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# Feller/Bunchers in Plantation Thinnings: Factors Affecting Productivity

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# FELLER/BUNCHERS IN PLANTATION THINNINGS: FACTORS AFFECTING PRODUCTIVITY

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Closely spaced plantations must be thinned early for optimal tree growth, but removing small trees is costly. Harvest costs can be lowered by using highly productive machines, such as feller/bunchers. To identify possible areas for improving design and operation of feller/bunchers, we used computer simulation to study the sensitivity of harvesting productivity to machine and stand characteristics.

Two basic feller/buncher designs were studied: the chassis-mounted and boom-mounted shear types. A feller/buncher with a chassis-mounted shear must drive to each tree and accurately position the shear head. In contrast, a feller/buncher with a boom-mounted shear can reach several trees from one location, thus reducing machine travel in the stand. Because of these operational differences, we used separate simulation models for each machine type (Winsauer 1980, Winsauer and Bradley 1982). The models were written in the simulation language GPSS, General Purpose Simulation System. The computer runs were made on the UNIVAC 1100/80 housed at Michigan Technological University, Houghton, Michigan.

The variables we considered in this investigation were:

1. Stand characteristics:
   Tree spacing
   Average tree diameter at breast height (d.b.h.)
   Basal area (BA)
2. Operational factors:
   Thinning pattern
   Thinning intensity (percent tree removal)
3. Machine characteristics:
   Accumulating capacity of shear
   Average travel speed
   Average shear time
   Average drop time
   Boom travel speed
   Maximum and minimum boom reach

These variables were used as input to the simulation. For each variable we chose a range of values representative of existing equipment and stands. Within this range, we chose a typical value to be used as a standard. Comparison of the model output values—productivity, elemental time, travel distance, and bunch size—formed the basis of the analysis.

## STAND CHARACTERISTICS

We limited our investigation to small-diameter plantations of equally spaced softwoods (table 1). We decided not to emphasize a particular species but to consider a generalized "softwood." Height and density values were fixed at representative values, and the

Table 1.—*Initial stand characteristics*

| | | | |
|---|---|---|---|
| **Assumptions** | | | |
| Species | Softwood (generalized) | | |
| Stand structure | Plantation—square spacings | | |
| Terrain | Flat | | |
| Strip length | 100 m | | |
| Tree volume($m^3$) | $0.021 + 0.00048 \times$ d.b.h.$^2$ (cm) | | |
| ($ft^3$) | $0.73 + 0.109 \times$ d.b.h.$^2$ (in.) | | |
| Tree height (m) | 10 | | |
| (ft) | 33 | | |
| Wood density (kg/$m^3$) | 600 | | |
| (green basis) (lb/$ft^3$) | 37 | | |
| **Variables** | | **Range** | **Base value** |
| Tree diameter at (cm) | | 6.0 to 16.0 | 10.0 |
| breast height (d.b.h.) (in.) | | 2.4 to 6.3 | 4.0 |
| Tree spacing (m) | | 1.0 to 2.5 | 1.5 |
| (ft) | | 3.3 to 8.2 | 5.0 |
| **Associated parameters** | | **Range** | |
| Stand density (trees/ha) | | 1,600 to 10,000 | |
| (trees/acre) | | 648 to 4,050 | |
| Basal area ($m^2$/ha) | | 15 to 50 | |
| ($ft^2$/acre) | | 65 to 217 | |

volume equations were developed from combined data of several softwood species (Winsauer and Steinhilb 1980).

We addressed the effects on productivity by varying two major stand characteristics—tree spacing and diameter. An average initial stand diameter was selected for each computer run. To allow for variability in the number of trees the accumulator could hold, the diameter of each tree was randomly assigned during simulation. We used the following distribution to keep the diameters within a range that would be expected in an even-aged plantation:

25 percent—Average diameter minus 2 cm,
50 percent—Average diameter, and
25 percent—Average diameter plus 2 cm.

To study the effect of stand density on harvesting efficiency, we chose a range of initial tree spacings (from 1 to 2.5 m) that correspond to actual plantations. Basal area, stand density, and diameter are interrelated—thus silvicultural considerations determine the actual density-d.b.h. combination that would exist (fig. 1). Tree growth is minimal in very dense stands. Therefore, we assumed that plantations would not be allowed to exceed a basal area (BA) greater than 50 $m^2$/ha (217 $ft^2$/acre). We also assumed that stands with a basal area less than 20 $m^2$/ha (87 $ft^2$/acre) would not require thinning. Only those spacing/diameter combinations falling between these basal area limits were considered in this analysis.

## Effects of Tree Spacing and Stand Diameter on Harvesting Efficiency

Computer runs were made to "harvest" stands at each of four tree spacings (fig. 2). Basal area was held constant at 35 $m^2$/ha (150 $ft^2$/acre) for these runs by increasing the average diameter as the trees/hectare decreased. We made runs for both machine types with the other input variables set at base values. As tree spacing increased the number of trees harvested per hour decreased, regardless of the feller/buncher used. Trees per bunch were primarily affected by tree diameter because the accumulator could not collect as many large trees; however some distance effect also was found because at wider spacings it became too far

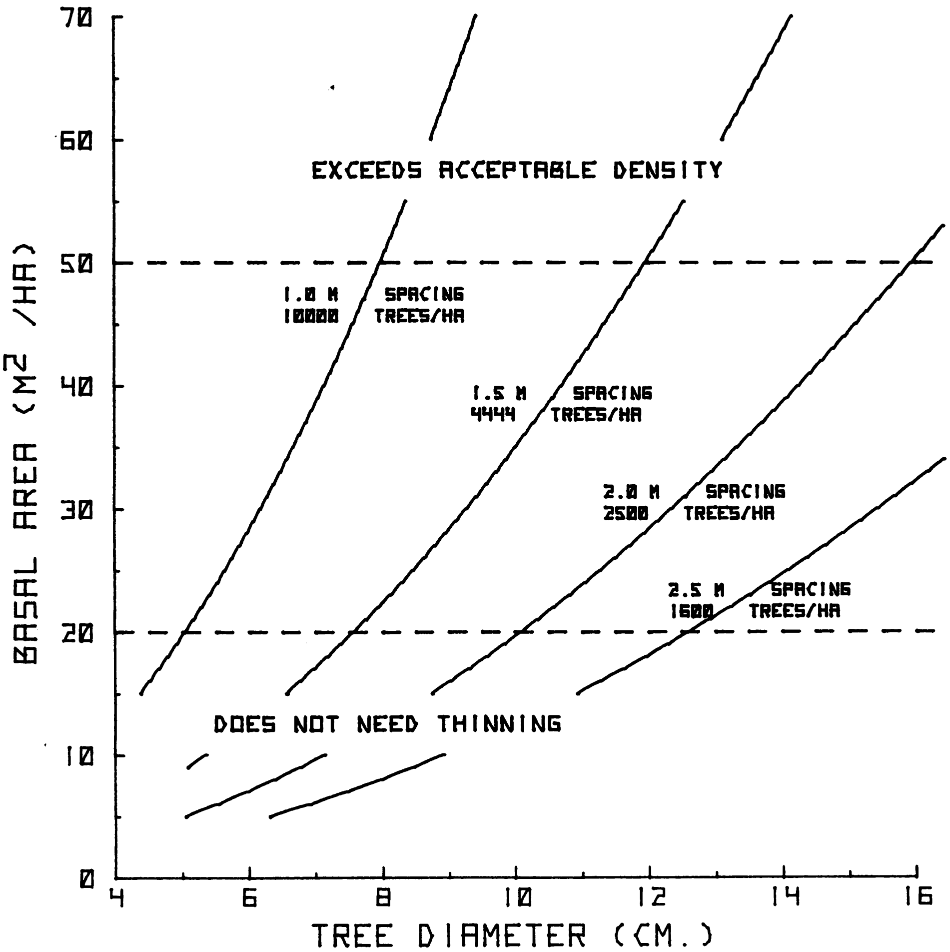


Figure 1.—*Basal area for a generalized plantation as a function of diameter and spacings.*

