Toppled pines - can they be fixed? Results from three toppling trials at Waiotira, Northland

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Abstract

Three trials were established in one- and two-year-old radiata pine stands, following toppling after a severe storm, with the aim of evaluating various treatments to correct the toppling. The treatments included straightening the trees and turfing, tying up with string, staking, and topping at different heights, some with or without crown lightening through wind-proof pruning. None of the remedial treatments was particularly effective, and it may be better to focus on measures to prevent toppling.

Introduction

Toppled trees are defined as having a lean of 15° or more from vertical following buffeting from wind. (Toppling may also be induced by the weight of snow, but this is never a cause in Northland!)

Toppling of young trees occurs frequently in the first three years after planting in plantation forests (Chavasse 1969; Mason 1985), and it has been postulated that toppling may be worse on fertile farm sites (Aimers-Halliday *et al.* 1999, Davies-Colley & Turner 2001), based on anecdotal evidence rather than a formal survey. Mason (1992), in a survey of 17 sites, found no correlation with fertilised sites and toppling, and in fact found greater toppling on low productive sites at higher altitudes. Toppling often, but not always, follows after a cone-shaped depression or socket has formed round the base of the stem as the result of the tree being blown around in wet soils (Mason 1985; Coxe 1999), (Fig. 1).

The initial lean is often remedied by the tree resuming upright growth, but in the process the stem develops sinuosity (S-shaped deformity), and the base remains with butt sweep (Fig. 2). Sinuosity reduces the value of the logs by increasing compression wood, and thus affecting the straightness, stability and strength of the sawn timber (Harris 1977, 1981), as well as necessitating special log lengths to be cut for transport. The financial losses from log sinuosity due to toppling could be as high as 36% of

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Fig. 1: Socket at the base of a pine tree

Fig. 2: Sinuous pine tree

potential No. 1 clears and $7,000 per hectare if thinning selection is poor (Mason 1985).

Toppling is a problem particularly during wet conditions in heavy clay soils on fertile farm sites. The Waiotira toppling trials were established in young stands on fertile ex-pasture, on Waiotira clay, with 'easy rolling' topography, location Grid Reference Q07 193 855, a northwest aspect and prevailing wind from the southwest.

A severe storm hit Northland on 22nd June 1996. In 24 hours, the wind came from almost every direction, wind speed varied from 2 to 29 knots with gusts up to 51 knots, and heavy rain fell with the easterly winds. Many 1- and 2-year-old trees toppled. It was an ideal opportunity to test different remedial methods for toppled trees, and to investigate whether wind-proof pruning influenced growth and prevented further toppling.

All three trials were conduced on *Pinus radiata* seedling trees that had been planted at 3 m spacing in rows 5 m apart on the contour. They were released by spraying about 50 ml of a mixture of 500 ml Gardoprim® and 125 ml Gallant® in 10 litres of water, around the base of each tree, covering about a square metre.

In the first trial, GF-19 seedlings, which had been planted in 1995, toppled in 1996 at one year. Six treatments were replicated in 11 blocks, a total of 66 trees. Two remedial methods on pines that toppled one year after planting were evaluated (securing with string and pegs, and securing with turf); plus the effect of wind-proof pruning of half the branch length was investigated. When toppled trees were straightened, their sockets were filled with mineral soil dug from a hole under the layer of humus-rich topsoil. Where string and pegs were used, three pegs were knocked into the ground in a triangular formation about 2 m from the tree. The string was attached to the branches and tensioned to keep the tree vertical in its straightened position after the socket was filled. Turf-secured trees were straightened and kept in an upright position by pieces of turf, approximately 25 cm x 25 cm, which were cut near the tree and wedged against the base of the stem.

In the second trial, GF-14 seedlings, which had been planted in 1994, toppled in 1996 at two years. Eight treatments were replicated in 12 blocks, a total of 96 trees. Five remedial methods on pines that toppled after two years were evaluated, (securing with string and pegs, cutting the stem in three different places); plus the effect of wind-proof pruning of half the branch length was investigated.

In the third trial, GF-26 seedlings (which had been inter-planted into an inadequate residual population of *Eucalyptus pilularis*, *E. microcorys* and *Acacia melanoxylon*, planted in 1992) were planted in 1994 and toppled in 1996 at two years. Seven treatments were replicated in 30 blocks, a total of 210 trees. Two remedial methods on pines that toppled after two years were evaluated (securing with turf, and securing with turf plus staking where the branches were tied by string to a stake that was hammered into the ground close to the trunk). The effect of two methods of wind-proof pruning (pruning by half the branch length, and removing half the number of branches) was also evaluated. In both pruning treatments, the foliage was reduced by approximately 50%.

