WOOD HARVESTING

Technical Note TN-292 July 1999

TN292

EFFECT OF TREE SIZE AND STAND DENSITY ON HARVESTER AND FORWARDER PRODUCTIVITY IN COMMERCIAL THINNING

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Abstract

In 1996 the Forest Engineering Research Institute of Canada (FERIC) studied commercial thinning on seven operating areas in Alberta in order to quantify the effect of tree size and stand density on harvester and forwarder productivities. As well, the cost of harvester and forwarder operations was determined and slash loading and damage to residual trees were measured.

Introduction

Fibre supply shortages have developed in western Canada as a result of withdrawals from the forest land base and updated timber supply analyses. Commercial thinning recovers fibre that might otherwise be lost to mortality, reduces the cost of final harvest by increasing average piece size, and allows some fibre recovery before final harvest.

Various types of logging systems can be used effectively for commercial thinning, including cut-to-length systems. With cut-to-length systems, the delimbing, topping and bucking occur in the stand rather than at the landing area; logs are carried, rather than dragged, during primary transportation; and the log trucks are configured to haul shorter log lengths. These systems also typically require less labour, less road and trail construction, and fewer landing areas than other ground-based systems (Bettinger and Kellogg 1993). Cut-to-length systems may produce higher quality end products of more consistent dimension, and may lower logyard management costs (Andersson 1991). The high initial cost of cut-to-length equipment is a significant factor to consider before beginning commercial thinning operations, and operators need to be aware of how stand characteristics influence productivity.

Kenmatt Logging of Whitecourt, Alberta has been contracted by Millar Western Forest Products Ltd., since 1995, to commercially thin stands using a Timberjack 608 feller-buncher with a Koehring Waterous 762B single-grip harvesting head and a Timberjack 1210 forwarder (Table 1). In early 1998, Blue Ridge Lumber (1981) Ltd., also of Whitecourt, contracted Brinkman and Associates Reforestation Ltd. to thin an area using a Rocan-T thinning harvester with a Pan 828 single-grip harvesting head and a Rottne Rapid six-wheel drive forwarder (Table 1).

In the fall of 1996, the Forest Engineering Research Institute of Canada (FERIC) began a study in cooperation with Millar Western and Blue Ridge Lumber to:

- quantify the effect of tree size and stand density on harvester productivity
- quantify the effect of tree size, stand density, and forwarding distance on forwarder productivity
- determine the cost of harvester and forwarder operations
- measure slash loading and damage to residual trees

Keywords: Commercial thinning, Harvesters, Forwarders, Productivity, Tree size, Stand density, Lodgepole pine, Spruce, Aspen, Balsam fir, Alberta

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Table 1. Machine Specifications

	Timberjack 608 harvester	Timberjack 1210 forwarder	Rocan-T harvester	Rottne Rapid 6WD forwarder
Engine power (kW)	125	114	74	125
Power transmission	2-speed drive motors	2-speed hydrostatic	4-wheel drive, hydrostatic	6-wheel drive, hydrostatic
Approximate weight (kg)	27 000	15 120	6 000	13 700
Width (m)	2.9	2.84	2.07	2.4
Crane reach (m)	7.0	7.1	6.6	6.0
Ground clearance (m)	0.50	0.69	0.60	0.56

Site and System Description

Six study areas with Millar Western and one with Blue Ridge Lumber were selected (Table 2). The study sites gave a range of tree volumes and stand densities and were located in the Upper and Lower Foothills Natural Subregions of Alberta. The Millar Western study areas (MW1 to MW6) contained mature stands 80–120 years old, while the stand in the Blue Ridge Lumber study area (BR1) was about 47 years old.

