- MITLIN, L.1968. Basic raw material for particle board manufacture: Fibruous raw materials, Particle board manufacture and Application ed. by L.Mitlin, Published by Press media Limited. .

- MOSLEM, A.A. 1974. Particle board. Volume 1. Materials. Southern Illinois University Press.
- MORK, E. 1928. 'Granvirkets kvalitet saerling med skte paa slip-och celluloseved'. Papir Journaleu, 1928. (Reviewed by Dinwoodie).
- NEUSTEIN, S.A. 1967. Slash disposal to aid regeneration. Paper presented to conference of the International Union of Forest Research Organisations. Munich, 1967. Forestry Commission Research and Development Paper No.39 4p.
- NILSSON, S.I. & MILLER, J. D. 1982. Forest growth as a possible cause of soil and water acidification: an examination of the concepts. Oikos 39 :40 - 49
- OMEIS, E. 1895. 'Untersuchung des wachstumsgands und der holzbeschaffenheit eines 100-jährigen kiefernbestandes.' Forstl. Naturw. Z. iv.137. (Not seen, reviewed by Schultze-Dewitz, 1959).
- OLOFSSON, L. 1975 Varmevarde for olika delar av tall gran och bjork. Summary: Heating values for different parts of pine, spruce and birch. Rapp. Upsats Inst. skogsteknik. Skogshogssklan. 90:1 - 40
- OLSSON, P. 1984. Firewood fire in small scale forestry: Forestry Energy in Sweden, Sweddish University of Agricultural Services.
- ORMAN, H.R. & G.M. WILL, 1960. The nutrient contents of Pinus radiata. NZ J. of Sci. 3:510 - 552
- OVINGTON, J.D. 1957. The volatile matter organic carbon and nitrogen contents of trees species grown in close stands. New Phytologist 56:1 - 111

- OVINGTON, J.D. & MADGWICK, H. A. I. 1959. Distribution of organic matter and plant nutrients in plantation of scots pine. *For. Sci.* 5:344-355
- RENNIE, P.J. 1966. A forest sampling procedure for nutrients uptake study. *Comm. For. Rev.* 45: 119 - 127
- ROBERTS, A.N. 1968. Mulches in maintenance planning. Oregon Ornamental short course session for landscape garden. Oregon State University.
- ROLLINSON, T.J.D. 1980. Biomass estimation for open grown trees. Unpublished. Forestry Commission Research Station, Alice Holt Lodge, Farnham, Surrey. U.K.
- SALO, D.J.; REINMAN; MCGUNK, B. J. & VERHOEF, J. 1977. Silvicultural biomass farms. Vol.III: Land suitability and availability. National Technical Service (Rep. MITRE-TR-7347-V3/LL, 204p) Springfield, Va.
- SANIO, K. 1872. 'Ueber die grosse der Holzzellen bei der gemeinen kiefer (*Pinus sylvestris*).' *Fahrh.f.wissenschaftl. Bot.*viii :401 - 420
- SCHULTZE-DEWITZ, G. 1959: Variation and frequency of fibre lengths in spruce'. *Holzals Ruh-und Werkstof*, XVII (8), 319 - 326. C.S.I.R.O. translation 4800. (Not seen. Reviewed by Dinwoodie, 1961)
- SMITHERS, L.A. 1964. The impact of mechanical logging on silviculture in Canada. *For. Res. Br. Contribution No.648*, Dept. of For., Canada. Proceeding of IUFRO section 32. 1964 Meeting.
- SPINGER, E.L. 1973. New and effective chemical treatments to preserve stored chips. *Tappi* 56 (6):157
- SPURR, S.H. and HIJUVARINEN, M. J. 1954. Wood fibre length as related to