Measurements and data analysis

The height, diameter, topple angle and direction, and sinuosity were measured for each tree in July for two years. Initial and Year 1 diameters were measured at the root collar, and Year 2 diameter was measured 30 cm above the ground level. Initial measurements of heights and root-collar diameters were recorded before any remedial treatments were imposed. A home-made topple meter was used to measure the topple angle (Fig. 3).

Fig. 3: Measurement of angle of topple using a home-made topple meter

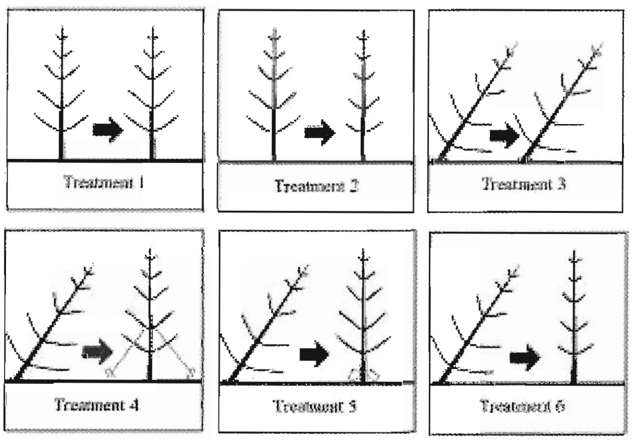
Sinuosity was assessed by measuring the maximum distance from the centre of the distorted trunk to a straight pole held next to it (Fig. 2). Heights, diameters, and their increments, as well as sinuosity, were subjected to analysis of variance (ANOVA) using the SAS Statistical package. Where there were significant differences at the 5% level or less, a LSD (least significant difference) test was done to detect which treatment means of a variable were significantly different from each other.

Each trial is described separately below, followed by overall conclusions based on the results for all three trials.

Table 1: Description of treatments in Trial 1.

Treatment	Topple Status	Description
1 NotTopCont	Not-toppled	No prune, Control
2 NotTopHalf	Not-toppled	Wind-proof prune by half branch length
3 TopCont	Toppled	No remedial treatment, no prune, Control
4 TopStr	Toppled	Straightened, socket filled, no prune, secured string and pegs
5 TopTurf	Toppled	Straightened, socket filled, no prune, secured with turf at base
6 TopHalf	Toppled	Straightened, socket filled, wind-proof pruned by half branch length

Fig. 4: Diagrammatic representation of treatments in Trial 1



Trial 1: Pines that toppled one year after planting
Materials and methods

The trial was established in a one-year-old stand in July 1996, with six treatments, shown diagrammatically in Fig. 4, and described in Table 1. Toppled trees and trees that had not toppled, which were not pruned or subject to remedial treatments, were included as controls to assess the consequences of taking no action.

Results

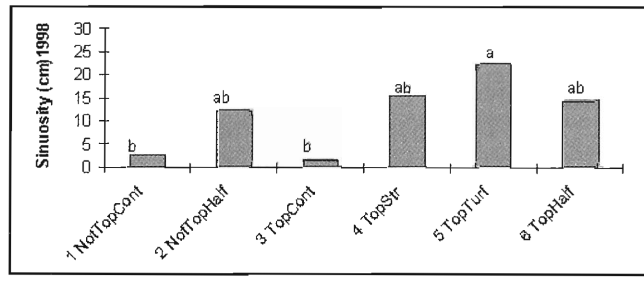
Initial tree size: In 1996, before any treatments were imposed, there were no significant differences in diameter measurements between toppled and not-toppled trees. Although there were some significant differences in initial height between treatments, the differences were not large and there was no definitive relationship between tree height and toppling.

Height increments 1996-1998 were similar for all treatments (312-360 cm).

Diameter Increment: For wind-proof pruned trees, there was a reduced mean diameter growth over the two years after treatment, compared to not-pruned trees, but this reduction in growth was only significant for the toppled trees (Treatment 3 compared with Treatment 6). Diameters were initially similar in 1996, but toppled pruned trees had significantly smaller diameters in 1997 and 1998 than toppled not-pruned trees. Wind-proof pruning could have contributed to this difference.

