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In your reply please quote
Your reference ....
Our reference .... LJP:RAH F.D. 245/81

FORESTS ... RECEIVED ... NOV 1981 ... WA

19th November, 1981

Mr. J. Havel,
Forests Department,
54 Barrack Street,
PERTH. 6000.

Dear Sir,

Mr. D. Douglas has asked me to provide you with some information on the costs of chopper-ploughing. The chopper-plough used is a prototype developed as a joint project by Geoff Williames (Australia) Pty. Ltd. (the manufacturer/inventor), Forests Commission, Victoria, A.P.M. Forests and this Department. Following trials in the forest areas of each contributor, the prototype was purchased by this Department for further development and evaluation. Unfortunately it must be pulled by a Cat. D8-size tractor, and our only machine of this size was damaged by fire early this year. Therefore further trials have been deferred until probably May 1982.

I enclose a copy of the interim report describing our trials. These covered two site types, the first was the Caroline fire area where young pines were killed by crown fire and were being removed for replanting; the second was following our "normal" clear felling operation in 50 year old multi-thinned Pinus radiata.

Also enclosed is a copy of a report prepared by Forests Commission, Victoria, on their trials, where they compared the chopper-plough and the chopper-roller. We would tend to agree with their conclusion that the roller is better value.

Production rates in our trials varied from 0.157 to 0.232 hectares per hour, Forests Commission, Victoria, achieved up to 0.635 hectares per hour and A.P.M. up to 0.370 hectares per hour. Production depends upon amount of debris on the site, depth of ploughing and size of stumps. It is also expected that production would improve with some modifications to the prototype and with operator experience.

Cost per hour for plough, bulldozer and operator at time of the trial (late 1979) was approximately $123 per hour. This gives a cost per hectare of ploughing from $194 to $783. Using an estimated 1981 cost of $137 per hour, this range would be $215 to $872 per hectare.

There are certain improvements in performance possibly by modifications to the prototype and these are now complete. You will note that our report refers to the Mark III "PL 600". This is the proposed configuration of a new plough which would be designed to minimize existing problems but still utilizing the plough concept. Current cost would be about $180,000.

Costs per hectare for this proposed unit are included to give an indication of "best possible" costs using the chopper-plough concept. These would range from $142 to $576 per hectare (1979 costs).

While these costs per hectare appear extreme, they must be offset by present clearing costs and the fertilizer value of the nutrients and organic matter which are retained on the site. Also, the finished job includes stump removal while most present methods do not.

In summary, this Department is looking to the chopper-roller approach to debris destruction, rather than the chopper-plough. However, the plough has sufficient attractions to make it worth developing as a realistic alternative.

Yours faithfully,

P.M. South

P.M. South
DIRECTOR

per

~~1) Mr~~ 27/1/81

2) Mr Bitcher — Please ensure ADFO at Bragança sees this, or gets a photocopy.

3) Mr Lejeune
4) Mr Dansoh — for your information & discussion 27/1

Enclosure 2

CHOPPER PLOUGH INTERIM REPORT

Introduction

This interim report does not include any results from plot sampling after ploughing - only visual assessment is disoussed. Similarily productive rates in plots are presented but there is no detailed analysis of downtime.

The plough completed 20 working days in the period 5.12.79 to 17.1.80 although many of these days constituted less than 2 hours actual ploughing because of breakdowns, repairs and shifting between plots.

P. Mitchell
January 1980.

Operational Method

Each trial plot required a different operational technique to obtain a ploughed finish that might be regarded as the minimum acceptable to enable hand planting and subsequent tending (i.e. access for fertilising and weedicide equipment). The following perameters were found to have a marked effect on finish produced:-

1. Rotor Speed - It was found early in the trial that the maximum rotor speed the drive chains could handle (9th gear/550 rpm) resulted in smaller piece sizes.

2. Travel Direction - it was found that ploughing in the row direction produced better results both in standing and felled timber. Ploughing across the rows in standing timber resulted in trees being pushed outside the swathe of the plough because of irregular planting intervals and in felled timber the operator could not be sure of treating all stumps if the plough travelled perpendicular to row direction.

3. Rate of Travel - was not limited by the Komatsu's pulling capacity but by the H.P. of the plough. That is, the operator selected the rate of travel which minimised stalling of the plough motors through overload.

4. Depth of Ploughing - it was found that shallow ploughing (approx. 2" deep) gave a more level finish than deep ploughing (4" - 6"), which resulted in many mounds and depressions. It was however, necessary to plough deeper in plots where tree pushing and ploughing occurred in one pass (1969/336 and 1969/335 P. pinaster) to remove stumps. On shallower passes many 3' - 4' high stumps were left. The addition of the tree pusher to the blade resulted in fewer stumps since trees were completely pulled out of the ground but a second pass was still necessary to remove all stumps. Deep ploughing was also necessary in felled stands if timber was buried e.g. 1931/33 where the skidder had buried tops and smash.

5. Number of passes - a second pass was necessary in 1969/336 to remove stumps. This was a slow deep pass where the blade was used for pushing and a fast shallow pass where the tree pusher was used.

Plot Characteristics that Affected Finish and Production

(1) Moisture Content of Wood - "green wood" (P. pinaster and C/F 1931/33) was chopped into smaller pieces and resulted in a mulch. By providing less resistance to chopping one can expect higher productive rates in fresh timber.

(2) Volume/hectare - Appendix II shows the relationship between volume of wood per hectare and productive rate (1931/33 not included because of the effect of large stumps).

A.P.M. found that their "break-even" point with windrowing was 0.33 ha/hour which corresponds to an estimated volume/hectare of 130 m3. (In the Caroline fire area this would encompass the 1977 - 1971 planting of which there is only 460 ha to be ploughed and replanted).

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It seems obvious that 1961/118 with 277 m3/ha was beyond the ploughs' capabilities as reflected in the very low productive rate (0.125 ha/hour) and correspondingly high cost per ha ($984) (See Appendix I).

(3) Stem Size - the larger logs were in fact chopped more thoroughly than the smaller stems (in both green and dry timber). The smaller stems (e.g. 1969/336) because of their light weight are thrown through the plough before the rotor teeth can act upon them completely. The larger stems (e.g. 1960/96) however, "stay put" longer because of their weight and are chopped more completely (although they do slow the travel rate).

(4) Felling Direction - in the plots where trees were aligned across the rows the tracks of the Komatsu tended to bury the wood making deeper ploughing necessary. Alignment of trees in row direction enables straddling by the Komatsu and eliminates the need for deep, unproductive ploughing which results in an uneven finish.

Productive Rates and Cost/hectare

Productive rates per Effective Machine Hour (EMH) are set out in Appendix I. In all cases the ploughing time was adjusted to 400m ploughing distance to allow for more direct comparison between plots since the turning element constitutes an unrepresentatively high percentage of EMH on the runs shorter than 400m. Engine stalling time has been included in EMH.