- position in tree and growth. *Bot.Rev.* 20:561 - 575
- SPROULL, R.C. 1969. Fibre, chemical and agricultural products from Southern pine bark. *Forest Product Journal*. 19 (10) :38 - 43
- STANEK, W. & STATE, D. 1978. Equations predicting primary productivity (biomass) of trees, shrubs and lesser vegetation based on literature. *Dep. Environ., Can. For. Serv., Victoria, BC Inf. Rep.* BC-X-183.
- STEWART, G.G. & NEUSTEIN, S. A. 1962. The protection of replanted groups within coniferous forest against Roe Deer. *Res. Rep.* 1961. Forestry Commission, London HMSO.
- THOMAS, H.H. 1969. A marketing study of fine wood residues in Southern Lower Michigan. Ph.D. thesis, Michigan University. (Not seen). Abstract.
- THORNTON, R. V. 1977. Whole tree chipping. *Forestry and British Timber* 6 (2): 27-28
- T.R.A.D.A., 1975 Wood waste : a technical and economic appraisal of its extraction, disposal and use. *Information Bulletin, Timber Research and Development Association, No. 1/1B/19.*
- U.C.N.W., 1974, The generation and disposal of wood residues in the U.K.. A report prepared for the Forestry Commission by the Department of Forestry and wood science, U.N.C.W.
- VAN WAGNER, C.E. 1968. The line intersection method in forest fuel sampling. *Forestry Science* 14(1):20-26.
- WAREN, W.G. and OSLEN, P.F. 1964. A line transect technique for assessing logging waste. *Forestry Science* 10(3):267-276.
- WHITTAKER, R.H. and WOODWELL, G.M. 1968. Dimension and production relations of trees and shrub in the Bookhaven forest, New

- York. *The Journal of Ecology*. 56:1-24.
- WITTERING, W.O. 1973. Standard time table and their uses in Work Study in Forestry. Forestry Commission Bulletin 47. HMSO LONDON.
- WITTERING, W.O. 1973. Costing and other Money Matters. Forest Commission Booklet 47. LONDON HMSO.
- WITTERING, W.O. 1977. Harvesting forest residues. *Forestry and British Timber*. 6 (2):31-43
- WOOD, D. 1978. Interviewing. pp.91-104. In Hoinville,g., Jowell,R.and Associates. *Research Practice*. Heinmann Educational Books. London.
- WRIGHT, T.W. and WILL,G.M. 1958. The nutrient content of scots and corsican pines growing on sand dunes. *Forestry* 31 :13-25.
- YOUNG, H.E. 1974. Complete tree concept 1964-1974. *Fibre conservation and utilisation*. Chicago, Ill. journal 18:83-86.

APPENDICES

Appendix 6.1 Labour cost for different forestry skill*

Type of skill	Cost in pence per standard minute
Chainsaw operator	4.34 ¹
Tractor driver	10.00
Forwarder/heavy chipper driver	11.00

* Forestry Commission rate for 1985.

Appendix 6.2 Machinery operating cost

Machinery type	Cost in pence per standard minute
1.Chainsaw	10% of labour cost (0.43) ¹
2.Farm tractor	4.9 ²
3.Forwarder	27.1 ³
4.Light chipper	6.7 ⁴
5.Heavy chipper	83.0 ⁴
6.Massey Ferguson Tractor & Hyratong	7.2 ³

Sources: 1. Forestry Commission (1985)

2. Estimated

3. Forestry Commission (1985b)

4.Hakkila (1984).

Appendix 6.3 Estimation of chipping cost by light chipper

Example: HS 500 HD LIGHT CHIPPER. Description: (Hakkila, 1984)

The HS 500 HD is a three knife drum chipper mounted on the three point linkage of a tractor. Its drum diameter is 450mm and weighs 200 kg. It is equipped with the desired hole size for crushing oversized particles. The feeding opening measures 20 x 40 cm. Its feeding device has two pulling rollers. The normal particle size of the chips can be adjusted over the range of 5-38mm Its prime mover is farm tractor.

The total weight of the machine is 1000 kg. It is manufactured by H - Steel Oy of Sweden. It has an hourly output between 6 - 8 m³

Operating Costs:

Cost price of chipper and accessories	=80,000 Finish Mark
Conversion rate from Finish Mark to sterling	=£1 to 8 FMarks (Cook 1985)
Cost price in £ sterling	=£10,000
Transportation cost from Finland to U.K.	=£500
Delivered price of the chipper & accessories	=£10500
Estimated life span of the chipper	=5 years = 200 x 5 day =200 x 5 x 8 hours =8,000hours

Machine running cost =Capital cost of the machine x 3 (Wittering, 1973 ~~a x b~~)

Estimated life span (hrs.)

=£10500 x 3

8000

=3.94 per hr.

Assuming a maintainance cost of 2% of running cost.

Operating cost per hour	=Running cost + maintainance cost
	=1.02 x £3.94
	=4.0188 =£4.02 (approx.)

