STUDY TO IDENTIFY SOURCES OF ERROR IN MEASURING SINUOSITY OF THE PRUNED BUTT-LOG USING A HEIGHT POLE

J. Turner

Report No. 37 **May 1997**

FOREST AND FARM PLANTATION MANAGEMENT COOPERATIVE

EXECUTIVE SUMMARY

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A comparison of methods for accurately measuring stem sinuosity of radiata pine butt-logs is needed because of the importance of the degree of sweep in the pruned section of the stem in determining the value of the pruned butt-log.

The aim is to identify the important sources of error in determining stem straightness using the centre to centre method, from observer, method of sweep estimate, degree of stem deviation, errors in identification of the plane and height of maximum sweep, and number of times sweep was measured. Thirty trees covering a range of levels of sweep at Kaingaroa compartment 905 were each measured twice by four observers using measured classes (as mm deviation) and also sweep diameter deviation classes sweep as a fraction of the stem diameter.

The results of analyses of variance indicate that observer is a strong influence on the precision and accuracy of stem deviation estimates. All observers using both methods underestimated sweep, with underestimation of sweep greater for trees which were more heavily swept. There was a significant difference in bias of stem straightness estimates using different methods for only one observer, who gave a lower bias when using the mm classes. For the remaining three observers both assessment methods resulted in the same level of bias. There was a significant difference in the level of variance in estimates between the two methods, with the measured classes proving to give less variable estimates of stem straightness than the diameter deviation classes. Incorrectly estimating the plane and/ or height of maximum sweep was found not to significantly contribute to bias in the estimation of stem straightness suggesting that bias in estimates arises when determining deviation of the stem. A components of variance analysis indicates that the greatest improvement in precision of stem straightness estimates may be achieved by increasing the number of observers.

OBJECTIVE

This study aims to identify the sources of error in stem straightness estimation in the 6 m pruned section of the stem from the following potential sources of error:

- observer;
- method of sweep estimation;
- errors in identification of the plane and height of maximum sweep;
- degree of stem deviation.

INTRODUCTION

Measurement of stem straightness in the pruned section of the tree provides valuable information for estimating grade outturns and hence final log value at harvest. Increases in juvenile sweep (expressed as a fraction of the stem diameter) in trees that had recently received the final pruning lift have been shown by West and Kimberley (1991), to lead to a considerable decline in log value (Table 1). For this reason research has been carried out to develop more accurate methods of assessing stem straightness on standing trees (Grallelis and Klomp 1982; West and Kimberley 1991).

JUVENILE SWEEP	CHANGE IN PRUNED LOG VALUE ($/ m^3)
0	0
D/4	-3.7
D/2	-14.8
D3/4	-33.3
D	-60.5

Table 1: Change in pruned log price (1985 Domestic Price List) due to juvenile sweep for a 5.4 m log with a stem diameter of 16 cm at the point of maximum sweep. Source: West and Kimberley, 1991.

Errors in the measurement of stem straightness arise from several sources:

- observer;
- method of sweep estimate;
- degree of stem deviation.

This study is based on the premise that the extent to which these sources of error in stem straightness contribute to the total error will suggest which error sources require attention when attempting to improve stem straightness estimates.

METHOD

Experiment Site

Thirty 20 year old trees were selected to cover the range of sweep from trees in the Genetics and Tree Improvement (GTI) 1975 "850" disconnected diallel trial at Kaingaroa Cpt 905. The trial has a stocking of 400 stems per hectare, and is relativly clear of undergrowth enabling clear identification of stem sinuosity. The trees measured were all pruned to just above 6 m and had a mean dbh of 42.4 cm and ranged from 26.7 to 56.3 cm. Mean sweep for the trees in the experiment measured using the centre to centre method (Grallelis & Klomp 1982) was 10 mm/ m and ranged from 1 to 33 mm/ m.

Stage I: Experimental Set Up

West and Kimberley (1991) showed that a sample of 30 trees was adequate for studying methods of assessing sweep, so this sample size was used in this study. Thirty trees were selected to cover the range of stem sinuosity, with an emphasis on extreme levels of sweep (Table 2).

LEVEL OF SWEEP CLASS	MEAN SWEEP (mm/ m)
1	48
2	59
3	97

Table 2: Mean stem straightness for the three levels of sweep.

Each of the selected trees were marked with a diameter band and north axis, and then measured for plane of maximum sweep, height of maximum sweep, stem diameter at height of maximum sweep, and stem deviation. It was not possible to achieve an absolute estimate of sweep on standing trees, but a near accurate estimate was achieved using the centre to centre method (Figure 2) as described by Grallelis and Klomp (1982). This method of sweep measurement involved identifying the centre of the stem in the plane of maximum sweep at the base and top of the 6 m log using callipers and placing a string between these points to estimate the height of maximum sweep on the log. The stem deviation at the point of maximum sweep was then measured using the callipers. Part of the absolute measurement process incorporated a comparison of the effect of using 3 different stump heights, 0.1, 0.2 and 0.3 m, on the estimate of stem straightness.