Cost/hectare was estimated using two methods :-

(A) Appendix III - it was assumed that if Woods and Forests bought the Mark II model (used in trials) for $100,000 and spent $20,000 on modifications (discussed under "Design Faults") then utilization would be increased from the 38.9% of the trial to 60%. This does not seem unrealistically high considering the trial was not a production situation; that the operator was relatively inexperienced and long service time required because of design faults that could be eliminated for $20,000.

This gave an hourly cost of $123.

(B) Appendix IV - it was assumed that if Woods and Forests bought the "PL600" Mark III model for $150,000 with its single 600HP engine (which would give more effective HP at the rotor due to elimination of much of the power loss through the two complex drive trains in the present model) and high speed chains which would allow 10th gear operation (~~550~~ 185 rpm) then utilization would be increased to 70% and production lifted by 25%. These are very speculative assumptions but it gives some indication of the very best performance we might expect from the next model, i.e. it is a minimum approach with regards to cost/hectare. This gave an hourly cost of $113.

In the Caroline burnt area only 25% of nutrient remains in the burnt trees and bark. Therefore the elimination of the need to windrow and burn is a saving of 25% of the fertiliser and application cost in this area. Therefore we have:

		$'s/ha over a 5 year period.
Fertiliser:	$110/~~ha~~t @ 3 tonnes/ha:	$330
Application:	$60/~~ha~~t. @ 3 tonnes/ha:	$180
		$510

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∴ Saving in fertiliser through using chopper plough is
$\frac{1}{4}$ x \$510 = \$128/ha.

Windrow and Burn

	\$'s/ha
Windrow	190
Burn	40
Extra Fertiliser	128
	\$358

The results from the trials show that no treatment which gave a "satisfactory" result for planting and tending was below \$358/ha. Using the Mark III costing the cheapest alternative is \$331/ha but it would still be expected that planting, fertilising and weedicide costs would be higher and considering that the Mark III model is an unknown quantity and that very liberal utilization and production rates have been used in the costing it does not appear that the chopper plough is a viable alternative to windrowing in the Caroline fire area.

The trial in the multi-thinned clearfelling resulted in a very good finish (a fine mulch of slash and wood with ground level stumps and only the occasional piece of buried smash material) but the productive rate was slow (0.157 ha/hr). The area could be hand planted without further treatment. When compared with windrowing we get:

WINDROWING

\$100	sweep
\$ 40	burn
\$510	fertilise
\$650	

CHOPPER PLOUGH

	Mark II	Mark III
Plough	\$783	\$576
Fertilise	\$170	* \$170
	\$953	\$746

*assume $\frac{1}{3}$ normal fertiliser rate would still be applied to make up for nutrient loss in logging.

Again the figures indicate that the chopper plough is not a viable alternative to windrowing in clearfelling site preparation, unless the elimination of stumps is worth at least \$100/ha.

It must also be noted that the Komatsu and chopper plough combination uses 32 gallons of diesel (145 litres) per hour or 204 gallons (918 litres) per hectare. I haven't looked at fuel consumption in the windrowing system yet, but it appears unlikely to be of this order.

The productive rate, finish and cost/hectare in P. pinaster (1969/335) was good. The low volume/hectare and green nature of the wood were the main reasons. It is likely, however, that the chopper rollers could produce a comparable finish at a lower cost/hectare in this small size material.

Design Faults in the Plough

The low utilization (38.9% of scheduled hours) was a direct result of high repair and service times. The design faults which caused excessive downtime and retarded productivity were:-

1. Chains and chain cases

The rotor is driven by four 2" chains which required re-tensioning (or checking) every day since they weren't designed for such a high speed/high load application. The chains had to be replaced at a cost of $1,500 after about 35 hours operation in our trials. Special high speed triplex or duplex chains appear necessary to handle the rigours of ploughing in our areas.

The chain cases are sealed by a mechanical inertia seal which did not seal when the rotor stopped and the oil was hot. Consequently the cases had to be checked and usually filled twice a day which meant about 45 minutes downtime/day.

2. Protection around Plough Engine Bay

When tree pushing the operator had to stop frequently to clear trees that had entered the engine bay and could cause damage to lines, pumps, electrical equipment etc. Simple shrouding of this area would not be expensive.

3. Plough Controls and Engine Stalling

When the engine stalled the operator had to leave the cab, start the motors, return to the cab and lift rotors, get out and engage clutch, open throttles then return to cab. This is obviously time consuming and could be shortened by having all plough controls (i.e. engine start, clutch engage etc.) in the cab.

Engine stalling time was excessive (7% of EMH in 1931/33) and could be eliminated by the incorporation of a fluid coupling which would absorb the impact when the rotor hits a major obstruction.

4. Two Engine Power Unit

During the trial one motor was not working to full capacity under load and this combined with the power loss through the drive train system would have drastically reduced the effective HP of the rotor. A single 600 or 800 HP motor coupled by a chain and fluid coupling to the rotor would increase effective HP and productive rate.

5. Plough Wheels

On the Mark II model the wheels are mounted in front of the rotor so that when the wheels climb over an obstacle the rotor is raised and the obstacle is not ploughed. This configuration makes depth control by the operator very difficult and much material is not

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chopped. Also any "pitching" of the Komatsu in uneven going is transmitted to the rotor and again depth control is difficult.

The Mark III "PL600"Model with its rear wheels mounted behind the rotor and an extra set of wheels on a trailing arch in front of the rotor would eliminate this problem and enable a better finish at a faster productive rate. The tractability of the plough would be increased by the additional wheels.

6. Teeth

The teeth used in the trial were unsatisfactory in two aspects. Firstly the shaft at the tooth was welded to the tightening bolt and the tooth would break at this weld resulting in1 to 2 teeth per day being lost (very expensive at $85/tooth). Drop forged teeth would greatly decrease the incidence of tooth failure.

Secondly the tungsten carbide tipped teeth wore rapidly on the mild steel face of the tooth. The tips themselves resisted wear but this face should be hard faced to reduce wear.

7. Air Filters

Air Filters (4) had to be cleaned twice a day when ploughing in the burnt area (up to 1 hour per day). Self cleaning blower type filters would eliminate this downtime.

8. Electrical System

Failures in the starter system resulted in 1½ lost days. The system was unnecessarily complex.

CONCLUSION

The trials did not come out in favour of the chopper plough when compared to the conventional windrow/burn system on both a cost basis and in terms of level of site preparation achieved in the Caroline fire area.

The use of the plough in clearfelling showed some potential in terms of finish achieved but again costs were prohibitive because of large stumps greatly limiting travel speed. The alternative treatment of clearfelled sites using the tree lowerer/stump cutter/chopper roller system should prove cheaper and has the advantage of recovering additional royalty through the elimination of log smash and degrade caused in the manual falling system.

The large volume/hectare of material in nearly all trial plots when compared to AFM's 25 year old clearfelling, and the resilient nature of the wood in the fire area were probably the main reasons why we did not achieve their productive rates or level of site preparation.