(i) Operating cost per minute =£4.02/60
 =£0.067 =6.7p

Power is from Farm Tractor.

Assuming a second hand tractor is used.

Cost price	=£5,000
Depreciation over five years	=£5,000/5 =£1,000
Maintenance (2% of the cost price)	=£100
Interest in capital at 8%	=£400
Total per annum	=£1,500
Cost per hour	=£1,500/1600 =93p
(ii) Cost per minute	=93/60p=1.6p
Cost of fuel consumption per hour	=£2 (Diesel fuel)
(iii) Cost of fuelling per minute	=£2/60=3.33p
Total operating cost per minute	=(i)+(ii)+(iii)=(6.7+1.6+3.3)p=11.6p
Output per hour	=6 - 8 m ³
Average output used in this calculation	=7.0 m ³
Cost per output hour	=£((11.6 x 60)/7)/100 =£6.95/7=99p per m ³
(iv) Operating cost for light chipping	=99p per m ³

Appendix 6.4 Estimation of chipping cost by heavy chipper

Example: TT1500L

Description: (Hakkila, 1984)

This is a truck with its own motor which drives the three-knife disc chipper with its hydraulic feeder and loader. Its disc diameter is 150 cm. It has a separate cabin for the driver in the load space. The feeding device has a 45 x 500 cm. chain conveyor and above it an adjustable roller. The dimensions of the feeding opening are 45 x 48 cm. The particle size of the chip can be adjusted over the range 24 - 32 mm. and on a special order, a range of 16 - 25 mm. is possible.

The total weight of the unit is 22,000 kg. Its prime mover is a truck. It has an hourly output of chips between 20 m³ and 25 m³. It is manufactured by Hameanlinnan Konepaja engineering works of Perusyhtynia Oy and sold in Finland by Tyovaline Oy.

Operating cost:

Cost price of the chipper = 1.0 million Finish Marks = £125,000

Transportation from factory to forest = £1,000

Delivered price of the chipper from Finland to UK. = £126,000

Estimated life span of the chipper (5 years) = 8,000 hours

Machine running cost per hour = Delivered price x 3

Estimated life span (hrs)

= £(126,000 x 3) / 8000 = £47.25p

Assuming a maintenance and fueling cost of 5% of running cost:

Operating cost per hour = 1.05 x £47.25p = £49.61p

Therefore operating cost per minute = £49.61p / 60 = 83p

Output per hour = 20 - 25 m³

Average output per hour used in this calculation = 22.5 m³

Cost m³ = £49.61 / 22.5 = £2.21

Therefore machine operating cost for heavy chipper = £2.21 m³

Appendix 6.5 Theoretical extraction of whole tree by tractor winching

Assumptions:

- (i) Travelling distance each way on road is 150 m.
- (ii) Travelling distance each way in wood is 150 m.
- (iii) Terrain is relatively flat
- (iv) Trees were already felled prior to winchings, set up with tips pointing towards the winch rack.

Extraction time components were built by synthesis of standard time modifications for 100 m in wood and on road distance each according to work study practice (Wittering, 1977; Workstudy Report No.57, FC 1978).

Calulation: (Estimation)

Average volume extracted per load	=0.92 m ³
Terminal time per load	=21.28 SM
Time spent on road unloaded	= 1.11 SM
Time spent on road loaded	= 1.52 SM
Time spent in wood unloaded	= 3.06 SM
Time spent loaded	= 2.44 SM
Total extraction time for 0.92 m ³	=29.41 SM
Total extraction time per m ³	=29.41/0.92 SM
Tractor operating cost (including fuel)	=cost per hour x 32/60
Tractor operating cost per m ³	=£2.93 (Appendix 6.2)
	=£1.56
Labour cost (Driver's wage in appendix 6.1)	=£6 per hour
Labour cost per m ³	=£3.2
Total extraction cost per m ³ =Tractor operating cost+Labour cost/ m ³	=£(1.56 + 3.2)
	=£4.76

SIMULATION OF PRODUCTION COSTS

Appendix 6.6 Estimation of cost of harvesting main produce
(merchantable volume) by conventional logging
and extraction methods.