The silvicultural prescriptions called for the removal of all small-diameter suppressed trees or trees with

Table 2. Pre- and Post-harvest Stand Descriptions

Study area	Net volume: Lodgepole pine (m^3/ha)	Spruce (m^3/ha)	Aspen (m^3/ha)	Balsam fir (m^3/ha)	Total (m^3/ha)	Merchantable trees (no./ha)	Net volume (m^3/tree)	Avg. dbh (cm)
MW1								
Pre-harvest	379	82	16	3	480	2371	0.20	16.7
Harvest	61	29	4	3	97	733	0.13	14.5
Residual stand [a]	318	53	12	-	383	1638	0.23	17.7
MW2								
Pre-harvest	339	79	4	-	422	2073	0.20	16.5
Harvest	47	21	-	-	68	533	0.13	14.2
Residual stand [a]	292	58	4	-	354	1540	0.23	17.3
MW3								
Pre-harvest	300	101	25	-	426	2667	0.16	15.9
Harvest	85	48	3	-	136	1260	0.11	14.0
Residual stand	215	53	22	-	290	1407	0.21	17.3
MW4								
Pre-harvest	163	73	2	-	238	1621	0.15	16.7
Harvest	44	21	2	-	67	614	0.11	14.9
Residual stand	120	51	-	-	171	1007	0.17	17.7
MW5								
Pre-harvest	128	132	-	-	260	2536	0.10	14.4
Harvest	46	42	-	-	88	1179	0.07	13.1
Residual stand	82	90	-	-	172	1357	0.13	15.6
MW6								
Pre-harvest	404	66	-	-	470	1577	0.30	20.0
Harvest	201	37	-	-	238	977	0.24	18.3
Residual stand	203	29	-	-	232	600	0.39	22.8
BR1								
Pre-harvest	171	-	-	-	171	1270	0.13	15.8
Harvest	55	-	-	-	55	610	0.09	13.7
Residual stand	116	-	-	-	116	660	0.18	17.7

[a] Densities were further reduced by handfelling.

scars and forks. In this thinning "from below", an effort was made to select for good crown development of final crop trees. Millar Western expected to extend the vigour of the mature stands by providing additional growing space and resources to the residual stand. Blue Ridge Lumber expected optimum growth on crop trees by spacing thrifty stands.

In all study areas the harvester operator followed pre-marked trails. Usually the harvester cut a trail from the main forwarding trail to the back of the block and continued in a loop, thinning along the adjacent trail back to the main trail. Logs were piled at the side of the trail, with no sorting.

The forwarding trails were spaced 20 m apart, except in areas MW1, MW2, and BR1. In areas MW1 and MW2, the trails were spaced 30 m apart. Trees that could not be reached with the harvester were later handfelled and processed by the harvester. In area BR1, the trails were spaced 25 m apart. The operator then created a "ghost trail" to remove trees that could not be reached from the forwarding trails.

The forwarder operator usually drove in reverse to the end of the trail, loaded the machine, then drove forward toward the main trail. At the Millar Western study areas, logs were not sorted by grade (i.e., pulp logs and sawlogs) at the landings but aspen logs were separated from the others. During loading of the forwarder, aspen was often piled on top of the load or on one side of the bunk. At the Blue Ridge study area, aspen was cut but was not used. The other species were sorted by grade, so a two-pass forwarding technique (separate loads of pulp logs and sawlogs) was used.

Methods

Pre- and post-treatment densities, diameter distributions, individual tree volumes, and stand volumes for the study areas were sampled using 100 m^2 fixed-area (5.64 m radius) cruise plots distributed throughout each area.

Detailed-timing of machine operations was done by FERIC personnel using hand-held data loggers and stop watches to sample cycle times. This information was used to calculate machine productivities. Distances traveled by the forwarder were also measured to compare the relationship between forwarder productivity and travel-empty distances. Machine costs were calculated using FERIC's costing methodology (Appendix I).

Following thinning, the cruise plots were resurveyed to determine damage to residual trees and slash loading. For each stem scar, the average length and width, height above ground, and the circumference of the tree at the middle of the damage location were measured (Hunt 1995). Scar area was estimated by multiplying the average length by average width. Slash loading was measured along two 20-m transects established at the centre of the cruise plots, the first on a random azimuth and the second at a right angle to the first (Sutherland 1986).