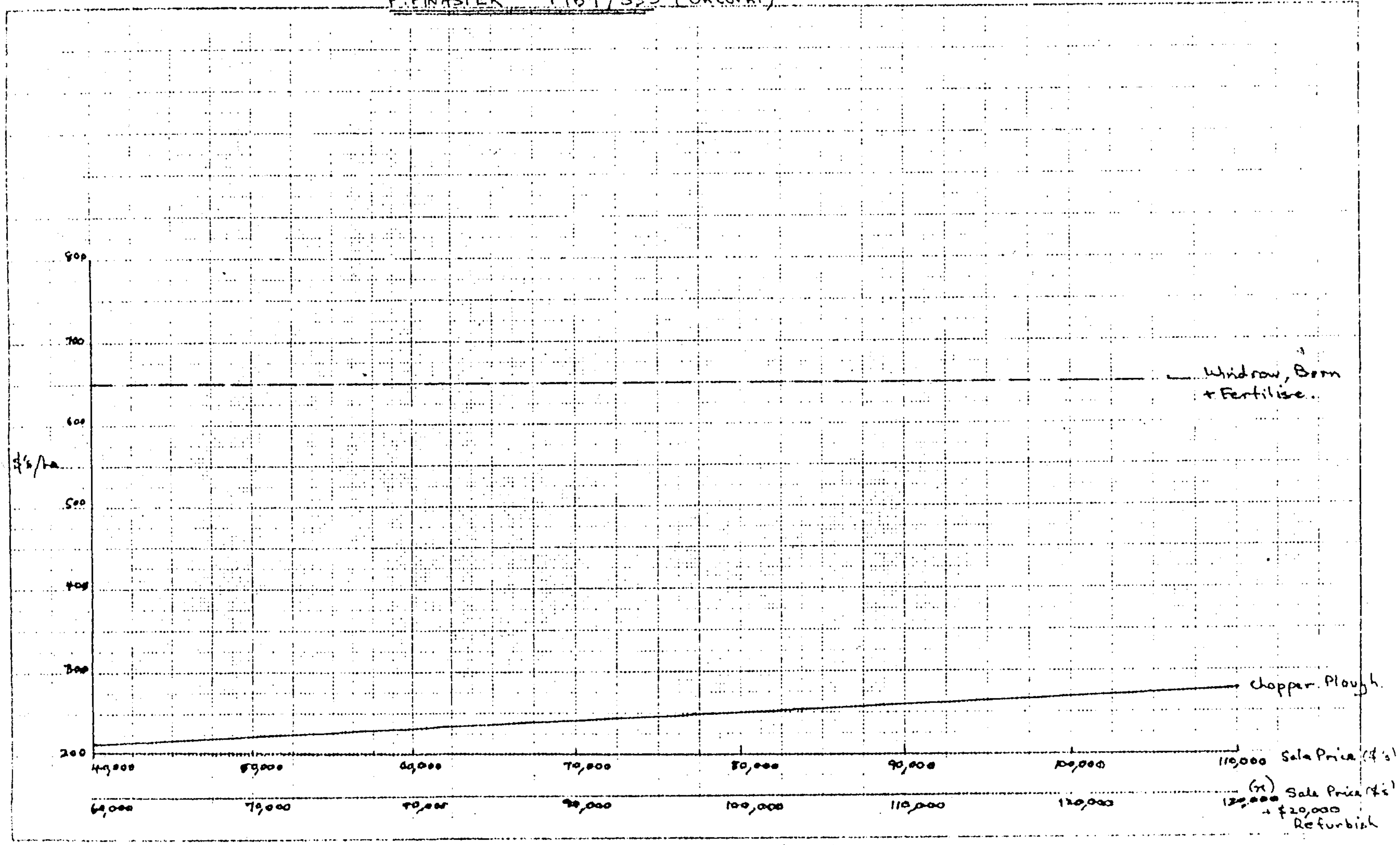
Trial Area	Previous Treatment	Vol. wood on site (m3/ha)	Av. DBH (cm)	Chopper Plough Treatment	Area Ploughed (ha)	No. of Hours Ploughing	Productive Rate (ha/EMH)
1969/336 Caroline	Standing Trees (Crown Fire)	170	14.7	1st pass 9" 2nd pass 6" No tree pusher	0.139	0.95	0.146
	Standing Trees (Crown Fire)	170	14.7	1st pass 4" 2nd pass 6" No tree pusher	2.849	12.28	0.232
	Standing Trees (Crown Fire)	170	14.7	1 pass 6" with Tree pusher	3.080	8.58	0.359
	Standing Trees (Crown Fire)	170	14.7	1st pass 6" 2nd pass 2" with Tree pusher	0.167	0.61	0.273
				Sub-total	6.235		
1960/96 Caroline	Area 1st thinned then felled after fire in May '79	207	20.0	1 pass 6"	3.203	13.81	0.232
1961/118 Caroline	Trees pushed down with D7	277	16.5	1 pass 3"	0.176	1.41	0.125
1969/335 P.pinaster Caroline	Standing Trees Butt scorched	40	-	1 pass 4"	0.704	1.55	0.455
1931/33 Myora	Clear felled Multi-thinned stand	100 Plus large stumps	-	1 pass 4"	3.000	19.11	0.157
				TOTAL AREA	13.318 ha		
				TOTAL HOURS		58.30	

Total scheduled hrs = 7½ x 20 = 150 hrs

Utilisation = $\frac{\text{Productive Hours}}{\text{Scheduled Hours}} = \frac{58.30}{150.00} = 38.9\%$

Appendix II : Production / cost graphs.

FIGURE 1. Chopper Plough Vs Conventional Practice (with Purchase Price of Plough as a Variable).
P. PINASTER 1969/335 (Unburnt)



Mk II as tested

Mk II + $20 000 of modifications.

FIGURE 2. Chopper Plough Vs Conventional Practice (with Purchase Price of Plough as a Variable).
1969/336 (Burnt)