Felling and conversion:

Average volume per tree	=0.30 per m ³
Standard time for felling, snedding & conversion	=6.71 SM
Standard time for stacking	=0.12 SM
Total	=7.04 SM
Standard time for felling & conversion/m ³	=7.04 x 10.3 SM =23.46 SM
Labour cost for chainsaw operator Appendix 6.1	=4.34p per SM
Labour cost (felling & conversion)/ m ³	=4.34 x 23.46p=£1.02
Machinery cost (including cost of chainsaw & fuel)=10% labour	=10p
Total cost of production/ m ³	=£1.02 + 10p =£1.12
Extraction to roadside using Brunnett 578F Forwarder	
Estimated extraction time/ m ³	(Appendix 6.5)=32 SM
Labour cost i.e. driver's wage per hour	=£6.5
Therefore labour cost for 32 SM will be	£((32 x 6.5)60) =£3.47
Operating cost per hour for Brunnett 578F Forwarder	= £16.28
Forwarder's operating cost for 32 SM	=£16.28 x 3260=£8.68
Total harvesting cost of the main produce by conventional method/ m ³	
=(cost of felling & conversion + cost of extraction) /m ³	
=£(1.02 + 3.47 + 8.68)	=£13.17 m ³

Appendix 6.7 Estimation of procurement costs for whole tree chipping at stump by light chipping machine (e.g.HS500 HD_Appendix 6.3)

Cost elements*	SM/ m ³	Cost (£)/ m ³
LABOUR : (i) Chainsaw felling	136.0	5.94
(ii) Loading, chipping & chip haulage to roadside	28.8	2.88
(iii) Supervision		0.41
Total labour cost		9.23
MACHINERY: Chainsaw operating cost at 10% labour cost		0.59
(iv) Tractor & Chipper operating costs		0.99 (Appendix 6.1)
Total machinery cost		1.58
TOTAL (Labour + Machinery) costs		10.81

* Derived from Hakkila (1984)

SM - Standard minute/ m³ (Hakkila, 1984)

Cost (£) _ Derived according to FC (UK.) 1985 wage rate for forestry workers.

Appendix 6.8 Procurement costs for whole tree chipping at stump
by heavy chipping machine (e.g. TT1500L)

Cost elements*	SM/ m ³	Cost (£)/m ³
LABOUR: (i) Cutting of trees	49.0	2.12
(ii) Chipping of trees	4.8	0.48
(iii) Haulage of chips to roadside	9.6	0.42
(iv) Work supervision	12.0	0.52
Total labour/ m ³		3.54
MACHINERY		
(v) Operating cost for chainsaw at 10% of labour		0.21
(vi) Operating cost for heavy chipper(Appendix 6.4)		2.21
Total machinery cost/ m ³		2.42
TOTAL (Labour + Machinery)		5.96

* based on current wage rate for forest skill worker in UK.

+ Hakkila (1984)

Appendix 6.9 Procurement cost for whole tree chipping at roadside
using light chipping machine

	Cost elements*	SM/ m ³	Cost (£)/.m ³
LABOUR:	(i) Chainsaw felling	136.8	5.94
	(ii) Extraction to roadside	32.0	3.20
	(iii) Chipping at roadside	24.0	2.40
	(iv) Supervision	9.8	0.41
	Total labour cost/ m ³		11.95
MACHINERY:	(v) Chainsaw operating cost(at 10% of (i))		0.59
	(vi) Tractor extraction		1.56
	(vii) Tractor power for chipping		1.15
	Total machinery cost/ m ³		3.30
TOTAL	(Labour + Machinery)		15.25

(vi) _ Derived from Appendix 6.5

(vii) _ Derived from Appendix 6.3 ((ii) + (iii)) x 24

Appendix 6.10 Procurement costs for whole tree chipping at roadside
using heavy chipping machine

	Cost elements*	SM/ m ³	Cost (£)/ m ³
LABOUR:	(i) Felling of trees	49.0	2.12
	(ii) Hauling of whole tree to roadside	32.0	3.20
	(iii) Chipping of whole tree	4.8	0.48
	(iv) Supervision	9.6	0.41
	Total labour cost m ³		6.21
MACHINERY	(v) Operating cost for chainsaw (10% of (i))		0.21
	(vi) Operating cost for Tractor extraction		1.56
	(vii) Operating cost for chipping machine		2.21
	Total machinery cost/ m ³		3.98
TOTAL	(Labour + Machinery)		10.19

SLASH CHIPPING

N.B. For all roadside chipping of logging slash i.e. tops and branches, the working techniques are modified. Instead of converting the main produce at stump (which is the usual practice in conventional harvesting), the whole tree is extracted after felling to a depot on the roadside. At this depot, the tree is converted into main produce e.g. sawlog, pallet log and chip log following the conventional method (Figures 6.2 - 6.5) and stacked on the one side while the branches and tops are piled on the other side of the depot to allow for the free movement of the chipper.