Results and Discussion

Time Distribution Study

Harvester. The results of the detailed-timing of the harvester are shown in Table 3. For areas MW1 to MW6, cycle times for the Timberjack harvester to select, cut, and process a tree ranged from 0.51 to 0.98

Table 3. Productivity and Distribution of Productive Cycle Elements: Harvester

	Study area							
	MW1	MW2	MW3	MW4	MW5	MW6	BR1	Overall
Productive time sampled (min)	446	236	591	418	199	332	293	2515
Cycles sampled (no.)	874	381	933	627	203	517	341	3876
Average time/cycle (min)	0.51	0.62	0.63	0.67	0.98	0.64	0.86	0.65
Distribution of time by element								
Swing empty (%)	32	27	31	23	20	23	21	26
Fell (%)	17	14	16	12	10	14	13	14
Process 1st log (%)	12	15	15	19	16	18	15	16
Process other logs (%)	11	10	9	15	5	16	11	11
Move (%)	12	13	10	16	16	14	15	13
Clean (%)	11	15	15	9	32	11	23	15
Delays (<10 min) (%)	5	6	4	6	1	4	2	5
Total (%)	100	100	100	100	100	100	100	100
Productivity (m^3/PMH)	15.3	12.6	10.5	9.9	4.3	22.5	6.3	12.1

min, while the average cycle time for the Rocan-T, in area BR1 was 0.86 min. In areas MW5 and BR1, with the smallest tree diameters, the harvesters spent a greater amount of time cleaning unmerchantable trees (32 and 23%, respectively) compared with the other study areas (9 to 15%). Cleaning allowed the operator to position the felling head, improved visibility, and prevented damage to the carrier.

The productivity of the Timberjack harvester ranged from 4.3 to 22.5 m^3/productive machine hour (PMH), and averaged 12.8 m^3/PMH, while the productivity of the Rocan-T was 6.3 m^3/PMH. For the range of tree sizes observed, there was a weak correlation (r^2=0.2215) between the productivity of the Timberjack harvester and tree volume; as tree volume increased the productivity of the harvester increased (Figure II-A). No significant relationships were demonstrated between Timberjack harvester productivity and pre-harvest stand density and stems removed (Figure II-A).

A relationship between the Timberjack harvester and pre-harvest stand volume was demonstrated (r^2=0.4830). In the statistical analysis, the effect of tree size was removed from the interaction of stand volume and stand density. No significant difference was found between the productivity of the harvester and stand densities in the Millar Western study, indicating tree size, not stand density, affected productivity.

A compilation by Kellogg *et al.* (1992) found that harvester productivity is generally closely related to tree size. Harvester productivity may be highly variable, depending on individual tree size, operator skill and motivation, branch size, numbers of unmerchantable and merchantable trees per unit area, and undergrowth density (Makkonen 1991; Richardson 1989).

Forwarder. Detailed-timing results for the forwarder are shown in Table 4. For areas MW1 to MW6, the average productivity of the Timberjack forwarder was the highest in area MW6 (23.2 m^3/PMH) and the lowest in area MW5 (14.7 m^3/PMH), which corresponds to the areas with the largest and smallest tree sizes. The average productivity for the Rottne forwarder in area BR1 was 11.8 m^3/PMH. The most time-consuming elements for both forwarders were loading (39–54 %) and unloading (9–29%).

No relationships between the productivity of the forwarder and pre-harvest stand density and stems removed were demonstrated (Figure II-B), indicating that stand density has no influence on the productivity of the forwarder.

Travel-empty distances averaged 90 to 306 m and ranged from 10 to 494 m. Only a very weak relationship between forwarder productivity and travel-empty distance was demonstrated (r^2=0.1197). This poor relationship can be explained by differences in the quality of trails throughout study areas and the proportions of travel time to total cycle time. Forwarding trails that were located on old seismic lines allowed faster travel speeds than other trails with tight corners, stumps, and ruts.

Costs

The cost of the logs on the landing for the seven study areas is summarized in Table 5. The unit costs were

Table 4. Productivity and Distribution of Productive Turn Elements: Forwarder

	Study area							
	MW1	MW2	MW3	MW4	MW5	MW6	BR1	Overall
Productive time sampled (min)	793	-	509	302	314	290	349	2557
Turns sampled (no.)	29	-	11	6	6	7	7	66
Average time/turn (min)	27.34	-	46.27	50.33	52.33	41.43	49.86	38.74
Distribution of time by element								
Travel empty (%)	9	-	13	13	9	11	6	10
Load (%)	53	-	39	39	42	42	54	46
Move (%)	7	-	6	6	9	6	15	8
Travel loaded (%)	7	-	14	14	10	10	13	11
Unload (%)	19	-	22	22	29	27	9	21
Delays (<10 min) (%)	5	-	6	6	1	4	3	4
Total (%)	100	-	100	100	100	100	100	100
Average pieces/turn (no.)	97	-	194	177	208	160	179	146
Average volume/turn (m^3)	9.2	-	14.8	16.9	12.8	16.0	9.8	11.9
Average productivity (m^3/PMH)	20.2	20.0 [a]	19.2	20.1	14.7	23.2	11.8	18.4
Average distance empty (m)	90	-	306	280	275	217	134	174
Average distance loaded (m)	102	-	361	249	210	160	306	196