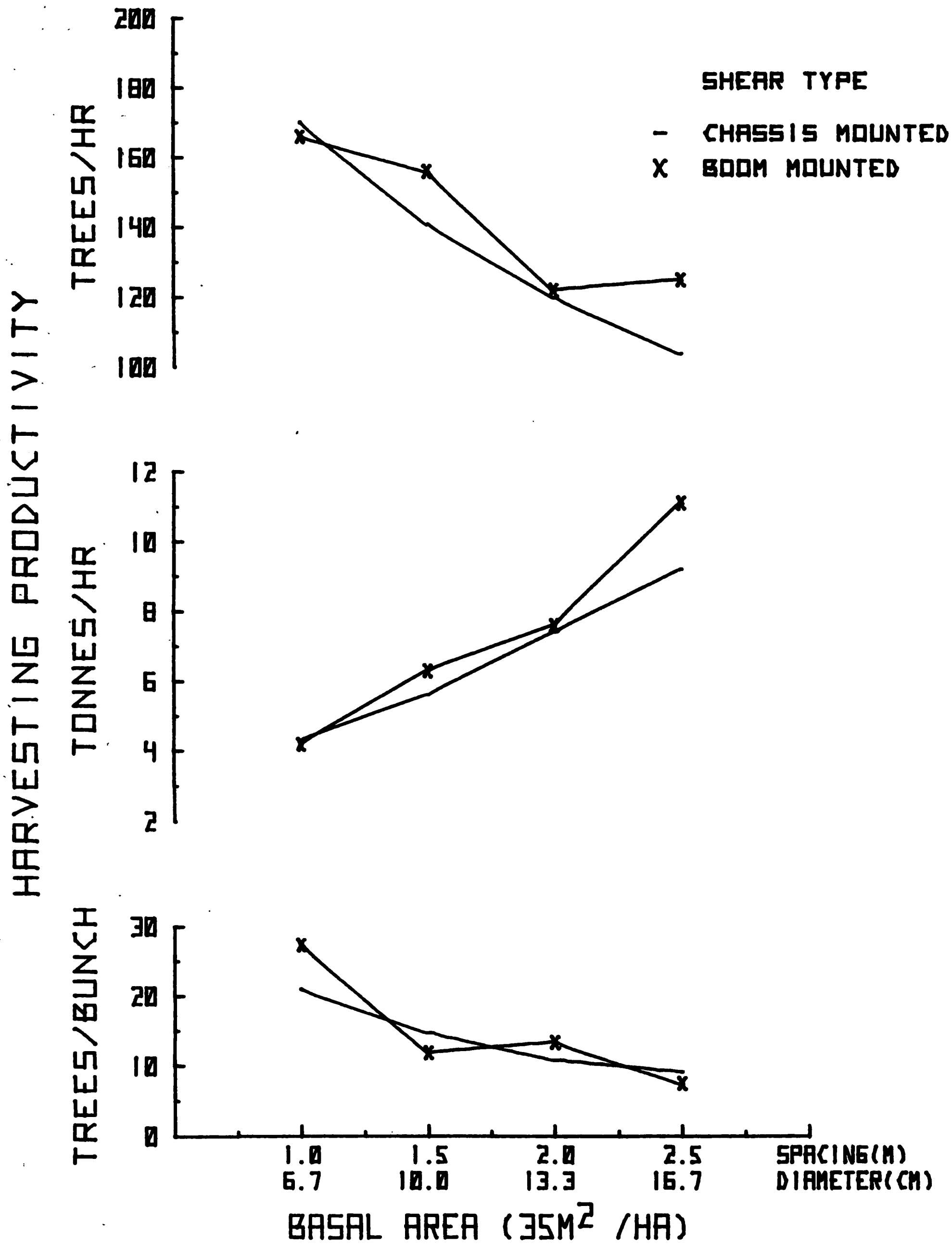


Figure 2.—*Effects of diameter and spacing on harvesting productivity.*

to travel or reach back to increase bunch size. But larger tree volumes more than compensated for the decrease in trees/hour and resulted in greater net productivity (tonnes/hour) and bunch sizes (tonnes/bunch).

We found that the boom-mounted shear was more efficient at some spacings than the fixed shear. The productivity of the two machines was almost identical at the 1.0- and 2.0-m spacings, but when tree spacings were 1.5 and 2.5 m the boom-mounted shear was 10 to 20 percent more productive than the fixed-shear machine. This was caused by the combination of strip-only thinning and the equal tree spacing in the plantation. In the 1.5- and 2.5-m plantations the previous bunch often fell just out of reach of the 10-m boom under consideration so that a new bunch had to be started. This resulted in smaller bunches dropped closer to the machine, decreasing boom swing time and increasing productivity. Although it would not be as distinct in a real harvest, a similar boom reach-spacing effect would be seen that would increase feller productivity at the expense of smaller bunch size and lower skidder production.

Chassis-mounted shear:

Feller must move to each tree to fell it.

To reach a tree outside the strip, it must back up an equal distance for maneuvering.

All felled trees will be laid in the strip. The feller will back up, drop the trees, and drive over them.

Maximum distance the feller will back up to add to a bunch is 20 m (65 feet).

Boom-mounted shear:

Feller will not back up.

Feller swings trees and drops them behind machine in strip.

Machine does not leave strip.

Desired bunch size for economical skidding (sum of tree diameters) (cm) 200 (in.) 80

| **Variables** | **Range** |
|---|---|
| Thinning pattern | Strips-only or strips with diagonal or herringbone thinning between strips |
| Thinning intensity (percent trees removed) | 25 to 50 |
| Machine length (m) | 2 to 5 |
| (ft) | 6.5 to 16 |
| Machine width (m) | 1.25 to 2.5 |
| (ft) | 4 to 8 |

the stand/machine interactions (table 2). They cannot be as neatly quantified as the stand and machine characteristics.

For most efficient skidding, trees should be collected into bunches of optimal size for the specific skidder (Bradley 1984). Small, low horsepower machines would be used in these stands, so the optimal skid load was set at 200 cm total diameter—that would be 33 6-cm diameter trees or from 12 to 13 16-cm diameter trees or equivalent, approximately 1 metric tonne.

However, it may not be feasible for the feller/bunchers to assemble the optimal skid load. It is impractical for the chassis-mounted shear type to back up more than two tree lengths (20 m) just to increase the skid bunch, and the machine with a boom-mounted shear will not back up. It will add to the bunch only if it is within reach from its current location.

Thinning pattern was the major operational factor considered in this analysis. Removing strips of trees is probably the most economical treatment but leaves uneven stand density with both silvicultural and aesthetic problems. At the other end of the scale, a selection thinning may be the most desirable but the least practical. In dense stands, machine maneuverability is limited, resulting in low production and high cost. Strip thinning with some thinning of the area between strips is an intermediate option with several possible variations. We confined our investigation to strip-only thinning and to strips with a herringbone or diagonal thinning pattern between strips.