Sinuosity: There was some indication in the results of this trial that trees which were left untreated showed less sinuosity after two years (Fig. 5). However, only the toppled trees straightened and secured with turf (Treatment 5) were significantly worse than the two control treatments (1 and 3).

Fig. 5: Mean sinuosity (cm) in 1998 for all six treatments (described in Table 1).



Trial 2: Pines that toppled two years after planting
Materials and methods

The trial was established in a two-year-old stand in July 1996, with eight treatments, shown diagrammatically in Fig. 6, and described in Table 2.

Because Treatments 4, 7 and 8 involved cutting the stem at different heights, their growth patterns were quite different to trees whose stems were not cut (Treatments 1, 2, 3, 5 and 6). Comparisons between these groups are, therefore, limited to survival and sinuosity.

Results

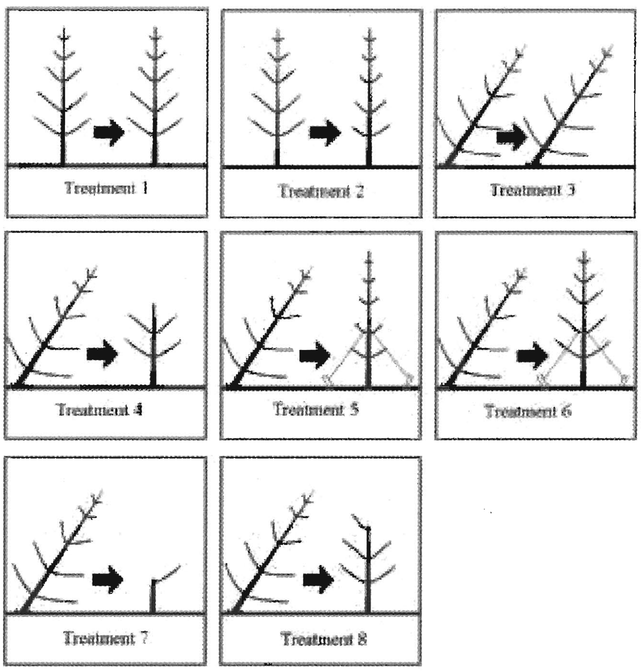
Initial tree size: Only diameter varied significantly, with not-toppled trees tending to have larger diameters than toppled trees, but the differences were not great.

Height and diameter increments 1996-1998: Wind-proof pruning of not-toppled trees resulted in a significant reduction of height increment by 25% in the first year after treatment and diameter increment over the two years compared to not-toppled, not-pruned trees (Treatment 2 compared with Treatment 1). Wind-proof pruning of toppled trees did not significantly reduce height increment but did significantly reduce diameter increment (Treatment 5 compared with Treatment

Table 2. Description of treatments in Trial 2.

Treatments		Topple Status:	Description:
1	NotTopCont	Not-toppled	No treatment - control
2	NotTopPr	Not-toppled	Prune 50% branch length
3	TopCont	Toppled	No treatment - control
4	TopHiInt	Toppled	Straightened, fill socket, stem cut at top of long internode
5	TopStrPr	Toppled	Straightened, fill socket, secured string and pegs, prune 50% branch length
6	TopStr	Toppled	Straightened, fill socket, secured string and pegs, no prune
7	TopBaWh	Toppled	Straightened, fill socket, stem cut above basal whorl, one branch left
8	TopHiWh	Toppled	Straightened, fill socket, stem cut above high whorl, one branch left

Fig. 6: Diagrammatic representation of treatments in Trial 2.



6). The reductions in diameter increments varied between 21% and 38%.

Mortality: The highest mortality (three trees dead) was recorded in 1998, two years after the treatments were imposed, for toppled trees that were cut above the basal branch whorl (Treatment 7). One tree was lost in each of Treatments 4, 6 and 8.

Sinuosity: In 1996, all trees were selected as being 'toppled' for Treatments 3 to 8. In July 1998, no 'toppled' trees were recorded as being present in any treatment. The initial topple angle or lean developed into sinuosity as trees resumed vertical growth. Varying degrees of butt sweep were observed.

Two years after treatment in July 1998, the worst average sinuosity was 28 cm for toppled trees that were not pruned or straightened (Treatment 3, the control treatment) (Fig. 7). The lowest average sinuosity in previously toppled trees was observed for Treatment 5 (secured by string and pegs and wind-proof pruned) which had 6 sinuous trees, and therefore 6 straight trees for final selection. Treatment 4 (stem cut at the top of a long internode) also had a lower than average sinuosity, but 5 trees were sinuous and 1 was dead, so there were only 6 trees for final selection. Any defect, such as a kink, resulting from the stem being cut would have been in the middle of a potential bottom log.