Given the above arrangement the extraction costs of whole tree to roadside are shared between conventional produce conversion and slash procurement operations. One of the advantages of this approach is that

there will be only one machine required to pass over the site by extraction instead of two extractions if the extraction of main produce in conventional harvesting has to be done separately, thus the fear of soil compaction is reduced.

Appendix 6.11 Procurement costs for post - logging slash chipping
at stump by light chipping machine.

Cost elements*	SM/ m ³	Cost (£)/ m ³
LABOUR: (i) Chipping & chip haulage to depot	28.8	2.88
(ii) Supervision	9.6	0.41
Total labour cost/ m ³		3.29
MACHINERY (iii) Operating cost of tractor & chipper		0.99
TOTAL (Labour + Machinery)		4.28

Appendix 6.12 Procurement costs for post - logging slash chipping
at stump using heavy chipping machine.

Cost elements*	SM/ m ³	Cost (£)/ m ³
LABOUR: (i) Chipping	4.8	0.48
(ii) Haulage of chips to roadside	12.0	1.2
(iii) Work supervision	3.8	0.17
Total labour cost/ m ³		1.85
MACHINERY (iv) Operating cost of chipper		2.21
(v) Operating cost of hauling chips to roadside		1.56
Total machinery costs/ m ³		3.77
TOTAL (Labour + Machinery)		5.62

Appendix 6.13 Procurement costs for chipping of post-logging slash at roadside using light chipping machine

Cost elements	SM/ m ³	Cost (£)/ m ³
LABOUR (i) Haulage of slash to roadside	16.0	1.60
(ii) Chipping of slash at roadside	24.0	2.40
(iii) Supervision	9.6	0.41
Total labour cost/ m ³		4.41
MACHINERY (iv) Operating costs of tractor & chipper		0.99
(v) Operating cost of extraction		0.78
Total machinery cost/ m ³		1.77
TOTAL (Labour + Machinery)		6.18

Appendix 6.14 Procurement costs for chipping of post-logging slash at roadside using heavy chipping machine

Cost elements*		SM/ m ³	Cost (£)/ m ³
LABOUR	(i) Extraction of slash to roadside	16.0	1.60
	(ii) Chipping of slash at roadside	4.8	0.48
	(iii) Supervision	3.8	0.17
	Total labour cost/ m ³		2.25
MACHINERY	(iv) Operating cost of heavy chipper (appendix 6.4)		2.21
	(v) Operating cost of extraction of slash ¹		0.78
	Total machinery cost/ m ³		2.99
TOTAL	(Labour + Machinery)		5.24

¹ cost of whole tree extraction divided by 2

Appendix 6.15 HARVESTING OF STEM TOPS AND LARGE BRANCHES BY CONVENTIONAL METHOD (i.e. using chainsaw)

Harvesting and extraction of post-logging residue for further uses is still unpopular in the U.K. The costing used in the economic consideration of their potential is based on both short time study carried out and standard time obtained by synthesis (Wittering, 1977) - all of which are stated as follows:

I. Provisional method and time studies for harvesting stem top

JOB SPECIFICATION

(i) The chainsaw operator should fell individual tree according to the standard logging and safety precaution (Bardy, 1977).

(ii) Main produce from merchantable volume should be converted into various size specifications according to market requirements for sawlog, pallet and chipwood.

(iii) Snedding and conversion should be done further to the stem tip approximately 3.0 cm. top diameter i.e. beyond the normal top diameter of 7.0 cm. and crosscut into short length between 1 and 2 metres long.