The proportion of trees removed in a thinning depends upon initial stand density/spacing. For the stands with basal area of 35 m²/ha (150 ft²/acre) or greater, it may be desirable to remove up to one-half the trees to achieve maximum growth and extend the time until another thinning is necessary. Stands with a basal area of 20 m²/ha (85 ft²/acre) are on the lower limit of needing thinning; removing one-fourth of the trees will give them sufficient room to grow.

Thinning intensities of 25, 33, and 50 percent can be achieved by cutting a strip of a single row and leaving three, two, or one uncut rows between or by cutting double rows and leaving six, four, or two, respectively. Removing single rows will result in more even tree distribution than removing double rows. However, in the stands with 1.5 meter spacing or less, removing double rows would be necessary for maneuvering even small machines (fig. 3). Machine sizes used in this study were chosen to cover the range of the smaller fellers currently available.

Thinning between strips leaves an even more uniform tree distribution. We restricted the thinning patterns between the strips to a herringbone or a diagonal pattern but still many options are possible (fig. 4). The machine must be small enough to fit between the "leave" trees, and the length and turning ratio of the feller/buncher must allow the necessary maneuvering to thin the area between strips.

The thinning pattern must be chosen carefully in the densest stands, where removing double rows is necessary to allow the machine to work without damaging residual trees. Some patterns will allow too much clumping, large empty areas, and too many edge trees, resulting in undesirable branching and uneven stand growth (fig. 5). It is necessary to make the thinned area between strips as wide as possible to improve stand distribution over the double-row strip-only pattern.

## Single- Versus Double-row Strip-only Thinning

For representative stands of each spacing category, thinnings of both single- and double-row strips were

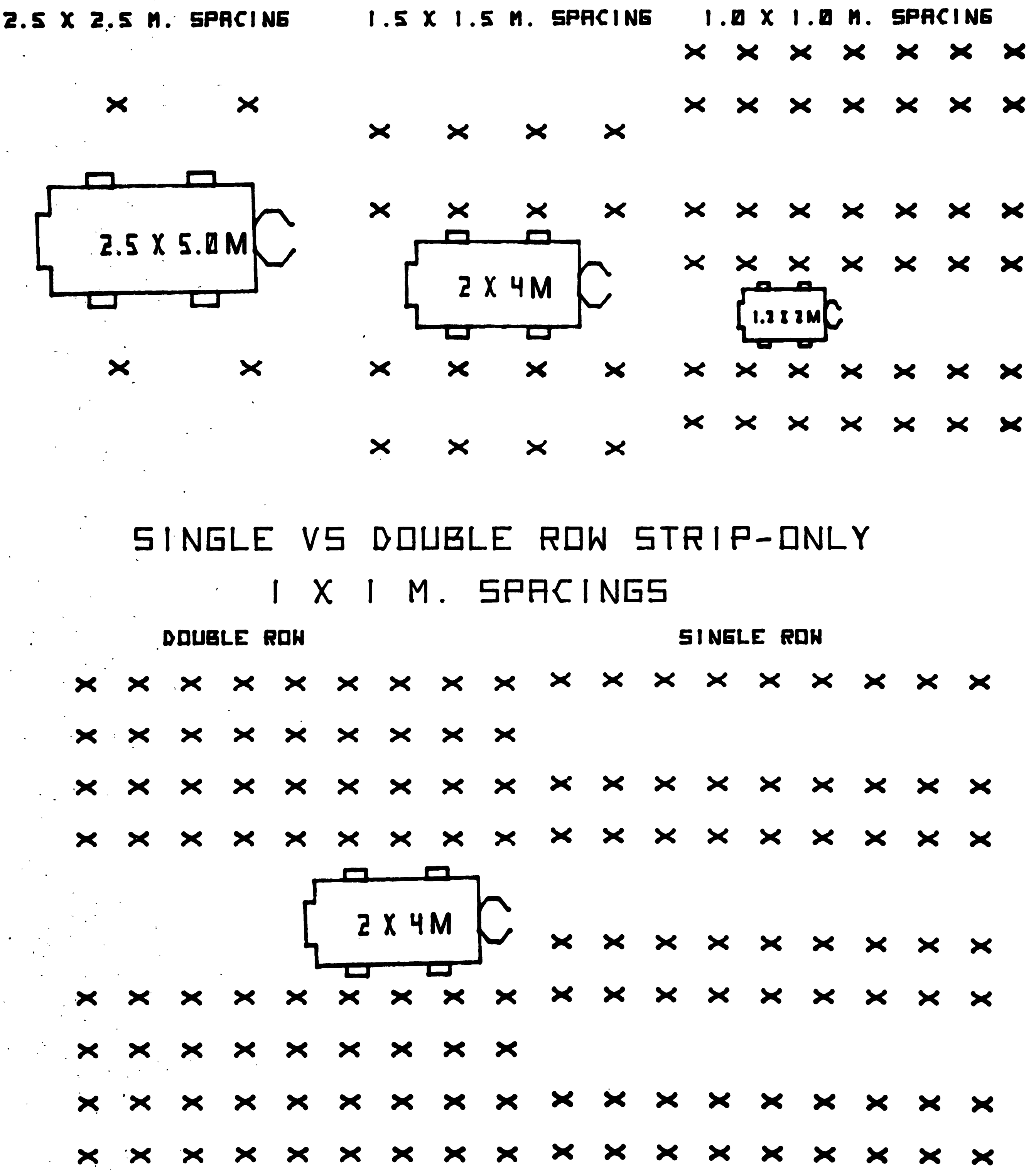


Figure 3.—*Limits on machine size due to tree spacing.*

simulated with all machine variables set at their base values. Both the chassis-mounted and boom-mounted shear machine types behaved similarly, and production rates differed little (less than 10 percent) for double-row versus single-row strips (fig. 6). However, the number of trees collected per bunch for the skidder was almost twice as large for the double-row strip thinning. Because skidding or forwarding also affects total system cost, the larger bunch size from the double-row strip would more than offset the slight advantage of feller/buncher productivity of the single-row.