Cutting the stem above a basal whorl (Treatment 7) or above a high whorl (Treatment 8) and leaving one branch was not very successful in minimising the number of sinuous trees or average sinuosity. Also, the non-pruned trees secured by string and pegs (Treatment 6) had significantly higher sinuosity (20 cm) than Treatment 5 and only 3 trees with no sinuosity for final selection. Use of string and pegs is expensive in labour and materials, so this result was disappointing.

In 1998, two years after treatment, the best form, expressed in terms of lowest sinuosity, was found in trees that had not toppled in June 1996.

Cutting the stem above the basal whorl (Treatment 7) resulted in negative growth increments one year after treatment, and low increments at two years. Nine out of 12 trees were sinuous, and 3 were dead, so the selection potential was limited! Also, it has been suggested that where trees had been cut above a basal whorl, the long-term stability may be reduced because the tree's growth is not exactly above the base of the stem and the original root system. People who

Fig. 7: Average sinuosity (cm) in 1998 for all eight treatments (described in Table 2).

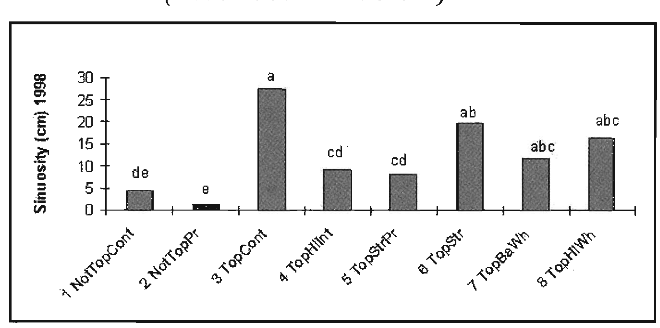
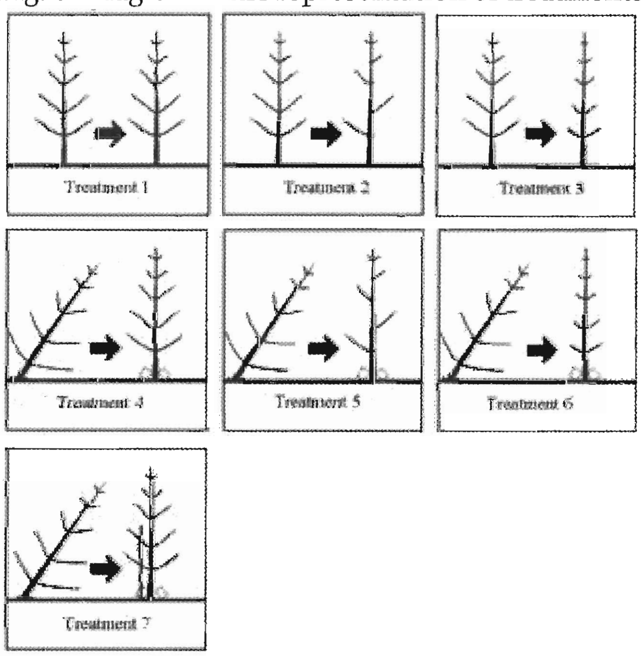


Table 3. Description of treatments in Trial 3.

Treatment		Topple Status	Description
1	NotTopCont	Not-toppled	No treatment - control
2	NotTopPrBrn	Not-toppled	Prune 50% branch number
3	NotTopPrBrl	Not-toppled	Prune 50% branch length
4	TopNoPr	Toppled	Straighten, fill socket, secure turf, no prune
5	TopPrBrn	Toppled	Straighten, fill socket, secure turf, prune 50% branch number
6	TopPrBrl	Toppled	Straighten, fill socket, secure turf, prune 50% branch length
7	TopNoPrStk	Toppled	Straighten, fill socket, secure turf, tie branches to stake, no prune

Fig. 8: Diagrammatic representation of treatments



have had success with this technique pointed out that an inadequate length of stem had been left above the branch whorl, and the cut was not healing in a healthy way. We did not find this method satisfactory, but other tree people have used it successfully.