[a] FERIC researcher not on site. Productivity estimated from regression analysis (r^2 = 0.6334).

calculated using comparable machine utilization rates (Andersson 1994), the hourly machine rates developed in Appendix I, and the productivities based on the detailed-timing studies. The calculated cost of commercial thinning varied between $15.83 and $56.86/m³, corresponding to the areas with the largest and smallest tree sizes, respectively. The average cost on the landing was $25.56/m³.

Holtzscher and Lanford (1997) also found tree size to have a significant effect on unit cost of wood produced. As tree size increased, unit cost of wood produced decreased.

Post-Treatment Surveys

Slash Loading. The volume of slash left on site was similar for all areas studied and ranged from 24.3 to 35.5 m³/ha (Table 6). There was a good relationship between the number of stems removed and the amount of slash remaining on site (r^2=0.6399).

Generally, the harvester processed all stems on the trail in front of the machine to provide a slash mat for travel. As a result, compaction and site disturbance may have been reduced. The distribution of limbs and tops throughout the stand leaves more nutrients on site, and may be more aesthetically pleasing than a large slash pile at the landing.

Residual Tree Damage. No relationship between the number of damaged trees and pre-harvest density or stems removed was demonstrated. The area of scars per tree ranged from 29 to 64 cm², with an average of 47 cm² (Table 7). Scars were caused by the harvester cleaning, positioning the felling head, falling trees, and processing stems. The forwarder also caused damage when pulling logs to the trail and picking up logs, as well as when the loaded logs and forwarder stakes contacted the standing trees along the trail. Residual tree damage appeared to be affected more by operator care than tree size or stand density.

Root decay is more likely to be caused by scars close to the ground than by those further up the tree (Bettinger and Kellogg 1993; Hunt and Krueger 1962). Although higher quality stands may be left after thinning, residual trees may be damaged particularly in high density stands and in stands thinned during the growing season (NSDLF 1999).

Conclusions

FERIC conducted a study of commercial thinning operations in cooperation with Millar Western Forest Products Ltd. and Blue Ridge Lumber (1981) Ltd. of Whitecourt, Alberta.

Statistical analyses revealed that tree size, but not stand density, affected harvester productivity. Generally, as tree volume increased, the productivity increased. As well, stand density did not influence the

Table 5. Cost on the Landing (based on productive machine hours)

	Study area						
	MW1	MW2	MW3	MW4	MW5	MW6	BR1
Harvester ($/m³)	12.83	15.58	18.69	19.82	45.64	8.72	22.67
Forwarder ($/m³)	8.16	8.24	8.59	8.16	11.22	7.11	11.64
Total ($/m³)	20.99	23.82	27.28	27.98	56.86	15.83	34.31

Table 6. Slash Assessment [a]

	Study area					
	MW1	MW2	MW3	MW4	MW5	MW6
Average pieces per 20-m slashline						
1–5 cm diameter (no.)	30.8	32.1	45.2	18.3	27.9	32.3
>5 cm diameter (no.)	12.9	9.6	12.9	8.2	13.6	9.3
Average diameter of pieces >5 cm diameter (cm)	9.4	10.0	7.5	8.7	8.2	9.5
Average length of pieces >5 cm diameter (m)	4.45	4.8	3.7	3.9	4.2	4.3
Average volume						
Pieces with diameter 1–5 cm (m³/ha)	2.4	2.6	5.4	2.1	3.2	3.4
Pieces with diameter > 5 cm (m³/ha)	29.1	26.4	27.5	22.2	32.3	28.3
Total volume (m³/ha)	31.5	29.0	32.9	24.3	35.5	31.7
Range in volume (m³/ha)	0–437.7	0–811.2	0–355.6	0–442.0	0–363.0	0–532.2
Slash depth (cm)	19.3	15.7	10.8	6.2	9.9	10.0

[a] Fire destroyed study area BR1 in June 1998. No slash assessment was done.

