Energy and force requirements for six pruning shear designs

P. Crossland, G. Murphy, G. Martin and M. Dean

Abstract
Six pruning shear designs were compared under laboratory conditions. Total energy and peak force required for cutting radiata pine and Douglas-fir branches were measured. Branch sizes ranged from 9 to 63 mm. Under one standard set of conditions some shears required over 50% more energy and peak force than others. Douglas-fir required more energy and force than radiata pine. Two brands tested on both species differed in terms of the magnitude of the additional requirement. Total energy and force requirements tended to increase with cutting edge angle and with blade thickness.

Introduction
Currently about 90,000 hectares of forests in New Zealand are scheduled annually for pruning (Knowles, 1995). The majority of this area is in radiata pine plantations. In the past a small amount of pruning has been carried out in Douglas-fir plantations (Reutebuch, 1995). Shears are the most common tools used for pruning.

Although experienced pruning contractors maintain that use of the correct technique may be more important to operating efficiency than tool selection, they acknowledge that different situations require different pruning shear designs (M. King, pers. comm.). Research aimed at improving pruning shear design has been going on in New Zealand for more than a decade. In 1984 the six most common pruning shears used in New Zealand were tested at the Forest Research Institute. The Wolf pruners and the Long Porter pruners were found to require the lowest peak force when radiata pine branches and dowelling were severed (E. Mason, pers. comm.).

Seven models of pruning shears were tested on radiata pine dowelling in 1986 (Hall and Mason, 1988). This time modified Prun-off and Hit 27 shears had the lowest peak force requirement and Wolf pruners were considered to be the least satisfactory.

In this paper we review the literature on design of pruning shears and report results of tests on six brands of shears representing a range of recent design modifications.

What design tips does the literature provide?
Terms used to describe design features of cutting implements in the following are explained in Figure 1.

In the late 1980s, Hall and Mason (1988) commented after tests on radiata pine dowelling that “the thickness and shape of the cutting blades had a profound influence on cutting efficiency” and that “careful grinding of the pruner heads reduced thickness of the blade and markedly increased efficiency”.

Chancellor (cited in Persson, 1987), Kempe (1967), and Johnston (1968a and b) also reported that the cutting force required when pruning a range of herbaceous (Phleum pratense) and woody (Picea glauca, Pinus resinosa, Pinus banksiana, Pinus taeda, Pinus radiata, Abies balsamea up to 18mm thick) materials was greatly affected by knife thickness. In some cases, doubling knife thickness resulted in a 50% increase in cutting force. Mattson and Sturos (1996), on the other hand, found that knife thickness did not affect cutting force required to shear sugar maple (Acer saccharum) branches. This may have been due to lower cutting speeds (>600 mm/sec compared with <10 mm/sec) later on.

While agreement exists about the effect of cutting edge angle on force and energy requirements, Johnston (1968a and b) found that angles between 20° and 60° had little effect on required peak force. Kempe (1967) reported that a 45° cutting edge angle required 20 to 30% less force to shear spruce logs than was needed with a 60° angle. Reduction from 45° to 30° resulted in no further change in required peak force. Mattson and Sturos (1996) found that reducing the cutting edge angle (A) from 45° to 30° resulted in a 55% reduction in peak force necessary for shearing sugar maple branches, but further angle change to 15° did not improve performance. Koch (1971) reported that a 9.5 mm thick blade with a 22.5° cutting edge required 45% less total energy and 25% less peak force for shear 130mm diameter Southern Pine logs than was required when using a 45° cutting edge (A).

The counteredge angle has also been shown to affect peak force requirements. Chancellor (1957) stated that a “fine” counteredge requires approximately 25% less force than a “blunt” counteredge.

Knife shape and knife friction have also been shown to affect force requirements. Kempe (1967) reported that knives with recessed sides required 20% less peak force for the same cutting edge angle and thickness than parallel-sided knives. Koch (1971)
found that tapered knives with a thin root also required less force. Koch (1971) and Johnston (1968a, b) both comment that small reductions in the necessary force could be achieved if the friction between the blade and the wood was lowered. Greasing the blade has been found to have no appreciable effect but a teflon coating of the blade surface is effective.

The manner in which the force is applied has also been shown to have an effect. Mattson and Sturos (1996) demonstrated that an oblique cutting angle (B) requires greater peak force. They also examined the effect of cutting speed (600 vs 1100 mm per second) on required force but found no significant difference at these high speeds.

In summary then, performance may possibly be improved by tuning such design features as knife thickness, cutting edge angle (A), knife shape, knife friction, oblique cutting angle (B) and counteredge angle. The literature contains no information about the most effective combination of these features.

Methods
Pruning Shears Tested
Six pruning shear brands1 (Fig. 2) were selected to represent the design range of implements currently available to, or used by, production pruning crews in New Zealand. Table 1 summarises their main design features. Weight varied between 1.58 and 2.28 kg. Maximum branch diameters compatible with the blade opening ranged from 55 to 63 mm. Four of the brands had cutting blades with a single cutting edge angle. Two had convex cutting blades with two (Prun-off) or three (Hit 27) cutting edge angles (Fig. 3).