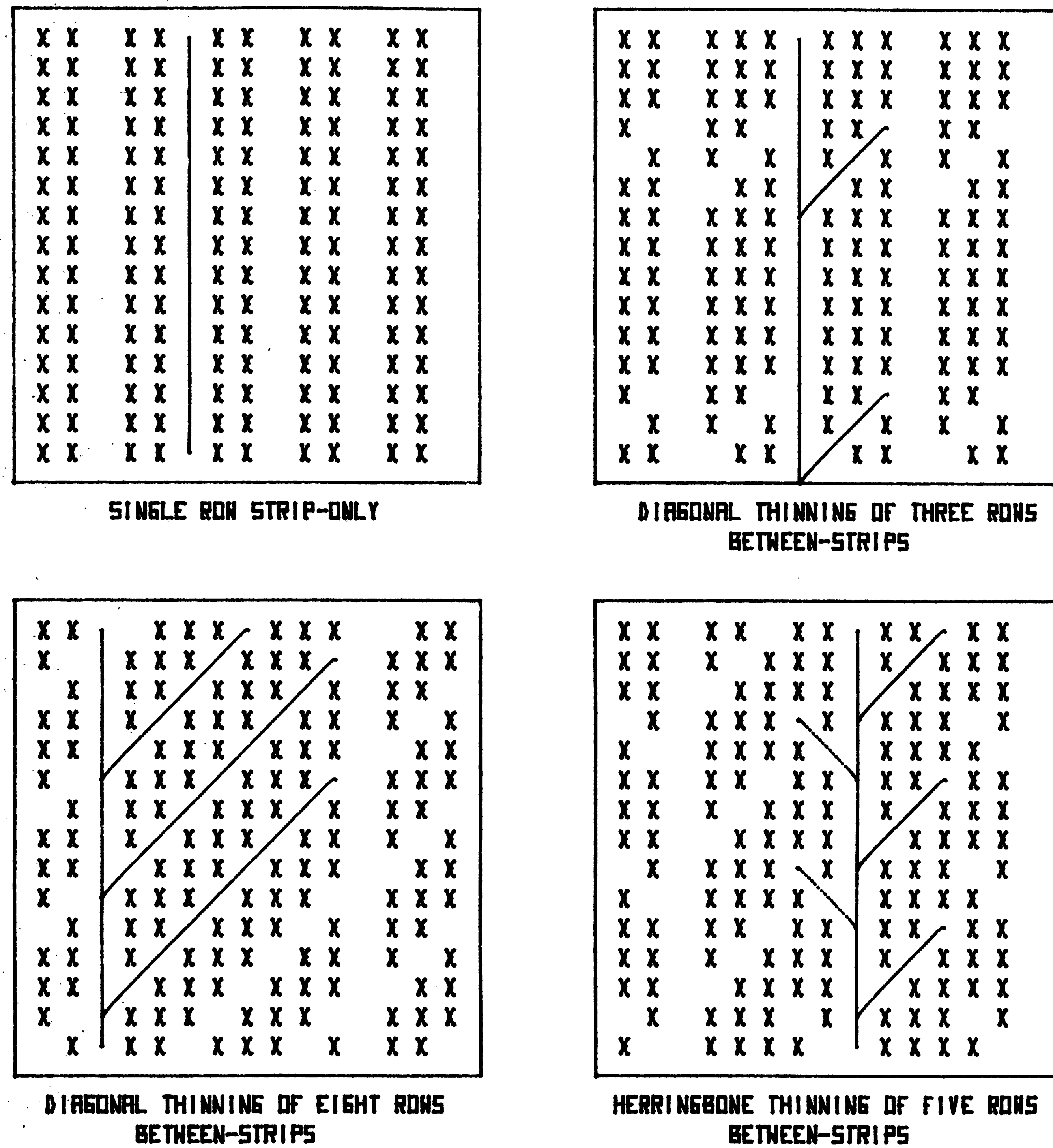

Figure 4.—*Some possible thinning patterns to achieve a 33 percent tree removal.*

## Herringbone and Diagonal Thinning Between Strips

Removing trees from the area between strips is more desirable silviculturally than strip-only thinning. To explore some facets of this type of thinning, we chose a thinning intensity of 33 percent because it offered a wide range of patterns. We simulated thinnings using both machines for each tree spacing, holding basal area constant at 35 m²/ha (150 ft²/acre). We picked an intermediate between-strip width of five rows to be thinned in diagonal and herringbone patterns. More trees are available from any location with thinning between the rows, so bunch sizes resemble those of the double-row strip-only.

For both machines, productivity was reduced when the areas between strips were thinned (table 3). The chassis-mounted shear showed the greater decrease

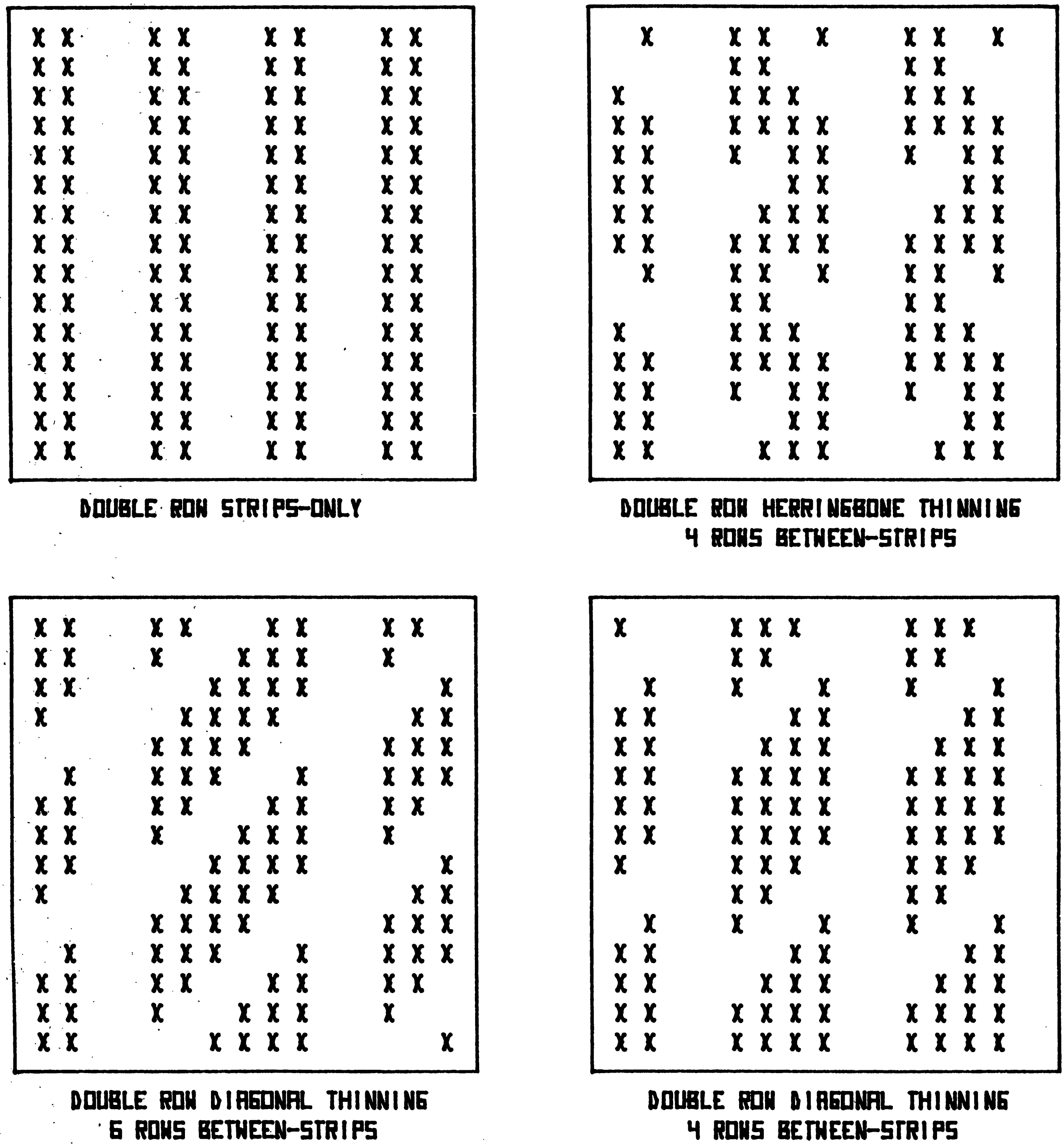


Figure 5.—*Thinning patterns in closely spaced stands requiring removal of double rows 50 percent tree removal.*

(approximately 18 percent) due to the additional travel needed for each tree. The decrease in productivity from the strip-only is less consistent for the boom-mounted shear—it ranged from 5 to 23 percent. This is largely due to the higher production found in the 1.5- and 2.5-m spacings because of the particular boom reach chosen for the study.

For the feller/buncher with the chassis-mounted shear, it made no difference which pattern was chosen except for the 2.5-m-spaced trees. For that stand, thinning with a diagonal pattern was almost as efficient as strip thinning only. The tree diameter/accumulator size combination was such that the feller always had a full accumulator when it reached the end of the diagonal. For the 2-m-spaced plantation, however, almost 50 percent of the time the feller did not have a full accumulator load when it reached the end of the diagonal.