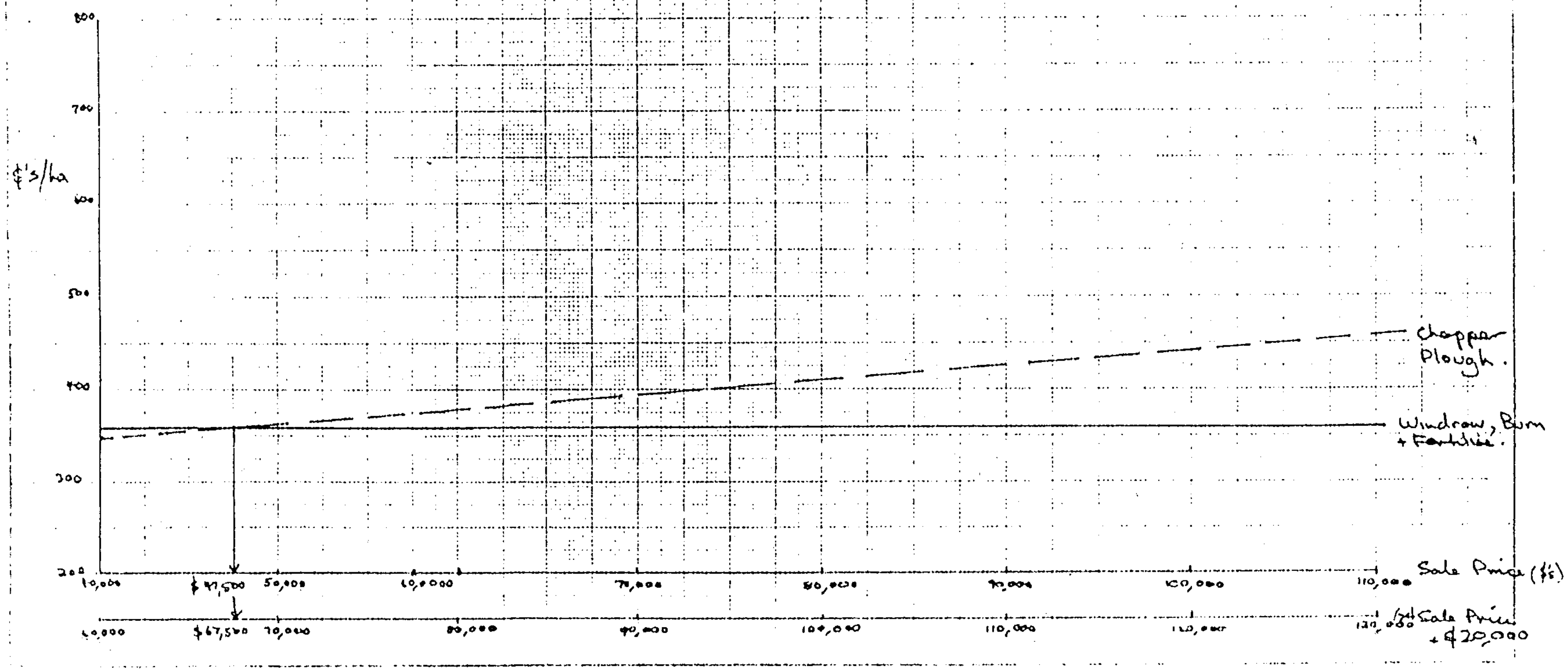


FIGURE 3. Chopper Plough VS Conventional Practice.
1960/96 (Burnt).

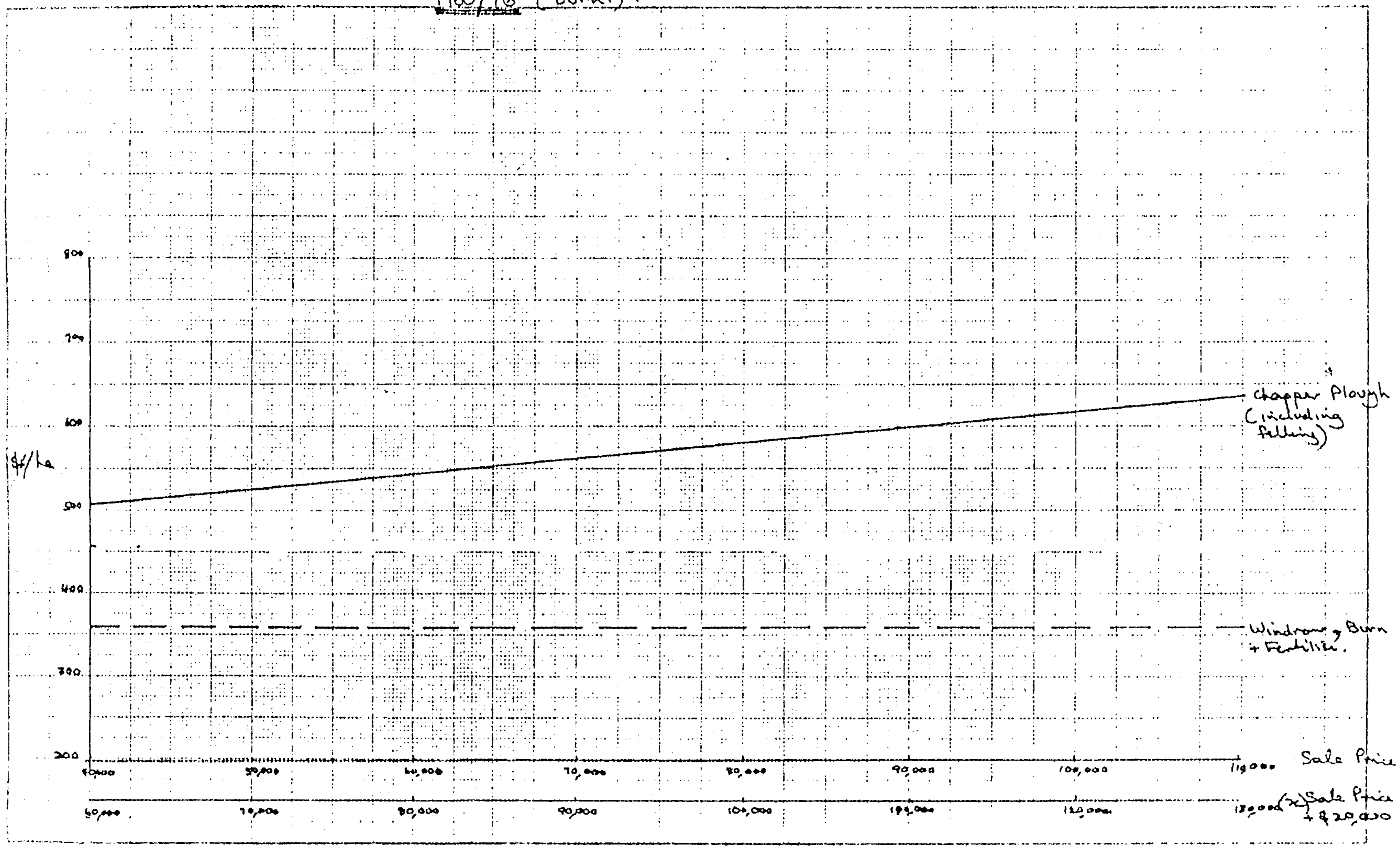
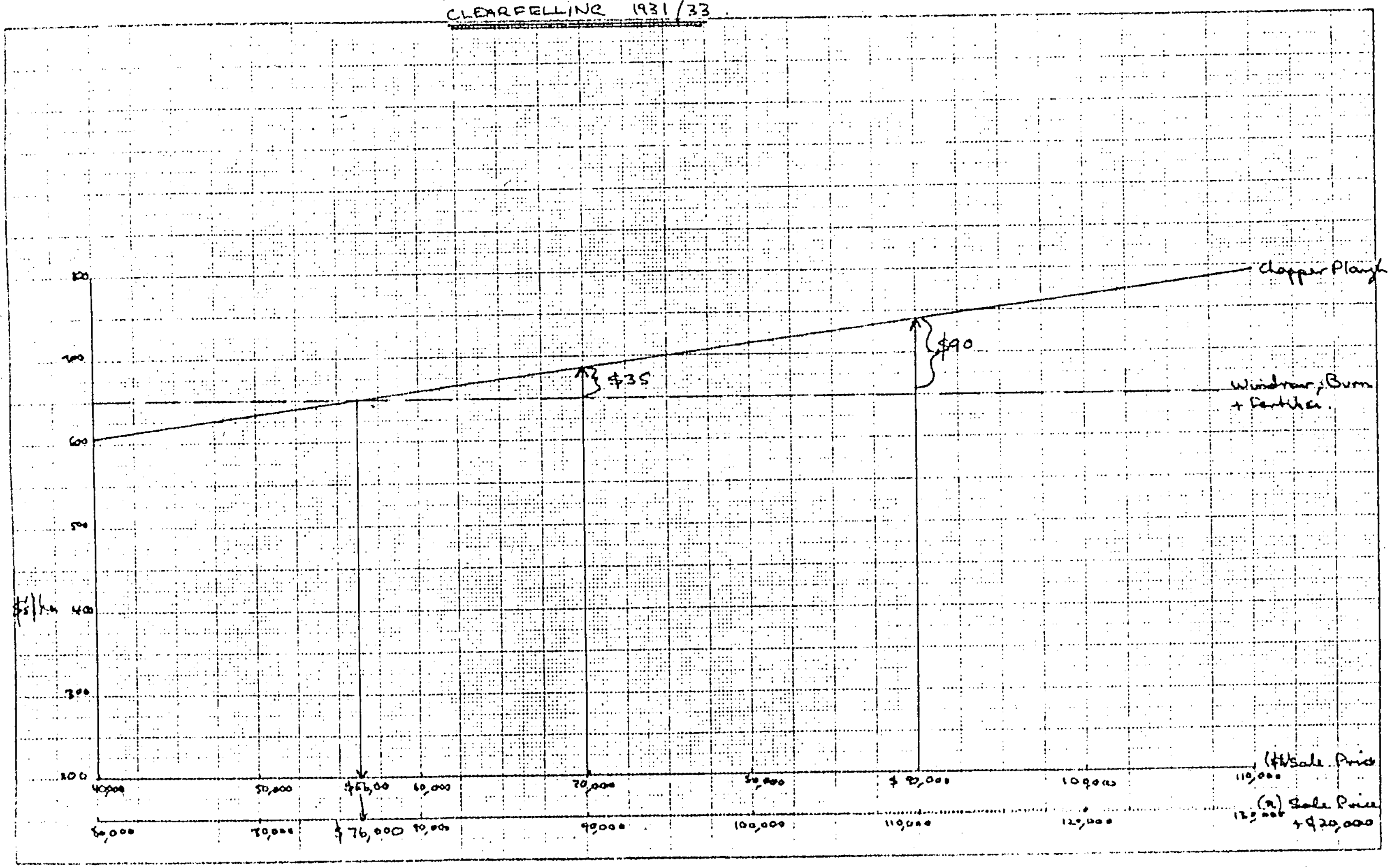