Trial 3: Pines that toppled two years after planting

Materials and methods

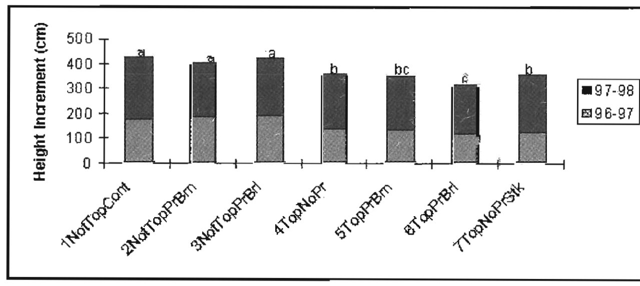
The trial was established in a two-year-old stand in July 1996, with seven treatments, shown diagrammatically in Fig. 8, and described in Table 3.

Results

Initial tree size: Trees that had not toppled tended to have greater heights and diameters than toppled trees, but the differences were not large and some differences were not statistically significant.

Height and diameter increments 1996-1998: Trees which had not toppled (Treatments 1 to 3) had significantly greater height increments than toppled trees (Treatments 4 to 7) in 1996-1998 (Fig. 9).

Fig. 9: Mean height increments (cm) during 1996-1998 for all seven treatments (described in Table 3).

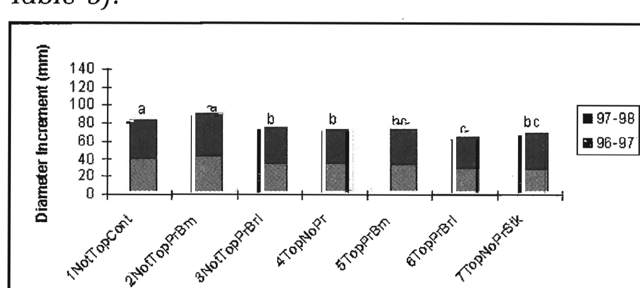


Over the two years after treatments were imposed, no significant differences in height increment were observed in trees that had not toppled that were pruned (Treatments 2 and 3) compared to not-pruned trees (Treatment 1). Among previously toppled trees, lower height increments were observed in pruned trees (Treatments 5 and 6) compared to trees not pruned (Treatment 4), but this difference was only statistically significant for the 50% branch length prune (Treatment 6) (Fig. 9). The pattern of diameter increments was similar to that of height increments (Fig. 10).

Mortality: Survival was generally very good. The highest death rates (3 out of 30, and 2 out of 30) were recorded for trees secured with stakes and string (Treatment 7) and the toppled not-pruned control (Treatment 4), respectively.

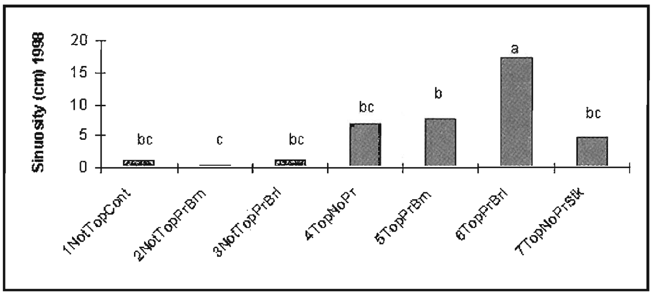
Sinuosity: In 1998, no trees were recorded as being toppled, but many of the toppled trees had subsequently developed sinuosity as they resumed vertical growth. The lowest number of trees with sinuosity, and the lowest average

Fig. 10: Mean diameter increments (mm) during 1996-1998 for all seven treatments (described in Table 3).



measure of sinuosity, was recorded for trees that had not toppled in 1996 (Treatments 1 to 3) compared with previously toppled trees (Treatments 4 to 7)(Fig. 11). About 50% of previously toppled trees exhibited sinuosity or were dead. However, only toppled trees that were wind-proof pruned by removing 50% of the branch length (Treatment 6) exhibited a significantly greater degree of sinuosity than all other treatments (and low height and diameter increments).

Fig. 11: Average sinuosity (cm) in 1998 for all seven treatments (described in Table 3).



Overall discussion

All the preventive (wind-proof-pruning) and remedial methods (turfing, cutting the stem, staking and securing with string) which were tested in the three trials have disadvantages. All require inputs of time, physical effort, and money. The aim of evaluating different methods was to find treatments which would allow a high selection possibility for final crop trees, minimising the number and severity of sinuous trees, and minimising mortality. In our judgement, the time, physical effort and money invested were not rewarded by improved quality of the trees.

The remedial treatments were imposed randomly in these trials, in the interests of scientific impartiality. All toppled trees except the toppled controls were treated the same, and straightened before the imposition of the other remedial measures described. In hindsight, the remedial treatments may have been more effective if they had been matched to the severity of the toppling, and only those with minor toppling - say 20° or less from the vertical, were straightened. By straightening severely toppled trees, part of the root system was often broken, probably affecting success of the treatment.