Table 7. Residual Tree Damage [a]

	Study area					
	MW1	MW2	MW3	MW4	MW5	MW6
Trees surveyed (no.)	350	426	222	145	198	84
Trees with scars (%)	30.9	15.7	27.9	20.0	19.7	39.3
Tree with more than one scar (%)	16.3	7.0	15.8	6.2	9.1	22.6
Size of damage						
Average width (cm)	4.7	4.9	4.0	5.1	4.2	4.1
Average length (cm)	9.7	9.4	6.8	12.2	7.2	7.2
Average area (cm^2)	52	54	29	64	29	43
Height of damage from base of tree (m)	1.27	1.74	0.92	2.12	1.10	1.18

[a] Fire destroyed study area BR1 in June 1998. No residual tree damage survey was done.

productivity of the forwarder, and only a weak relationship between forwarder productivity and travel-empty distance was demonstrated.

The productivity of the harvesters ranged from 4.3 to 22.5 m^3/PMH, while the productivity of the forwarders ranged from 11.8 to 23.2 m^3/PMH. Average productivities of the harvesters and forwarders were 12.1 and 18.4 m^3/PMH, respectively. The calculated cost averaged \$25.56/m^3 on the landing. The range of \$15.83–\$56.86/m^3 corresponds to the areas with the largest and smallest tree volumes, respectively.

Post-treatment surveys showed that slash levels were, as expected, directly related to the number of trees harvested. Residual tree damage was affected more by operator care than tree size and stand density.

References

Andersson, B. 1991. Evaluation of Rottne cut-to-length harvesting systems. Pages 61-67, *in* Proceedings of the Forestry Operations in the 1990's: Challenges and Solutions. Council on Forest Engineering Annual Meeting, July 22-25, 1991, Nanaimo, B.C.

Andersson, B. 1994. Cut-to-length and tree-length harvesting systems in central Alberta: A comparison. FERIC, Vancouver, B.C. Technical Report TR-108. 20 pp. + App.

Bettinger, P.; Kellogg, L.D. 1993. Residual stand damage from cut-to-length thinning of second-growth timber in the Cascade Range of western Oregon. Forest Products Journal 43(11/12): 59-64.

Holtzscher, M.A.; Lanford, B.L. 1997. Tree diameter effects on cost and productivity of cut-to-length systems. Forest Products Journal 47(3): 25-30.

Hunt, J.A. 1995. Commercial thinning a coastal second-growth forest with a Timberjack cut-to-length system. FERIC, Vancouver, B.C. Technical Note TN-235. 14 pp.

Hunt, J.; Krueger, K.W. 1962. Decay associated with thinning wounds in young-growth western hemlock and Douglas-fir. Journal of Forestry 80(5): 336-340.

Kellogg, L.D.; Bettinger, P.; Robe, S.; Steffert, A. 1992. Mechanized harvesting: a compendium of research. Forest Research Laboratory, College of Forestry, Oregon State University, Corvallis, OR. 401 pp.

Makkonen, I. 1991. Silver Streak single-grip harvester in Nova Scotia. FERIC, Pointe Claire, Que. Field Note No.: Processing-23. 2 pp.

Nova Scotia Department of Lands and Forests (NSDLF). 1991. Productivity of a Valmet 901 single-grip harvester in merchantable thinnings. Forest Res. Rept. 27. Nova Scotia Dept. of Lands and Forests, Truro, N.S. 16 pp.

Richardson, R. 1989. Evaluation of five processors and harvesters. FERIC, Pointe Claire, Que. Technical Report No. TR-94. 18 pp.

Sutherland, B.J. 1986. Standard assessment procedures for evaluating silvicultural equipment: a handbook. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ont. 96 pp.