FIGURE 4. Chopper Plough vs Conventional Practice.

CLEARFELLING 1931/33



← i.e. MK II as tested

← MK II + $20 000 worth of modifications.

APPENDIX III

CHOPPER PLOUGH COSTING

A. If purchased Mark II and modified.

Present value	$100,000	
plus modifications	20,000	: Fluid couplings, alter chain drive, mount all controls in cab, protection, drop forged teeth.
	$120,000	

Expected life 5,000 hours

Expected utilization: 60% on a 10 hour day, i.e. 6 hours/day

∴ Hours p.a. = 6 x 230 = 1,380

∴ Expected life = $\frac{5000}{1380}$ = 3.6 years

Residual Value 20% : $24,000

∴ Depreciation: $96,000

∴ Annual Depreciation: $26,667 : over 3.6 years

Cost per annum

Interest on capital:	$12,000	: 10%
Depreciation:	$26,667	
Operator and vehicle:	$18,533	: $11,000 p.a. + 2 hours O/T per day ⇒ $15,125 plus 6% overheads ⇒ $16,033 plus $2500 (vehicle) ⇒ $18,533
Repairs and Maintenance: (excluding teeth)	$16,000	: 60% Depreciation
Replacement of teeth:	$23,460	: $85 each; 40/set with 200 hours life/set ∴ @ 1380 hours p.a. require 6.9 sets p.a. ⇒ $3400 x 6.9
Fuel:	$20,700	: 20 Gals/hour ⇒ 27,600 gals p.a. @ $0.75/gal.
Oil:	$ 2,070	: 10% of fuel
Hire Komatsu:	$48,300	: $35/hour for 1380 hours
Transport between blocks:	$ 2,000	
	$169,730	

∴ @1380 hours p.a. Cost/hour = $123

B. <u>If purchased "PL 600" Mark III Chopper Plough</u>

Purchase Price	$150,000	
Expected Life	7,500 hours	
Utilization 70% on a 10 hour day i.e. 7 hours/day		(higher availability due to fluid coupli[ng] 1 motor and simpler drive train)

∴ Hours p.a. = 7 x 230 = 1610 hours

∴ Expected life 4.66 years

Residual 20% i.e.	$30,000
∴ Depreciation	$120,000
∴ Annual Depreciation	$25,751

<u>Cost per annum</u>

	$		
Interest on Capital:	15,000		
Depreciation:	25,751		
Operator and Vehicle:	18,533		
Repairs and Maintenance:	15,450	:	60% Depreciation
Replacement of teeth:	27,370	:	200 hours/set 1610 hours p.a. ∴ 8.05 sets p.a. @ $3400/set
Fuel:	25,200	:	1680 hours @ 20 gals/hour ⟹ 33600 gals. ⟹ $25,200
Oil:	2,520	:	10% Fuel
Hire of Komatsu:	58,800	:	1680 x $35
Transport between blocks:	2,430	:	More hours ∴ more shifts
	$191,054		

∴ @ 1680 hours p.a. $113/hour

Assume 25% higher productive rate because of more effective HP, no engine stalling due to fluid coupling, operator skill increased.

C. J. LEITCH, B. E. (Agric.), M.Eng.Sc. (Civil), M.I.E.Aust., Research Engineer, Forests Commission, Victoria.
P. W. FARRELL, Dip. For. (Cres.), B.Sc.F. (Hons.), Research Forester, Forests Commission, Victoria.

Evaluation of mechanical methods for treating *Pinus radiata* logging residue.

SUMMARY An evaluation of three methods of mechanically treating *Pinus radiata* logging residue on site showed that it is both physically and economically feasible to form a residue mulch rather than windrowing and burning the residue as is the conventional treatment. This mulch should enhance tree growth by conserving soil moisture, suppressing weed growth and conserving nutrients and organic matter which would otherwise be lost during burning. Roller-chopping was found to be the cheapest treatment but the Williames Chopper Plough was better suited to sites with dense residue.