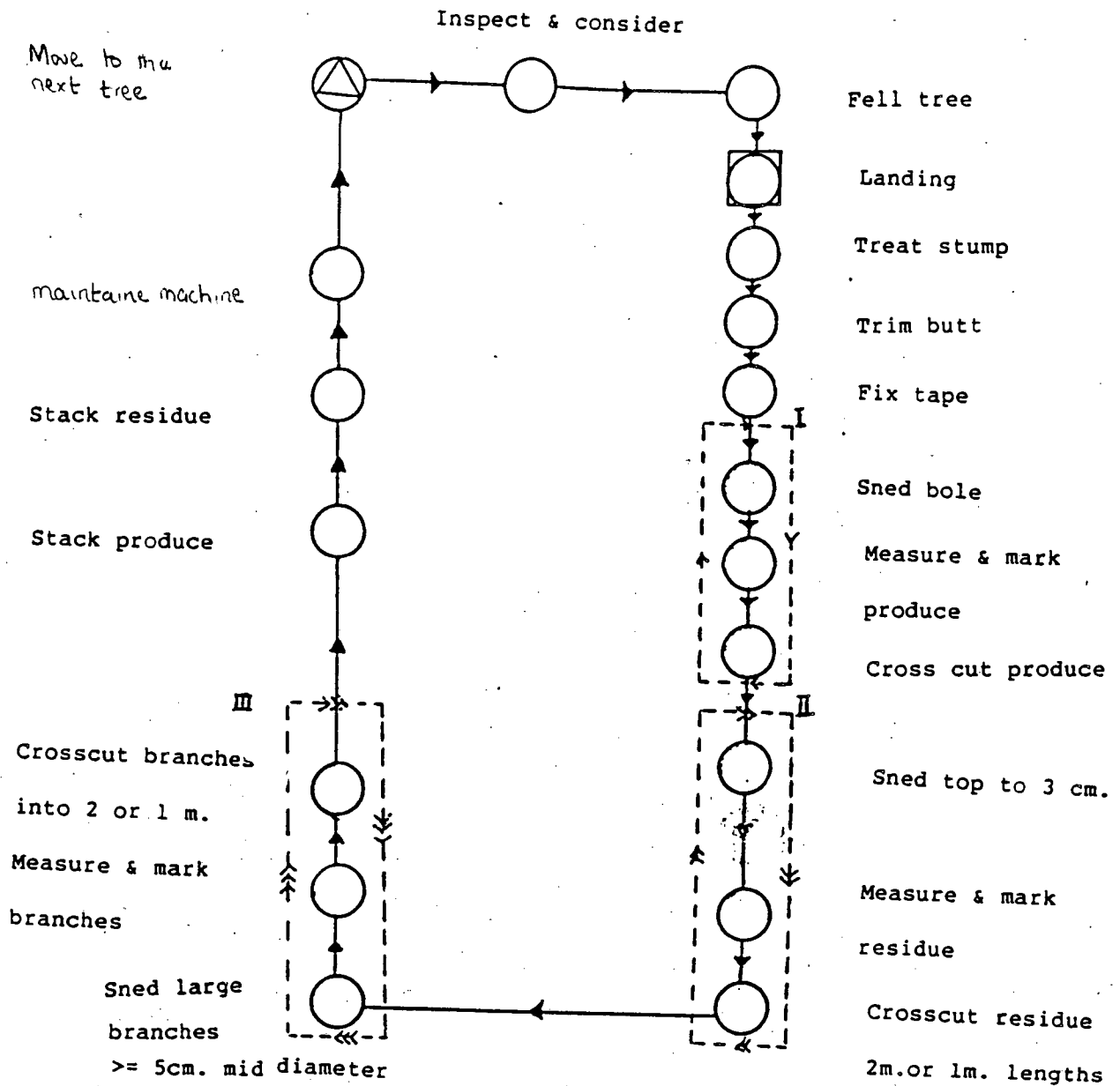
(iv) The chainsaw operator should after awhile gather and stack the main produce according to type (i.e. sawlog, pallet and chipwood) and residue including stem tops and large branches separately but not far from each other, within an area preferably in rows for easy extraction.

JOB CONDITION:

The site condition is assumed to be gentle in slope and pose no threat to the safety of the operator.

ASSUMPTION - Establishment of a standard time for any operation requires more than studying a single worker at work place. In order to obtain an average repeated studies requiring many workers are necessary. This was not possible for this exercise because of time and resources. It was therefore assumed that the only one chainsaw operator studied was an average worker.