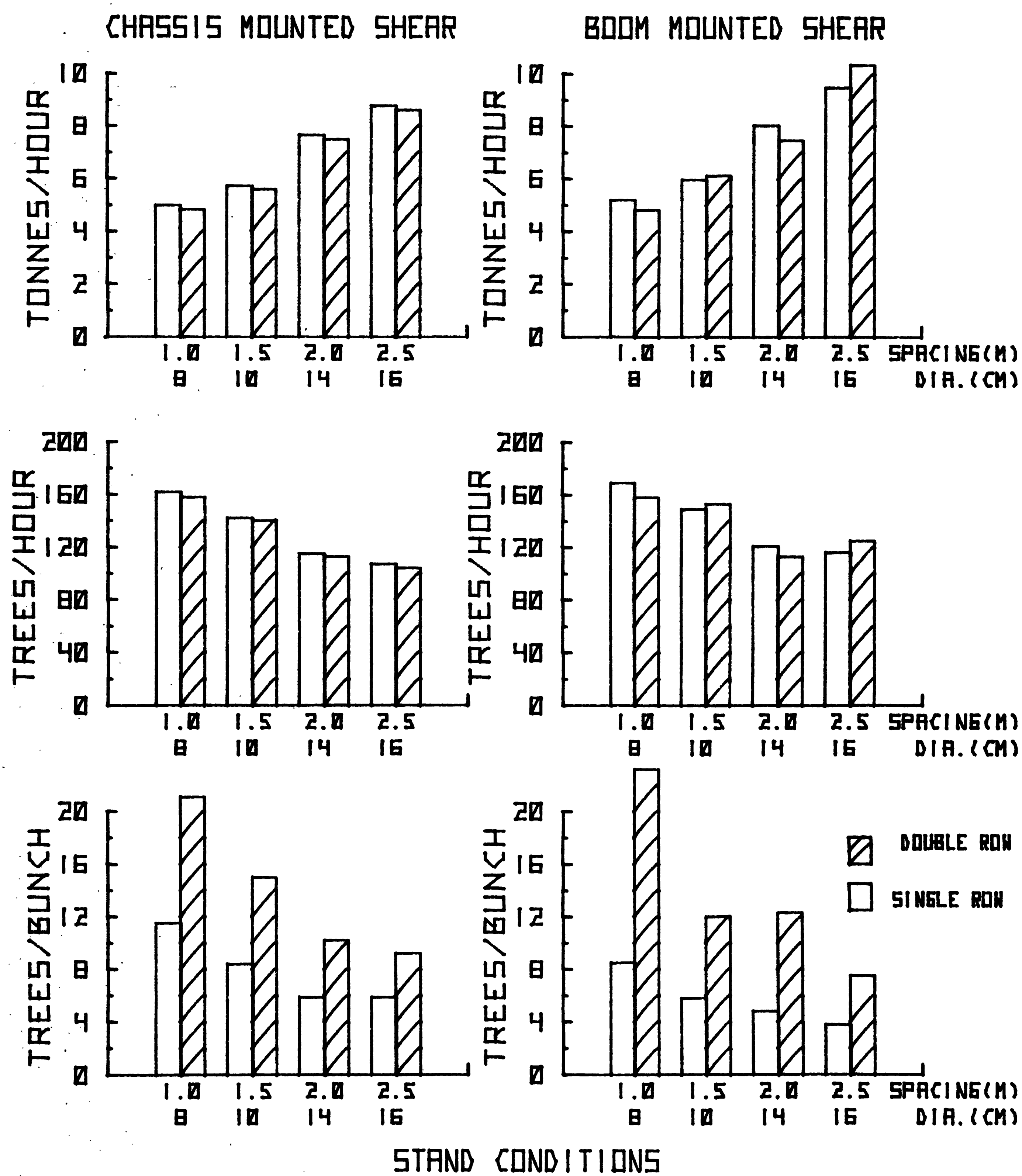


Figure 6.—*Effects on productivity—single row versus double row strips only.*

Table 3.—*Comparison of feller/buncher productivity—herringbone or diagonal thinning versus strips-only*

| Productivity | 1 × 1 m (6.7 cm) | | | 1.5 × 1.5 m (10.0 cm) | | | 2 × 2 m (13.3 cm) | | | 2.5 × 2.5 m (16.7 cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strip[1] | Diag[2] | Herr[3] | Strip | Diag | Herr | Strip | Diag | Herr | Strip | Diag | Herr |
| **CHASSIS-MOUNTED SHEAR** | | | | | | | | | | | | |
| Trees/hour | 170 | 143 | 137 | 140 | 116 | 118 | 120 | 99 | 100 | 104 | 98 | 83 |
| Tonnes/hour | 4.3 | 3.6 | 3.5 | 5.6 | 4.7 | 4.7 | 7.4 | 6.1 | 6.2 | 9.2 | 8.7 | 7.4 |
| Decrease in tonnes/hour (percent of strip-only) | | 16 | 1 9 | | 16 | 16 | | 18 | 16 | | 5 | 20 |
| Trees/bunch | 21 | 23 | 23 | 15 | 14 | 13 | 11 | 11 | 11 | 9 | 9 | 9 |
| Distance traveled/tree (m) | 8.0 | 11.6 | 12.1 | 11.5 | 16.2 | 15.4 | 14.7 | 20.9 | 20.3 | 9.1 | 21.3 | 26.9 |
| **BOOM-MOUNTED SHEAR** | | | | | | | | | | | | |
| Trees/hour | 167 | 156 | 154 | 154 | 122 | 129 | 122 | 110 | 115 | 125 | 96[4] | 103 |
| Tonnes/hour | 4.2 | 4.0 | 3.9 | 6.1 | 4.9 | 5.2 | 7.6 | 6.8 | 7.1 | 11.1 | 8.5 | 9.2 |
| Decrease in tonnes/hour (percent of strip-only) | | 5 | 7 | | 20 | 15 | | 11 | 7 | | 23 | 17 |
| Trees/bunch | 25 | 25 | 24 | 12 | 18 | 16 | 14 | 9 | 12 | 8 | 8 | 10 |

Spacing (tree diameter)

[1]Strip-only—double-row strip-only, 33 percent removal.
[2]Diagonal—single-row strip with five thinned rows between, 33 percent removal.
[3]Herringbone—single-row strip with five thinned rows between, 33 percent removal.
[4]Ten percent of trees missed because they were beyond reach of the boom.

The choice between a herringbone and diagonal thinning pattern for the boom-mounted shear machine had a significant affect on production once—in the 2.5 m spacing. Because of the length of the diagonal, 10 percent of the trees marked for thinning were missed because they were beyond the reach of the boom. The particular spacing at which this becomes a problem depends upon boom length and number of rows in the selection area. However, this generally can be avoided by using a herringbone pattern.

## Effect of Thinning Intensity

When thinning in strips only, the proportion of trees removed affects only the width of the between-strip area. For these closely spaced trees, this difference in width is not sufficient to affect productivity in terms of tonnes/hour or trees/hour. But, of course, it does affect the hectares per hour because the number of trees removed per hectare changes with thinning intensity (table 4).

Many different between-strip widths can be used to achieve the same overall thinning level. For example, some of the options for removing 25 percent of the trees in a stand using single-row strips with between-strip thinning are:

| Between-strip width (No. rows) | Fraction of trees to be removed from each row |
|---|---|
| 5 | 1/10 |
| 7 | 1/7 |
| 9 | 1/6 |
| 15 | 1/5 |

Each option results in a different diagonal length and a different number of trees available from a given machine location, affecting travel and boom reach time and the number of accumulator loads. In addition, trees will be out of reach for the boom-mounted shear for some options and spacings.