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Appendix I

Machine Costs [a]

	Timberjack 608 harvester	Rocan-T harvester	Timberjack 1210 forwarder	Rottne Rapid 6WD forwarder
OWNERSHIP COSTS				
Total purchase price (P) $	495 000	330 000	452 000	340 000
Expected life (Y) y	5	5	5	5
Expected life (H) h	10 000	10 000	10 000	10 000
Scheduled hours/year (h) = (H/Y) h	2 000	2 000	2 000	2 000
Salvage value as % of P (s) %	25	25	30	30
Interest rate (Int) %	7.0	7.0	7.0	7.0
Insurance rate (Ins) %	2.0	2.0	2.0	2.0
Salvage value (S)=((P•s)/100) $	123 750	82 500	135 600	102 000
Average investment (AVI)=((P+S)/2) $	309 375	206 250	293 800	221 000
Loss in resale value ((P-S)/H) $/h	37.13	24.75	31.64	23.80
Interest ((Int•AVI)/h) $/h	10.83	7.22	10.28	7.74
Insurance ((Ins•AVI)/h) $/h	3.09	2.06	2.94	2.21
Total ownership costs (OW) $/h	51.05	34.03	44.86	33.75
OPERATING COSTS				
Fuel consumption (F) L/h	20	10	15	15
Fuel (fc) $/L	0.39	0.39	0.39	0.39
Lube & oil as % of fuel (fp) %	15	15	15	15
Annual tire consumption (t) no.	-	1	1	1
Tire replacement (tc) $	-	2 000	3 150	3 150
Track & undercarriage replacement (Tc) $	25 000	-	9 500	9 500
Track & undercarriage life (Th) h	5 000	-	5 000	5 000
Annual repair & maintenance (Rp) $	75 200	52 480	70 296	52 376
Shift length (sl) h	10	10	10	10
Operator wages (W) $/h	24.29	24.29	22.33	22.33
Wage benefit loading (WBL) %	35	35	35	35
Fuel (F•fc) $/h	7.80	3.90	5.85	5.85
Lube & oil ((fp/100)•(F•fc)) $/h	1.17	0.59	0.88	0.88
Tires ((t•tc)/h) $/h	-	1.00	1.58	1.58
Track & undercarriage (Tc/Th) $/h	5.00	-	1.90	1.90
Repair & maintenance (Rp/h) $/h	37.60	26.24	35.15	26.19
Wages & benefits (W•(1+WBL/100)) $/h	32.79	32.79	30.15	30.15
Total operating costs (OP) $/h	84.36	64.52	75.51	66.55
OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	135.41	98.55	120.37	100.30
TOTAL OWNERSHIP AND OPERATING COSTS ((OW+OP)/machine utilization)[b] $/PMH	196.25	142.83	164.79	137.40

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead, and are not the actual costs for the contractor or company studied.

[b] Machine utilization used for the harvesters and forwarders in the calculation were 69% and 73%, respectively (Andersson 1994).