II.FLOW DIAGRAM FOR HARVESTING OF MAIN PRODUCE, TOP & LARGE BRANCHES BY CHAINSAW OPERATION.



I Repetitive elements in the main operation (produce harvesting)

II Repetitive elements in the stem top harvesting operation

III Repetitive elements in the large branch harvesting operation

() Operation

I I Storage

V Temporary halt or delay

III RESULT OF TRIAL WORK MEASUREMENT: Time study for harvesting of main produce and stem tops only

WORK ELEMENTS	AVERAGE TIME*
Produce	
Inspect & consider	0.35
Fell tree	0.40
Treat stump	0.26
Landing	0.22
Trim butt	0.16
Fix tape	0.13
Turn tree & sned bole	1.77
Measure, mark & crosscut	0.47
Maintain saw	0.86
Total productive time for produce harvesting tree	4.62
Plus 30% contingency & other work allowance	6.01
Plus 26% Personal rest allowance	7.56
Provisional standard time (approx.)	7.56 SM. (cf. append. 6.6)
Residue: stem tops and or large branches	
Sned to stem top diameter 3.0 cm.	0.81
Measure and mark residue	0.16
Crosscut residue into 2 or 1 m. length	0.12
Stack residue	0.26
Total productive time for residue harvesting tree	1.34
Plus 30% contingency & other work allowance	1.75
Plus 26% personal rest allowance	2.20

* Average of two work measurements conducted on the field.

IV Estimation of production cost of stem top or large branches by conventional harvesting (to the roadside)

Felling & Conversion

Mean produce volume per tree (Scots pine) = 0.249 m³ Mean produce and residue volume per tree = 0.262 m³ Mean residue (stem top) volume per tree = (0.262 - 0.249) m³

= 0.013 m³ Provision

standard time for harvesting (logging & conversion) 0.013 m³ of residue

= 2.2 SM Time required to harvest 1 m³ of stem top = 2.20.013 SM

= 169 SM Labour cost

for chainsaw operator = 4.34 per SM Labour cost of harvesting 1 m³ of stem top = £169 x 4.34100

= £7.33 Machine

operating cost (for chainsaw = 10% labour cost) = £0.73 m³

= 73p m³

Extraction

Synthesis of extraction time for top or large branches is based on FC standard time extraction by Massey Ferguson MF 135 fitted with hydratong. (FC 1972)

No. of pieces grapple = 20.5 (approx. 21)

Distance travelled to make a grapple full = 45.2

(i) Terminal time per piece = 0.01 SM

(ii) Terminal time per piece until a full grapple is made

= 0.055 SM for a distance of 45.2m

(iii) Terminal time per piece on ride or rack for a distance of 150m.

= 0.13 SM

Total time piece = (0.01 + 0.06 + 0.13) SM

= 0.2 SM.

Volume of piece = 0.013 m³

Therefore time required to extract 1 m³ of topsor a large branches

=0.20.013 SM

=15.4 SM

Costing

Labour cost for the driver =£6.5 per hr.

Therefore 15.4 SM (i.e.1m³) costs =£15.460.0 x 6.5

=£1.67 m³

Operating operating cost for Ferguson for 15.4 SM (1m³)

=15.460 x 4.29

=£1.10m³

Total extraction cost

=£1.67 + £1.0

=£2.77m³

Felling & conversion: Labour cost =£7.33m³

Machinery cost =£0.73m³

Extraction to roadside: Labour cost =£1.67m³

Machinery cost =£1.10m³

1. Whole tree chipping at stump by light chipping machine
2. Whole tree chipping at stump by heavy chipping machine
3. Whole tree chipping at roadside using light chipping machine
4. Whole tree chipping at roadside using heavy chipping machine
5. Chipping of post logging slash at stump by light chipping machine
6. Chipping of post logging slash at stump by heavy chipping machine
7. Conventional conversion of main produce and chipping of post logging slash at roadside by light chipping machine
8. Conventional conversion of main produce and chipping of post logging slash at roadside by heavy chipping machine
9. Conventional (i.e. chainsaw) harvesting of stem tops and any large branches to 3.0 cm. at stump.
10. CONTROL i.e. No procurement of residue - which is the standard practice whereby only the currently merchantable parts of the tree are harvested by conventional shortwood logging methods to minimum top diameter of 7.0 cm. while the residues (i.e. tops and branches) are left behind on the forest floor.