Table 4.—*Productivity of the chassis-mounted shear for different thinning intensities*

| Thinning intensity[1] (percent) | Trees/ hour | Tonnes/ hour | Hectares/ hour |
|---|---|---|---|
| 25 | 139 | 5.6 | 0.13 |
| 33 | 140 | 5.6 | 0.10 |
| 50 | 140 | 5.6 | 0.06 |

[1]*Stand spacing 1.5 m; 10 cm average tree diameter.*

The difference in productivity caused by the choice of between-strip width is greater than the differences caused by percent tree removal or the choice of the herringbone or diagonal pattern (fig. 7). The optimal

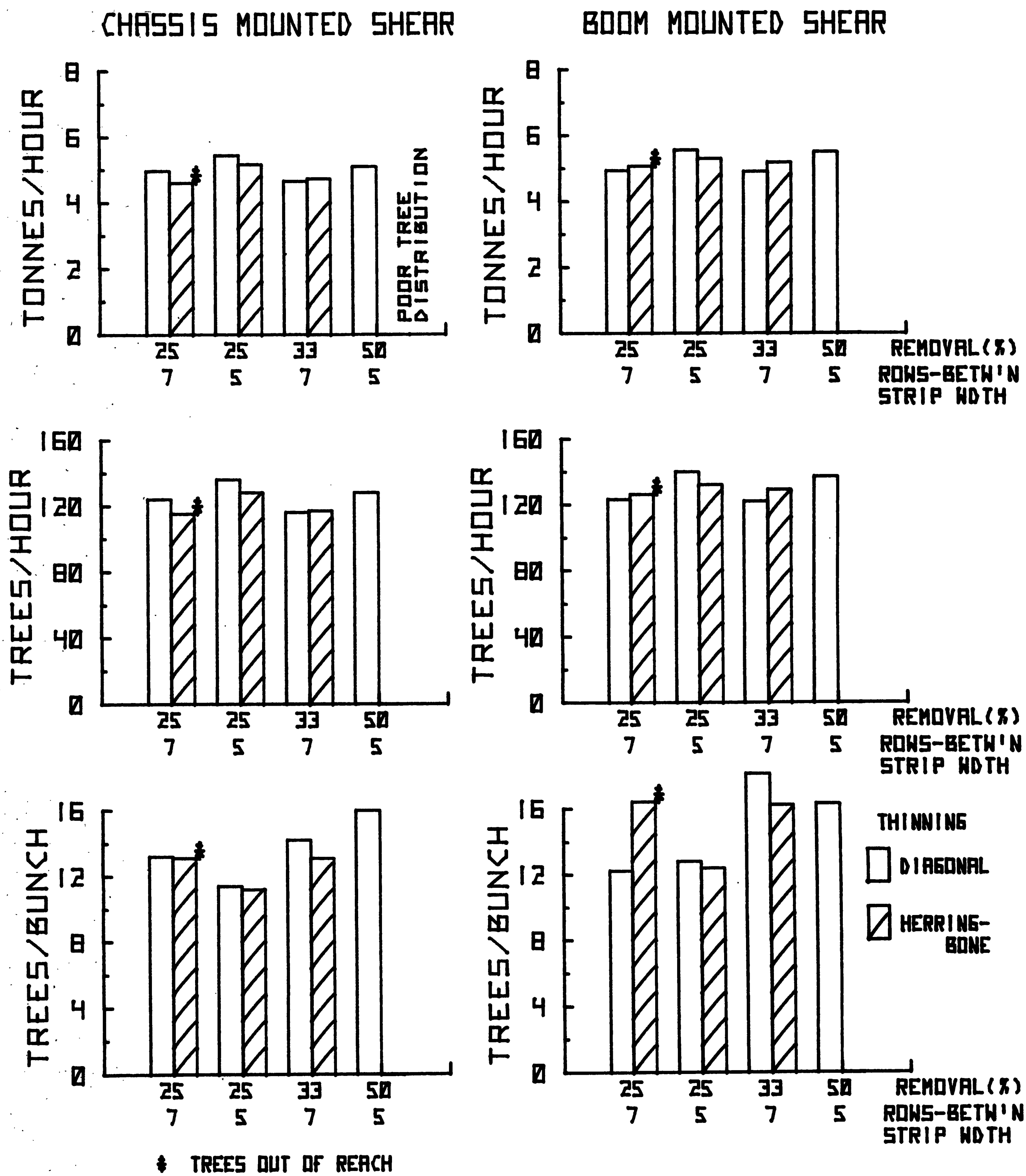


Figure 7.—*Effects on productivity—percent tree removal, between strip width, and thinning pattern.*

between-strip width for a given pattern and tree removal rate will depend on tree spacing, tree diameter, accumulator head capacity, and boom reach (for the boom-mounted shear). This interaction of factors makes it difficult to determine the optimum width, and it deserves a separate analysis.

## Herringbone and Diagonal Thinnings in 1- by 1-m Spacings

To permit machine maneuverability and to avoid tree damage in dense stands—i.e., 1- by 1-m spacings—it may be necessary to remove a double row of trees when thinning the between-strip area. To determine what effect this would have on productivity, we simulated a 50-percent removal rate with a diagonal pattern of both single and double rows (table 5).

Productivity increased while bunch size remained similar in contrast to the strip-only thinning where productivity was similar, but the bunch size doubled when double rows were cut. Overall efficiency improved because of the greater number of trees available for each pass the machine or boom had to make into the between-strip area.

## MACHINE CHARACTERISTICS

An understanding of how productivity is affected by each of the machine characteristics could lead to development of the most efficient machine for these thinnings (table 6).

An accumulator head to collect multiple stems increases productivity. The number of stems the accumulator can hold depends on the size of the individual trees. To specify the size of the accumulator, we used a total sum of tree diameters. We studied a range of machines from these with no accumulating ability to machines with an accumulating capacity of 55 cm—that is, nine 6-cm trees or four 16-cm trees. This would be an accumulating head approximately 40 cm (16 in.) in diameter capable of handling 250 Kg or 500 to 600 lbs. We felt that a larger accumulator would not be mechanically feasible on these small machines.

Table 5.—*Effect of removing double rows in the between-strip area*

| | Chassis-mounted | | Boom-mounted | |
|---|---|---|---|---|
| | Single row | Double row | Single row | Double row |
| Trees/hour | 141 | 148 | 151 | 176 |
| Tonnes/hour | 3.6 | 3.8 | 3.8 | 4.5 |
| Trees/bunch | 22 | 28 | 27 | 24 |

Table 6.—*Feller/buncher machine characteristics*

| Variable | Range | Base value |
|---|---|---|
| Shear accumulator | | |
| Capacity—total diameter (cm) | 0 to 55 | 30 |
| (in.) | 0 to 22 | 12 |
| Average travel speeds | | |
| Chassis-mounted shear (k/hr) | 2 to 8 | 4 |
| (mph) | 1.2 to 4.8 | 2.4 |
| Boom-mounted shear (k/hr) | 1 to 4 | 2 |
| (mph) | .6 to 2.4 | 1.2 |
| Average shear time (min/stem) | .1 to .4 | .2 |
| Average drop time (min/load) | .1 to .4 | .2 |
| Boom reach speed—boom-mounted only | | |
| Unloaded (m/sec) | .5 to 2 | 1 |
| (ft/sec) | 1.7 to 6.7 | 3.3 |
| Loaded—10 percent longer for each tree in accumulator head | | |
| Boom reach | | |
| Minimum (m) | 2 to 3 | 2 |
| (ft) | 6.5 to 10 | |
| Maximum (m) | 5 to 15 | 10 |
| (ft) | 15 to 50 | |

Travel speeds in the woods have been shown to be normally distributed, with a standard deviation from 25 to 30 percent of the average value (Blinn 1983). The simulation model samples a normal distribution to obtain each travel speed. The average travel speeds were chosen to cover the range of values observed in the field. In general, machines carrying a boom are slower than those with a fixed shear, so we chose a greater base speed for the fixed shear.