Performance Tests
Each brand was tested on fresh branches taken from a six-year-old Pinus radiata shelter-belt. Tests were conducted using a Sin-tech MTS materials testing workstation2 at Lincoln University. Two sets of shears (Haumi Big and Hit 27) were also tested on Douglas-fir. They were selected because they showed distinct performance differences in radiata pine. The Douglas-fir branches were taken from the top six metre portion of a felled 38-year-old tree in Ashley Forest. All branches were collected in mid-winter. Branch sizes ranged between 10 and 65 mm diameter in radiata pine and between 9 and 61 mm in Douglas-fir. Bark was left on the branches of both species for the tests.

Because the total energy required to cut through a branch with pruning shears is independent of the length of the handles, measurement of total energy requirement provides a better comparison between brands than peak force requirement, which depends on the length of the lever arm about which the force is applied. Peak force measurements assess the integrated effect of design features, but only for a limited period during the cutting action.

Figure 2. The six tested brands. Left to right: Haumi Small, Haumi Big, Lane, Prun-off, Hit 27 and Wiringi shears.

![Figure 2](image)

Table 1. Key design features of the pruning shears tested

<table>
<thead>
<tr>
<th></th>
<th>Weight (kg)</th>
<th>Total length (mm)</th>
<th>Maximum aperture (mm)</th>
<th>Cutting blade thickness (mm)</th>
<th>Cutting edge angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haumi Small</td>
<td>1.8</td>
<td>615</td>
<td>55</td>
<td>6.4</td>
<td>12</td>
</tr>
<tr>
<td>Haumi Big</td>
<td>2.1</td>
<td>688</td>
<td>66</td>
<td>6.1</td>
<td>13</td>
</tr>
<tr>
<td>Lane</td>
<td>1.8</td>
<td>568</td>
<td>55</td>
<td>6.7</td>
<td>13</td>
</tr>
<tr>
<td>Prun-off</td>
<td>2.2</td>
<td>671</td>
<td>58</td>
<td>6.4</td>
<td>18/10</td>
</tr>
<tr>
<td>Hit 27</td>
<td>2.3</td>
<td>702</td>
<td>63</td>
<td>6.8</td>
<td>24/15/9</td>
</tr>
<tr>
<td>Wiringi</td>
<td>1.6</td>
<td>700</td>
<td>60</td>
<td>7.2</td>
<td>14</td>
</tr>
</tbody>
</table>

Figure 3. Profiles of the cutting blades.

![Figure 3](image)

The head of each pair of shears was removed from the handles and placed in specially-made grips which fastened it to the testing machine. The machine closed the shears at a rate of 400 mm per minute in a plane at right angles to the branch axis and recorded the total energy (Joules) and peak force (Newtons) required for each cut. The measured peak force was then adjusted, by taking the length of the blade lever arm into consideration, to give the peak force directly over the cutting point. The cross-sectional area of the branch at each cut was measured using a planimeter.

A total of 160 measurements were taken on the Douglas-fir branches; 80 measurements each using the Haumi Big and Hit 27 shears. A total of 549 measurements were taken on the radiata pine branches; 95 using Haumi Big, 87 using Haumi Small, 95 using Lane, 86 using Wiringi, 96 using Hit 27 and 90 using Prun-off.

Data were pooled and analysed using the Giant Size Regression technique (Cunia, 1973). Differences between brands and between tree species were considered to be significant if they exceeded the tabulated F values at the 0.05 probability level.

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1 Use of trade or firm names in this publication is for reader information and does not imply endorsement or criticism by the authors or by their employers.

2 The tests were carried out under controlled conditions in an engineering laboratory. Neither sturdiness of the shears nor frequency of sharpening required was taken into account.
If you think this looks wait until you see
Impressive, isn't it? Not only does it make a stunning panorama, it also delivers some pretty impressive returns.

Last year, Carter Holt Harvey Forests produced 4.5 million tonnes of radiata pine - in 50 grades - for both domestic and export processing. And because our forests are a renewable resource, the future looks even more promising.

As one of the largest forest and building product companies in the Southern Hemisphere, our forests support several more thriving industries in downstream processing.

These industries produce a wide range of wood-based products including lumber, panel products and pulp and paper.

And our company will continue to provide first class products, export earnings and employment for the future benefit of all New Zealanders.

Our forestry is one of this country's most valuable resources.

We all stand to make something from it.
RESULTS

Performance with radiata pine branches

For all brands peak force and total energy required to sever a branch increased greatly with branch size. Figure 4 shows an example of the relationship between branch diameter and peak force required for the Haumi Big brand. For example, Haumi Big shears required about 400 N peak force to sever a 1 cm *Pinus radiata* branch and 7700 N to sever a 6 cm branch. Regression equations were derived for all brands and predictions relating to one branch size (cross-sectional area equal to that of a 4 cm diameter branch) were compared.