1 INTRODUCTION

In Victoria, mature crops of *Pinus radiata* D. Don are harvested by clear-felling between the ages of 30 and 60 years leaving a residue of stumps, defective stemwood, branches, needles and litter. This logging residue represents a fire hazard and an obstruction to replanting and fertiliser and weedicide applications. Conventional methods of residue treatment (prior to re-establishment of the second crop) have been either to broadcast burn or to heap into windrows and burn.

Flinn (1978) compared these site preparation methods with one in which residue was not burnt on the infertile sandy soils of Rennick State Forest in south-western Victoria. Approximately 100 000 ha of conifer plantations have been established on soils of this sort in south-western Victoria and south-eastern South Australia. He showed that significantly better early growth of the second crop was achieved by retaining litter and logging residues from the first crop compared with either broadcast or windrow burning of the residues. This was mainly attributed to conservation of soil moisture by the residue mulch. The degree of residue maceration in this trial was not sufficient to provide a uniform mulch which significantly inhibited weed growth but it was concluded that if this could be achieved there would be a reduced need for weedicide.

In another study at Rennick, Flinn *et al*. (1979) showed that a moderately intense broadcast burn reduced the dry weight of logging residue to 16% of its original value and caused losses of 220 kg ha^{-1} of N, 123 kg ha^{-1} of Ca, 21 kg ha^{-1} of K and smaller losses of other elements. Such losses can be avoided and fertiliser costs reduced if fire is not used in second-rotation establishment. Florence and Lamb (1971) estimate that logging residue retained on site after clear-felling decomposes within 7 years, presumably returning much of the nutrients it contains to the soil during this period.

In the present study three methods of mechanically treating *P. radiata* logging residues were evaluated in trials in the Rennick State Forest. The first two methods involved a prototype machine called the Williames Chopper Plough which treated the residue either by macerating it and spreading it over the relatively undisturbed soil surface to form a mulch or by chipping it and ploughing it into the surface soil. In the third method, a Roller Chopper was used to flatten and chop the woody material into pieces of variable size which form a mulch layer above the relatively undisturbed soil surface. Machine productivity, fuel consumption, the depth of the treated residue and its particle size distribution were recorded and analysed.

2 DESCRIPTION OF MACHINES AND SITE

The Williames Chopper Plough is a prototype machine designed and manufactured by Geoff Williames (Aust) Pty Ltd of Warragul, Victoria and financed jointly by that company, the Forests Commission Victoria, APM Forests Pty Ltd and the Woods and Forests Department South Australia. The Chopper Plough is towed by a crawler tractor and for these trials a Komatsu D85A was used (Figure 1). The Chopper Plough has a horizontal-axis rotor 2.4m wide, to which are attached 40 self-sharpening teeth. Power is provided by twin GM Detroit diesel V871 motors rated at 239 kW each. These motors apply torque to each side of the rotor via Spicer 10-speed gear boxes, right angle drives (converted from Euclid differentials) and chain drives. The gearboxes provide an operating range of rotor speeds from 266 to 700 rpm which allows treatments varying from deep ploughing to residue mulching.

Figure 1 The Williames Chopper Plough being towed by a Komatsu D85A tractor

The Roller Chopper used in this study was designed and manufactured in 1977 by the Woods and Forests

Department South Australia. The roller is 1.52 m wide and has twelve 250 mm long spring steel blades attached to a 900 mm diameter steel drum (Figure 2). The drum is filled with concrete and has additional ballast attached to the hitching arms to bring the total weight to approximately 12 t. A Komatsu D85A crawler tractor was used in the trial to tow the Roller Chopper.

The trials were carried out in Compartments 024 and 025 of the Rennick State Forest. These compartments are located within the coastal sand belt and are virtually flat with local undulations and depressions providing the only relief. The soil type is Caroline sand (Stephens et al. 1941). Compartments 024 and 025 were clearfelled early in 1972 and 1978 respectively. Trees were extracted along every fifth row (outrows) and falling was directed away from these outrows leaving dense swaths of logging residue alternating with the residue-free outrows. The stand parameters prior to clearfelling and the volumes of timber harvested and residue remaining are given in Table 1. Only sawlogs were harvested which accounts for the high volume of residue greater than 100 mm in diameter. Compartment 024 had been thinned once previously whereas Compartment 025 had not. Both compartments contained large hardwood stumps and logs which were remnants of the original hand-clearing.

Figure 2 Woods and Forests Department South Australia Roller Chopper being towed by a Komatsu D85A crawler tractor

TABLE I

STAND PARAMETERS, LOG YIELDS AND RESIDUE VOLUMES FOR THE STUDY SITES

	Comp. 025	Comp. 024
Stand parameters		
Age (years)	27	28/24
Stocking (stems ha^{-1})	1320	595
Basal area (m^2 ha^{-1})	57.1	41.9
Mean DBHOB (mm)	223	293
Top height (m)	32.4	30.6
Site index	27.1	26.2
Timber harvested (m^3 ha^{-1})	437	443
Residue volumes (m^3 ha^{-1})		
Wood with D>100 mm	100	42
Wood with D>40 to <100 mm	46	15
Wood with D<40 mm	60	40
Fresh needles	110	75
Litter	339	225
Total	654	397

3 METHOD

The Chopper Plough was used at high rotor speeds to macerate the logging residue and form a surface mulch with minimal soil disturbance. The maximum rotor speed of 700 rpm was used in Compartment 024 (medium slash) but the next lower rotor speed of 550 rpm was used in Compartment 025 (heavy slash) as mechanical problems had been experienced at maximum speed. The machine had sharp new teeth fitted when operating in Compartment 024 but well-worn ones were used during the trials in Compartment 025. The Chopper Plough was also used at slower rotor speeds of 440 and 344 rpm in Compartment 025 (heavy slash) to simultaneously chop the residue and plough it into the surface soil (termed ploughing).

The technique used for treating the logging residue with the Roller Chopper was to spread the slash more evenly over the compartment on the first pass and to chop and flatten it on the second pass. Spreading was necessary because only the top layer of slash was chopped when the roller was towed along a swath of heavy slash and the lower levels of slash were left virtually unaffected. This would have made planting extremely difficult. The slash was most easily spread by the crawler tractor and roller traversing diagonally across the compartment at 45° to the outrows, and this method was used. The second pass was made parallel to the outrows.

The Chopper Plough was field tested and the elements of its operation timed for a total of 55 hours on 16 working days between June and October 1979 and the Roller Chopper for 17 hours on 5 working days in August and October 1979. Times spent in normal operation and delays were recorded. However delays were not included in calculations of machine productivity for the following reasons:

a both the Chopper Plough and the Roller Chopper were experimental units which required modification during the trials,

b the Komatsu D85A tractor used for towing the two machines was deficient in either power, traction or underbelly clearance in various situations. This resulted in both minor delays when a new path had to be negotiated and major delays when the tractor became bogged, and

c part of the trials were carried out on 1.4 ha plots which required considerably more turnaround and travel time than would normally be encountered.