Neither shear times nor drop times are normally distributed. Approximately 3,500 field observations were used to develop distributions for shear and drop times (fig. 8). These distributions were then normalized to the mean so they could be used with the different mean values and still maintain their properties. The base values were taken as being equal to the field observation means, while the "fast" and "slow" times were one-half and twice the base values, respectively. The simulation program sampled these distributions for each shear and drop time.

One meter per second was determined to be a reasonable boom travel speed. Again, one-half and twice that rate were used for the "slow" and "fast" limits to determine effect of boom speed on production. Boom travel time was increased 10 percent for each tree in the accumulator head to compensate for maneuvering and the additional weight. Boom reach was limited to the range of values for currently available machines.

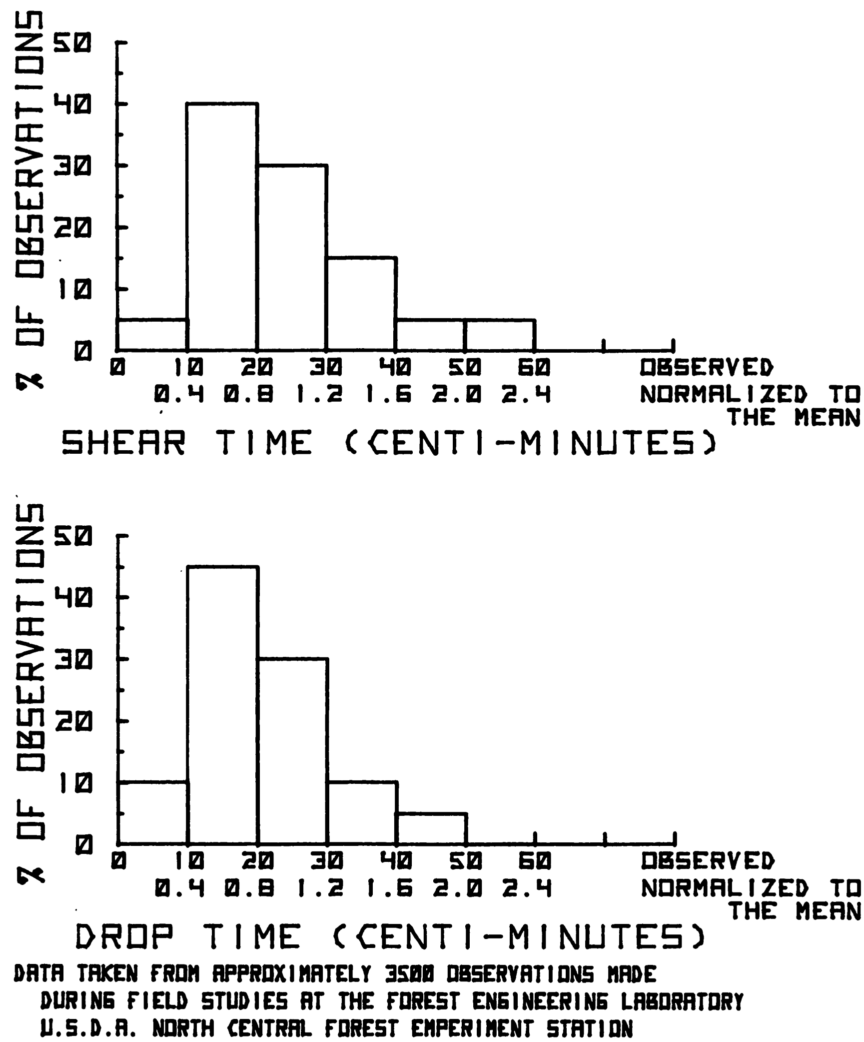


Figure 8.—*Distributions of shear and drop times used in simulation model.*

## Sensitivity of Productivity to Machine Variables

To determine sensitivity of production to each of the machine variables, runs were made for both machine types changing one variable at a time. Each variable was tested at a "slow" and "fast" rate, and the results were compared to the standard runs; i.e., all values set to base values (table 7). Runs were also made with all machine variables set "slow" and then all set "fast" to obtain lower and upper bounds on production rates. These runs were all made at the 1.5-m spacing and an average tree diameter of 10 cm giving a basal area of 35 $m^2$/ha (150 $ft^2$/acre). Shear rate greatly affected productivity for both machine types. Productivity increased at least 30 percent when average shear time is reduced from 0.2 to 0.1 minute per tree. Travel speed also significantly affected productivity for the fixed-head shear; however, it made little difference for the boom-mounted machine. Because machine travel is replaced with boom motion for that machine, the boom reach speed becomes the significant factor.

The most important machine characteristic is the existence of an accumulating head. We assumed an accumulator for the base value. Increasing the size of the accumulator; i.e., the "high" value, increases production by 15 to 30 percent. However, if no accumulator is used, production drops 50 percent! The number of trees the accumulator head can hold depends upon tree size; the small head can hold four or five small trees but only one or two large ones. Additional runs for various tree spacings and average tree diameters were made to further investigate the effect of the use and size of an accumulating head. Trees per hour and tonnes per hour increase dramatically with the use of an accumulator (fig. 9). For small trees, the production rate with a large accumulating head is three times that of no acculmulator.

Table 7.—*Sensitivity of feller/buncher productivity (tonnes/hour) to changes in machine variables*

| Production | Fixed-head shear | Boom-mounted shear |
|---|---|---|
| Minimum—all machine values set low | 1.34 tonnes/hr (-77%) | 1.67 tonnes/hr (-73%) |
| Average—all machine values set base | 5.59 tonnes/hr | 6.12 tonnes/hr |
| Maximum—all machine variables set high | 14.97 tonnes/hr (+168%) | 15.55 tonnes/hr (+154%) |

| | Variable | | Fixed-head shear | | Boom-mounted shear | |
|---|---|---|---|---|---|---|
| | | | Change in production (percent) | | | |
| Machine | Low rate | High rate | Low | High | Low | High |
| Travel speed | | | | | | |
| Fixed-head | 2 k/hr | 8 k/hr | -31 | 29 | | |
| Boom-mounted | 1 k/hr | 4 k/hr | | | -5 | 5 |
| Shear rate | 0.4 min/tree | 0.1 min/tree | -30 | 31 | -32 | 34 |
| Drop rate | 0.4 min/tree | 0.1 min/tree | -12 | 9 | -14 | 11 |
| Accumulator head capacity (total diameter) | No accumulator | 55 cm (large) | -50 | 29 | -43 | 16 |
| Boom reach speed | 0.5 m/sec | 2 m/sec | | | -33 | 23 |