![Figure 4. Relationship between radiata pine branch size and peak force per cut required during use of Haumi Big pruning shears.](image)

Table 2 and 3 show that the Haumi Big shears required least total energy and least peak force. The lowest-ranked brand required 43% more total energy and 50% more peak force than the highest-ranked brand.

![Table 2. Ranking of the brands in order of least amount of total energy required to cut a 40 mm diameter radiata pine branch.](image)

![Table 3. Ranking of brands in order of least peak force required to cut a 40 mm diameter radiata pine branch.](image)

Performance with Douglas-fir branches

With both brands tested, requirements for total energy and peak force were significantly higher for Douglas-fir than for the radiata pine branches. No branchwood physical properties, such as wood density or moisture content, were gathered, so we are unable to account for the differences between the species.

Table 4 shows that there was a difference between brands in terms of magnitude of energy and force requirements for the two species. Haumi Big and Hit 27 shears respectively required 5 and 30% more energy for the Douglas-fir than for the radiata pine branch. Likewise Haumi Big required about 30% more peak force and Hit 27 about 55% more peak force for the Douglas-fir than for the radiata pine branch.

![Table 4. Energy and peak force required by two selected brands for cutting 40mm diameter radiata pine and Douglas-fir branches.](image)

Discussion

It is obvious that huge gains can be made by improving shear design. Some currently available shears require 50% more...
energy and peak force than others to cut a radiata pine branch of the same size. More energy and force are needed to prune Douglas-fir branches than radiata pine branches of the same size. Potential gains are likely to be accentuated in Douglas-fir stands.

The three designs ranked highest for total energy requirement were also ranked highest in terms of peak force requirements. The remaining three designs did not rank equally for peak force efficiency and energy efficiency.

The tests provided some basis for the endorsement of design features but inconsistencies were apparent.

The Haumi Big shears, which were ranked first for energy efficiency, had the thinnest cutting blade, a straight blade profile and the second-smallest cutting edge angle. Shears ranked second and third had straight blade profiles and cutting edge angles similar to those of Haumi Big shears but the blades were 5 to 10% thicker. This increase in blade thickness was associated with a 9% increase in total energy requirement. The Wiringi shears, which had the thickest cutting blades, but a straight profile and cutting edge angle only slightly larger than Haumi Big, required about 20% more total energy than the Haumi Big shears. The two lowest-ranking shears - Hit 27 (29% more energy required than for Haumi Big) and Prun-off (43% more energy) - both had convex blade profiles and the largest cutting edge angles in the first few millimetres of blade. The Hit 27 shears performed better than the Prun-off shears even though the latter had slightly thinner cutting blades and smaller cutting edge angles. Hit 27 had a sharper counteredge than Prun-off, which might account for the difference.

Although tests were conducted in a laboratory and may not represent operational conditions, the observed energy requirement differences between pruning shears designs warrant further investigation. Issues such as frequency of sharpening and durability also need attention. The object of future studies should be the definition of a combination of design features and practice that minimises energy input during pruning.

Acknowledgements
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References
USDA Forest Service, North Central Experiment Station, Research Paper NC-327, 8pp.

Soil disturbance effects on Pinus radiata growth during the first 11 years

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Abstract
The effect of soil disturbance (forest litter removal, topsoil removal and compaction) on the productivity of second-rotation Pinus radiata growing on a clay loam soil was assessed in a long-term trial. Relative to the controls, tree volumes at age 11 years were reduced by about 20% where litter had been removed by machine, about 55% where the topsoil had been removed and subsoil compacted with two passes of a loader, and about 65% where the topsoil had been removed and the subsoil compacted with eight passes of a loader. Long-term indications are that although relative growth differences between trees in treated and untreated plots are decreasing with time, negative effects of topsoil removal combined with compaction of subsoil are likely to be apparent when the trees are due to be harvested.

Keywords: soil compaction, litter removal, soil removal, site productivity, tree growth.

Introduction
Each year in New Zealand, approximately 20,000 hectares of plantation forest are harvested with the aid of ground-based logging equipment such as felling machines, mechanical processors, skidders and crawler tractors. These machines inevitably disturb the soil and extensive litter removal, topsoil removal, horizon mixing and soil compaction may occur. A number of worldwide literature reviews (e.g., Wronski & Murphy, 1994), as well as earlier research in New Zealand (Ballard, 1978; Berg, 1975; Murphy, 1983; Skinner et al. 1989), have indicated that soil disturbance relating to harvesting may result in reduced tree growth. In particular, the effects of soil compaction may be apparent for decades unless remedial measures are taken. Modification of the soil as a result of harvesting is of particular importance in New Zealand where fast-growing Pinus radiata D. Don only requires 30 years to reach economic maturity and up to one-third of a site may be disturbed to some extent (Murphy, 1984).

To evaluate the long-term effects of harvesting practice on soil characteristics and the growth of second rotation Pinus radiata, the Forest Research Institute established an experiment on a clay loam soil in Maramarua Forest in 1982. Skinner et al. (1989)