Appendix II

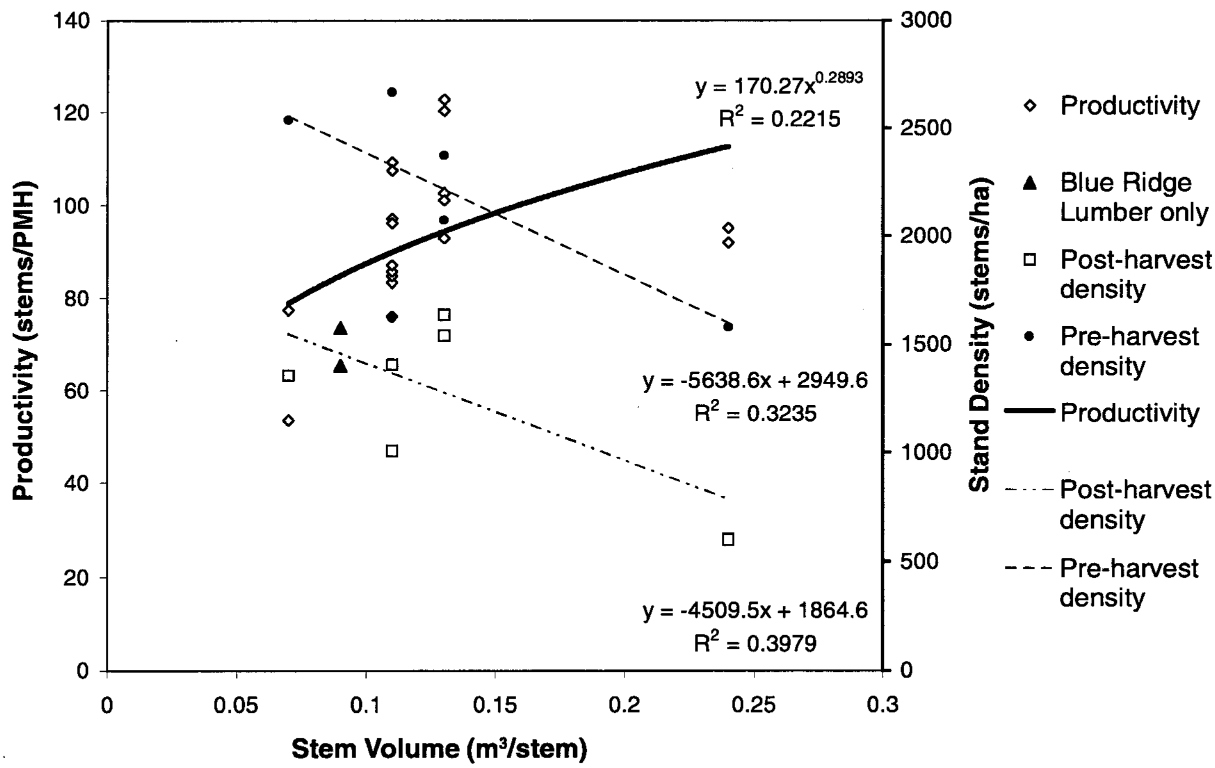

Figure II-A. Harvester productivity in various stand densities and tree sizes.

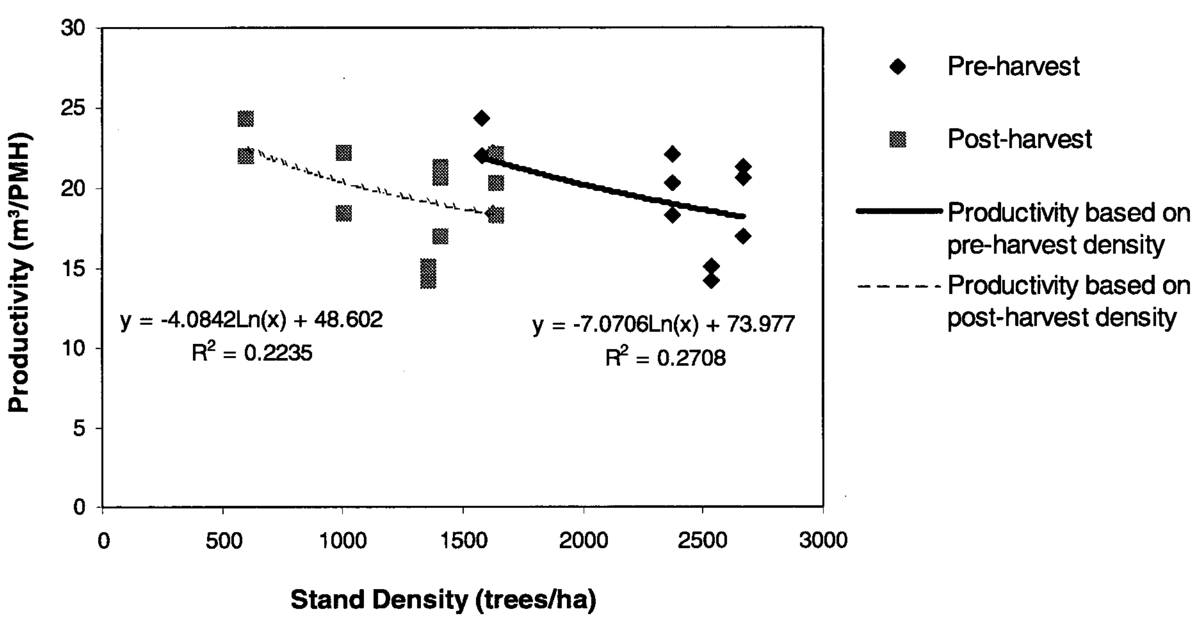

Figure II-B. Relationship between forwarder productivity and pre-harvest and post-harvest stand densities.