For wind-proof pruning, it is easier to prescribe pruning 50% branch length than pruning 50% branch number. With the former, it is easier to monitor if the prescription is being followed, as the results are clearly visible. Branches may be cut by loppers, or hedge-clippers, and the smaller branches held together and cut by secateurs. The cost of this pruning method has been estimated at less than 20 cents a tree.

Whether wind-proof pruning is worthwhile depends on the risk management strategy of the grower. Some people would consider it a good insurance on fertile fast-growth, topple-prone sites to wind-proof prune earlier, at one year, in the expectation of reducing the number of trees toppling later. Form pruning to correct double leaders and ramicorns may be done at the time of pruning, which will increase the later selection potential.

In the second trial, wind-proof pruning by cutting half the length of branches did not significantly affect height increment after two years, but significantly reduced diameter increment in all trees (not toppled and toppled) after two years. However, wind-proof pruning did reduce the number of sinuous trees, and mean sinuosity. However, it is difficult to say whether the reduced sinuosity in wind-proof pruned trees, compared with not-pruned controls, is due to prevention of topple subsequent to June 1996, or due to directly influencing subsequent form, possibly as a result of decreased growth increments.

The third trial focused on comparing pruning treatments. Removing 50% of the branch number reduces the canopy density, and increases permeability to the wind. Removing 50% of the branch length reduces the foliage width and, therefore, the 'sail area'. Pruning 50% of the branch number did not significantly alter degree of sinuosity, or height and diameter increments in toppled trees. However, significantly higher sinuosity occurred in trees pruned by 50% of the branch length, which also reduced height and diameter increment compared to trees that were not pruned. On the basis of this trial alone, wind-proof pruning 50% of the branch length cannot be recommended because it has negative effects, and pruning 50% of the branch number has no positive effects, and incurs costs.

There were some reductions in growth in the second and third trials as the result of wind-proof pruning, but it is not known these differences would be maintained to harvest.

There is a great deal of anecdotal evidence in Northland that wind-proof pruning reduces toppling, and as a result reduces sinuosity and improves form. A nearby trial at Paerata and also on Waiotira clay (Davies-Colley & Turner 2001) showed that crown lightening of 2-year-old pine trees (by shortening the branches in whorls above half tree height) had no negative effects on growth and resulted in zero incidence of topple and subsequently better stem straightness, compared with 50% topple in the not-pruned control.

However, it is important to note that the pruning treatment at Paerata was imposed before the trees had toppled and the pruning was less severe (shortening of branches only above half tree height) compared with the pruning treatments at Waiotira, which resulted in 50% reduction in foliage.

There is an urgent need to further test the effect of different wind-proof pruning techniques on the growth and stability of plantation trees on fertile farm sites. Another trial conducted on pines on the same site as these reported trials, has now been completed, and other trials are being conducted on different methods, and timing, of wind-proof-pruning cypresses.

Ideally, toppling should be avoided, so that remedial actions are not necessary. There are a number of precautions that may be taken. Firstly, matching the species to the site, and avoiding wet or badly drained areas. Secondly, using well conditioned and trimmed planting material, carefully handled and planted without root distortion (Trewin 1981, 2003). Root deformation because of poor planting is a primary contributory cause of toppling (Mason 1985). Also, distorted roots close to the root collar can cause strangulation and stem failure just below ground level (Trewin & Cullen 1985). Thirdly, it can be effective to plant aged cuttings, rather than seedlings, on topple-prone sites (Aimers-Halliday *et al.* 1999, Coxe 1999). They are probably less prone to topple because of their more open canopy, and stiffer (more difficult to distort) root system. Fourthly, on fertile farm sites, extra fertiliser should not be applied to young trees, unless specifically advised to correct deficiencies. Also, there is the precaution of wind-proof pruning.

Conclusions

Before undertaking remedial treatment, it would be sensible to assess the number and distribution of the toppled trees. If an adequate number of trees were planted per hectare, and enough potential final crop trees remained, the toppled trees could be left to help control branch size and then thinned later, without incurring the costs of remedial treatments. None of the remedial treatments was particularly effective, and the effort and costs involved in remedial treatments would be difficult to justify. If the toppling rate was so high that the number and distribution of non-toppled trees was inadequate for the final crop, replanting should be considered.

Acknowledgments

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