In this study, therefore, the productivities were only measured whilst the machines were actually engaged in treating residue. This will be termed "effective time" productivity to avoid confusion with "machine hours" productivity which is more commonly used (Haarlaa* pers. comm.).

A record of the quantity of diesel fuel used by the crawler tractor and Chopper Plough was maintained.

Depth above mineral soil and piece-size of the mulches formed by the Chopper Plough and Roller Chopper were measured; mulch depth, in order to indicate its effect on weed germination and piece size, to indicate the rate of decomposition of the woody residue and the degree of obstruction which the treated residue would present to replanting and other management operations. For each treatment, the depth of mulch was measured at 250 mm intervals along ten randomly located transects, each 10 m in

*Haarlaa, R., Assoc Prof of Forest Technology, Univ of Helsinki, Finland length (Figure 3). Along three of these transects in each treatment all pieces of woody residue intersected were collected and categorized by length and width into one of the 9 size classes shown in Table III and Figure 4.

Figure 3 Transect, 10m in length, in an area macerated by the Chopper Plough operating at maximum rotor speed. A dense swath of residue previously occupied this site. Untreated residue can be seed in the background.

Figure 4 Woody residue from transect in Figure 3 divided into piece-size categories

4 RESULTS AND DISCUSSION

4.1 Mulch Assessment

Measurement and observations of the depth and condition of mulches on the macerated and roller-chopped sites are summarized in Table II and the size distributions of the treated residue collected from these sites are presented in Table III. The mulches on the two macerated areas and on the roller-chopped area were all of satisfactory mean depth, but 35-46% of the areas contained a mulch less than 25mm or greater than 150mm in depth. It is thought likely that the former would be inadequate to suppress weed germination whilst the latter would make planting difficult. These proportions could be reduced however by changing the techniques of tree felling such that logging residue is spread more uniformly over the site and not concentrated in swaths.

The mean depth of mulch on the roller-chopped sites was significantly ($p<0.01$) greater than that on the adjacent macerated site due to the former having a higher proportion of large pieces of wood which did not pack together as efficiently as the chipped particles on the macerated sites. The roller-chopped mulch may therefore be an inferior type of mulch as it is more variable in depth and is likely to be less effective in conserving soil moisture and suppressing weed germination than uniform mulches.

The Chopper Plough produced a deeper mulch when operating with sharp teeth and at maximum rotor speed in the lighter slash of Compartment 024. This mulch was of smaller average chip size and was less dense than the other mulches and it is likely that it will be more efficient at conserving soil moisture and suppressing weed germination.

Both the Chopper Plough and the Roller Chopper left large pieces of woody residue as obstructions to pedestrian and vehicular movement on the treated sites. The Roller Chopper produced significantly ($p<0.001$) more long pieces of residue than the Chopper Plough but its' mulch was subjectively assessed as being only marginally more difficult to walk across than the macerated heavy slash. The mulch produced by the Chopper Plough on the medium slash site was considerably easier to traverse due to both the greater proportion of small pieoes and the smaller quantity of slash on this site.

TABLE II

CHARACTERISTICS OF CHOPPER PLOUGH (MACERATING) AND ROLLER CHOPPER TREATED RESIDUES

	Chopper Plough in Comp. 024 (medium slash)	Chopper Plough in Comp. 025 (heavy slash)	Roller Chopper in Comp. 025 (heavy slash)
Mulch depth			
- mean (mm)	77	60	72
- S.D. (mm)	21	56	67
Mulch observations			
- litter intact	89%	65%	61%
- litter disturbed	8%	23%	24%
- bared soil	3%	12%	15%
- mulch<25 mm	24%	39%	30%
- mulch>150 mm	11%	7%	11%

Soil and duff disturbance was relatively high on both heavy slash sites but this was probably due to the difficulty in treating the large swaths of residue. The disturbance created by the Chopper Plough in Compartment 024 where the residue was less dense gives a better indication of this machine's performance in this respect . The Roller Chopper is also likely to cause less disturbance if the slash is lighter and can be chopped in one pass without prior spreading. Both treatments therefore appear to have the potential for creating a mulch without excessive disturbance, which promotes weed germination. With the tree-felling technique used on the study areas there was little slash along the outrows and weeds, including wildings (pine regeneration), had

TABLE III

NUMBERS OF RESIDUE PIECES ON TRANSECTS OF CHOPPER PLOUGH (MACERATING) AND ROLLER CHOPPER TREATMENT SITES

Length of residue pieces (mm)	Treatment	Average width of residue pieces (mm) 0 – 25	26 – 100	>100
500 +	CP macerating in medium slash	50	8	8
	CP macerating in heavy slash	52	22	10
	Roller Chopper in heavy slash	96	30	16
150 - 500	CP macerating in medium slash	309	50	11
	CP macerating in heavy slash	461	29	0
	Roller Chopper in heavy slash	700	18	2
0 - 150	CP macerating in medium slash	2126	257	31
	CP macerating in heavy slash	2484	16	0
	Roller Chopper in heavy slash	1270	2	1

TABLE IV

"EFFECTIVE TIME" PRODUCTIVITY OF THE CHOPPER PLOUGH AND ROLLER CHOPPER

	Chopper Plough macerating in Compartment 024 (medium slash)	Chopper Plough macerating in Compartment 025 (heavy slash)	Chopper Plough ploughing in Compartment 025 (heavy slash)	Roller Chopper in Compartment 025 (heavy slash)
"Effective time" productivity (ha h^{-1})	0.70	0.57	0.23	0.40
Travel Speed (km h^{-1})	3.0	2.4	1.2	4.0

TABLE V

ESTIMATED COSTS OF SECOND ROTATION CROP ESTABLISHMENT (1980 $ PER HECTARE)

	Windrowing and burning	Chopper Plough maceration	Chopper Plough ploughing	Roller Chopper
Residue treatment	90	125	395	55
Planting	60	100	100	100
Weedicide application	50	25	50	25
Total excluding fertiliser application costs	200	250	545	180
Fertiliser application costs	770	370	560	370
Total incl. fertiliser appl. costs	970	620	1105	550

established prior to the treatment. Neither the Chopper Plough nor the Roller Chopper effectively eliminated these weeds. It is noteworthy that wildings may be a continuing problem on all unburnt sites because of the large number of viable seeds remaining after clearfelling.

Neither the macerated nor the roller-chopped sites were regarded as being a serious fire hazard for the establishment phase of the crop.

Measurements of residue particle size were not made on the ploughed sites but they were subjectively assessed as being difficult to plant in because of the looseness of the soil and the large residue pieces on and just below the soil surface.

4.2 Fuel Consumption

The average fuel consumption was 30.5 l h^{-1} for the Komatsu D85A crawler tractor and 53.2 l h^{-1} for the Chopper Plough. These are average values for all operations throughout the trials and are of limited value because approximately 40% of the total working time was spent debogging the machines. During these periods the crawler tractor only worked hard for about half the time and the Chopper Plough engines were running at full speed but not under load for a similar proportion of this time.