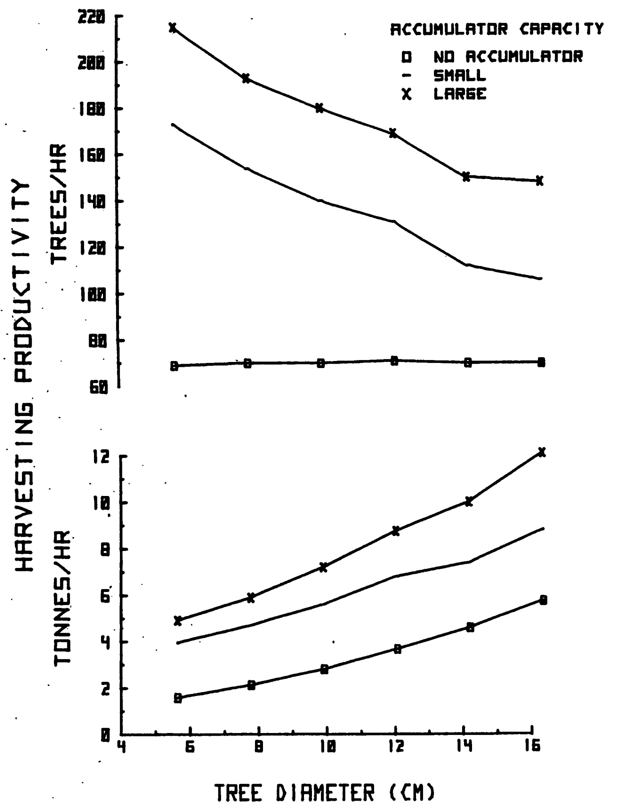


Figure 9.—*Effects of accumulator head on productivity.*

For large trees, the production rate is twice that of no accumulator. Also when using an accumulator head skid bunch size increases which is an additional advantage when considering the entire system.

Additional thinnings were tested with a herringbone pattern between strips for machines with various accumulating capacities. The percent change in production due to eliminating the accumulator or increasing its capacity is identical to those outlined in the preceding paragraph.

## Maximum and Minimum Boom Extension

To determine the effect of the boom reach limits, runs were made for each spacing at a basal area of 35 $m^2$/ha. In these dense stands, the shorter the boom reach, the higher the productivity (fig. 10). We feel this is due to the close spacings and the nature of the strip thinnings. Although a machine with a shorter boom reach spends more time traveling, the extension time for the boom is shorter and overall productivity is greater. This effect was less pronounced as the boom travel speed increased. Production increase was at the expense of leaving smaller bunches for the skidder or forwarder; those from a machine with a 5-m boom were one-half the size of those made with a 10- or 15-m boom.

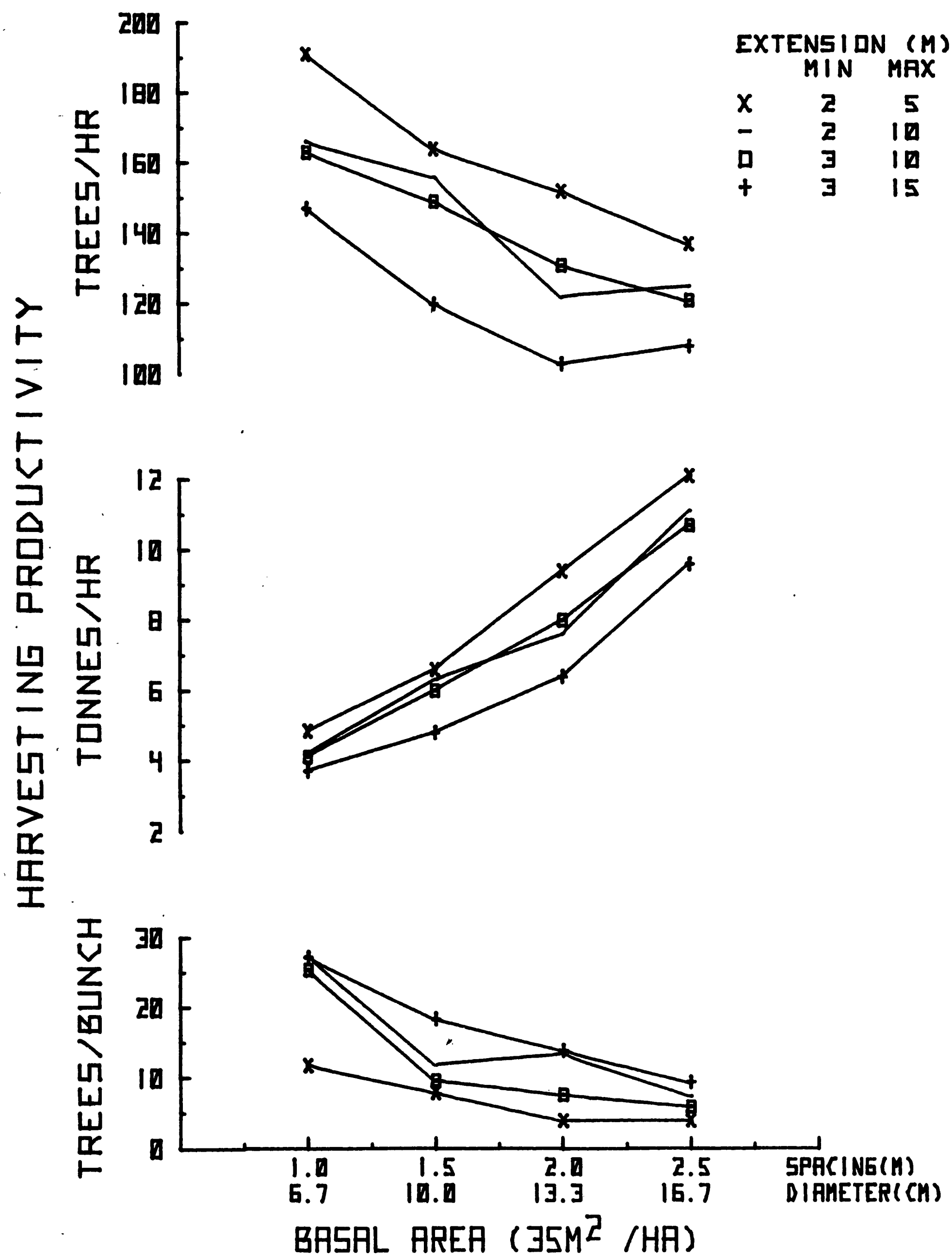


Figure 10.—*Effects of boom extension on harvesting productivity.*

Changing the minimum boom reach; i.e., how close the shear could be to the machine, produced less well-defined results. Bunch sizes for the 3-m minimum reach decreased slightly, but the productivity was affected more by the boom/spacing interaction than the minimum distance. Boom rech is a more critical factor when the thinning pattern involves more than just removing strips. It is necessary for the boom to be able to reach all the trees to be removed in the thinned areas, particularly in the diagonal pattern.

## CONCLUSIONS

The purpose of this analysis was to determine the effect of various factors on the performance of feller/bunchers in thinning plantations. The validity of the results derived from this analysis is subject to the assumptions made in developing and implementing the simulation models. Our approach addressed the sensitivity of production to each variable independently. It was impossible to consider all the possible characteristics and their interactions, yet the values considered for each variable were within the range of current conditions and technology. Therefore, the results of this study should be useful in determining the elements of machine design and operation that warrant the most attention. In particular, the use of an accumulator head and/or an increase in cutting speed can significantly improve productivity. This indicates that new concepts providing for simultaneous cutting and/or collecting of multiple stems could greatly enhance the mechanized harvesting of these plantations.

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Computer simulation was used to identify possible areas for improving the design and operation of feller/bunchers for thinning closely spaced plantations. Some of the variables considered were average stand diameter, tree spacing, thinning pattern, operational machine speeds, and shear head accumulating capacity.

KEY WORDS: Simulation, machine characteristics, stand characteristics, computer, felling.