4.3 Productivities and Costs

4.3.1 Productivity Measurement

The "effective time" productivities and travel speeds of the Chopper Plough and Roller Chopper are given in Table IV.

As expected, the productivity of the Chopper Plough was higher when operating in less dense residue but this was partly due to the higher rotor speeds and sharper teeth used in Compartment 024. The Chopper Plough was therefore operating at close to its maximum efficiency in this Compartment. Additionally, in Compartment 024 there was no need to treat the extraction rows which occupied 30% of the Compartment and the operating productivity effectively became 1.0 ha h^{-1}.

The lower productivity of the Chopper Plough whilst ploughing was due, firstly, to the extra work required to continually displace soil (approximately 400 t h^{-1}) and chip additional stump wood (approximately 5 m^3h^{-1}) and, secondly, to overlapping of the plough lines being necessary to provide a uniformly ploughed surface.

The main reasons for the high travel speed and yet relatively low productivity of the Roller Chopper were that the entire areas were roller-chopped twice and also that the Roller Chopper was narrower than the Chopper Plough. A 2.4 m wide roller would not only cover 60% more ground than the 1.52 m wide roller used here but it would be more stable when climbing obstacles and a faster travel speed could be achieved.

4.3.2 Cost Estimates

Estimated costs of the four methods of preparing clear-felled P. radiata sites for establishment of the second rotation crop are presented in Table V. In these estimates, no account has been taken of enhanced tree growth which is likely to result from residue retention.

Chopper Plough residue treatment costs were based on a hire rate of $110 per hour for the machine and crawler tractor; the FCV internal hire rate for a Class M25 crawler tractor (e.g. Komatsu D155A), which is considered to be the most appropriate size for towing the Chopper Plough, is $50 per hour, and the hire rate of the Chopper Plough was estimated to be $60 per hour on the assumption that the purchase cost of a production model will be approximately the same as that of a Class M25 crawler tractor and that operation and maintenance costs will be higher. Long term productivity was calculated by allowing for a 10% increase in productivity due to design improvements and by estimating that 20% of machine work time is unproductive (e.g. warming up, travel, minor repairs).

Roller Chopper costs were based on an estimated hire rate of $15 per hour for a single drum roller costing $20 000 and the FCV internal hire rate of $40 per hour for a Class M20 crawler tractor (e.g. Komatsu D85A). These estimates are confirmed by the Woods and Forests Department South Australia internal costing of $58 per hour for a Class M25 crawler tractor and a set of twin rollers. (Mitchell* pers. comm.). Long-term productivity was calculated by assuming one pass of a 2.4 m wide roller and a 20% involvement in unproductive activities.

Planting costs on the macerated, ploughed and roller-chopped sites will all be higher than those for windrowed sites (Rennick Forest District costing) due to difficulties in traversing the area and planting out the seedlings in either mulch or loose soil. This increase in cost was estimated to be 67%.

Weedicide application costs for macerated and roller-chopped sites were estimated to be half those of bared areas (Rennick F. D. costing) as it was assumed that weedicide would only be required along outrows.

Fertiliser application costs were based on a rate of $1 per kg of fertiliser (Rennick F. D. costing). It was assumed that the nutrient status of the site would be maintained at pre-harvest levels and that the following losses (Flinn et al. 1979) would be replaced where appropriate:

370 kg ha^{-1} of nutrients removed in harvested wood

400 kg ha^{-1} of nutrients lost during windrow burning

It was assumed that on ploughed sites 20% of the residue nutrients would reach beyond the root zone before the crop could utilize them.

4.4 Discussion

Table V shows fertiliser application to be the highest establishment cost but it should be noted that total nutrient replacement is not a wide-spread practice. In this locality however, nitrogen which is removed in harvested wood and lost during slash burns comprises approximately 28% of the nitrogen in the ecosystem to a soil depth of 50 cm (Flinn et al. 1979), so that it is likely that these sites will be less productive in subsequent rotations unless these losses are replaced.

When all costs are considered, roller-chopping is the least costly treatment followed by Chopper Plough maceration. Both of these methods are

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substantially less costly than windrow burning and Chopper Plough ploughing. In situations where no fertiliser would be applied or where only a routine application would be made, roller-chopping is still the cheapest method but the cost of windrow burning is comparable.

An important consideration when evaluating these results is that the logging residue contained a large amount of defective stem wood and small diameter wood which would normally have been harvested for chipping and pulping. There was 42 and 100 m^3 ha^{-1} of this material in Compartments 024 and 025 respectively (Table I) which is a substantial proportion of the woody residue on the sites. Where pulpwood was removed, therefore, there would be little woody residue to be treated and the full power of the Chopper Plough would only occasionally be required to macerate hardwood logs and stumps and much of the time even its idling power would be under-utilized. The Roller Chopper would have little difficulty chopping and flattening a light residue and would ride over the few large residue pieces. Considering that the estimated operating costs of the Roller Chopper are less than those of the Chopper Plough it is the most appropriate method to use where logging residues are light. The Chopper Plough produces a higher quality mulch than the Roller Chopper on sites where logging residues are substantial and there is likely to be a requirement for such a high-powered macerating machine for treating mature pine logging slash and for post-wildfire re-establishment.

The prototype Chopper Plough used in these trials was initially developed for ploughing operations; high-speed maceration was an additional use which had not been envisaged and it caused problems with housing the cutting teeth and with the drive chains and right-angle drives. A suitable method of housing the teeth was developed during the trials and preliminary design of a production model which will overcome the other problems has commenced. The modified Chopper Plough will have the following features:

* a single 800 kw motor
* a 10 speed gearbox with belt drive to rotor
* the same rotor and cutting teeth as in prototype
* bogey wheels for reduced bearing pressure

5 CONCLUSIONS

Trials at Rennick have shown that it is both physically and economically feasible to treat and retain logging residue on the site rather than heaping and burning it. By so doing it is anticipated that the crop will benefit from the nutrients, organic matter and moisture conserved in the mulch and soil and also from the suppression of weed competition.

Of the four treatments studied, the two mulching treatments - Chopper Plough maceration and roller-chopping - show considerable cost savings over windrow burning and Chopper Plough ploughing when the costs of replacing nutrients lost as a result of timber harvesting and site preparation are considered. When fertiliser application costs are ignored the costs of the mulching treatments and windrow burning are comparable, with roller-chopping again being the least costly.

The Chopper Plough produced a more uniform mulch than the Roller Chopper in heavy slash areas and it is likely that it will therefore be more effective in conserving soil moisture and suppressing weed competition. Where slash contains less woody material, however, it is unlikely that there will be a marked difference between the macerated and roller-chopped mulches. The power of the Chopper Plough in this case would largely be unused whereas the Roller Chopper would perform satisfactorily at lower cost.

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