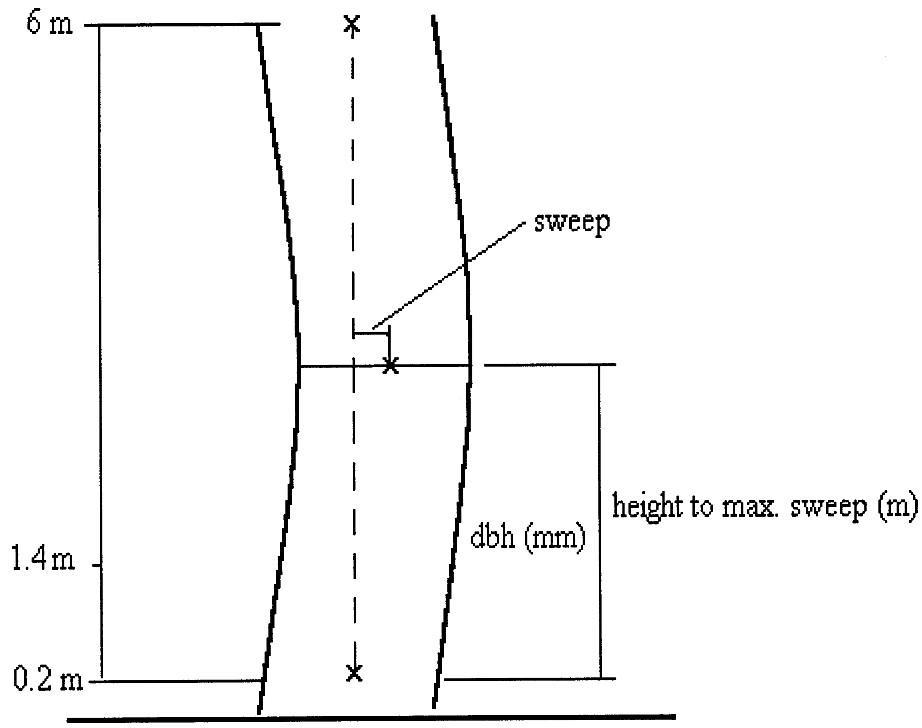

Fig. 2: The centre to centre method of sweep measurement. Source: Grallelis and Klomp, 1982.

Stage II: Observer Measurement

Four observers then each made estimates of stem straightness by the centre to centre method using a height pole. The four observers spent half an hour calibrating their estimates of stem straightness amongst themselves before measuring the 30 trees without discussion with the other observers. Each of the 4 observers measured the 30 trees for the following characteristics;

- diameter at breast height (mm);
- plane of maximum sweep (mm) on the circumference of the tree at breast height (1.4 m) from the marked north point. This measure was converted to an angle for use in the analysis;

- height of maximum sweep (m) measured to the nearest decimeter using the height pole;
- stem straightness - 5 stem diameter deviation classes;
    - 1 - no sweep;
    - 2 - < D/8;
    - 3 - < D/4;
    - 4 - < D/2;
    - 5 - > D/2.
- stem straightness - five measured classes:
    - 1 - 0 to 10 mm deviation;
    - 2 - 11 to 30 mm deviation;
    - 3 - 31 to 60 mm deviation;
    - 4 - 61 to 100 mm deviation;
    - 5 - > 100 mm deviation.
- time of day to determine if accuracy of sweep estimates changes as the day progresses.

The observers measured all 30 trees initially, took a short break then remeasured the same 30 trees. This allowed an estimate of an individual observers consistency in measuring stem straightness. On the first two measurements cumulative errors (Figure 3) due to measuring the wrong plane and height of maximum sweep were measured.

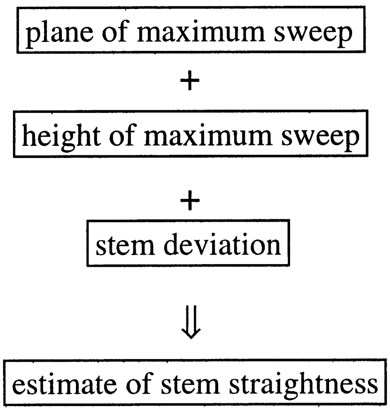

Fig. 3: The three stages of measurement of stem straightness in which errors occur. These three sources of error lead to a cumulative error in the estimate of stem straightness.

The third re-measurement allowed for an estimate of the error in measuring each individual characteristic involved in stem straightness assessment to be calculated. This was done by correcting each observers measure of plane of maximum sweep, and height of maximum sweep, to the absolute measures made during the original experimental set up (Stage I) which were provided on a list to be referred to after estimating each individual characteristic involved in stem straightness assessment. Measuring both cumulative and individual errors allowed analyses to be carried out to determine to what extent errors in estimating each of the separate characteristics contributed to the cumulative error in the sweep estimate.

ANALYSIS

To calculate sweep in terms of mm/ m when stem straightness was estimated using the diameter deviation classes, the stem diameter at the point of maximum sweep needed to be estimated due to the difficulties involved in directly measuring stem diameter at the height of maximum sweep. Two methods were used to estimate the diameter, the first involved using a taper equation, while the second assumed a simple cone shaped stem using dbh and actual diameter measured at another point on the stem to calculate the shape of the cone.

Sweep calculated using a taper equation involved using the heights of 15 trees selected from the entire disconnected diallel trial in Kaingaroa Cpt 905 to develop Petterson curves. The Petterson curve enabled heights to be estimated for all other trees measured based on their dbh measurements. Using estimated tree height and measured dbh, a volume function (volume function 326 for all New Zealand radiata pine on a direct sawlog regime (Eggleston, 1992)) was used to estimate tree volume. The tree volume, and height of maximum sweep information were then input into a taper function (326) to predict the diameter under bark (dib) at the height of maximum sweep. The diameter under bark (dib) was converted to diameter over back (dob) using a relationship between dob, and dib developed by Gordon (1983).

The second estimate of stem diameter at the height of maximum sweep involved using dbh and actual diameter measured at another point on the stem to estimate the mean taper of the stem which was assumed to be cone shaped. This estimate of stem diameter is anticipated to be more accurate than that made using a taper equation as it does not have the cumulative errors of height, volume, taper, and bark thickness estimates.

The analyses performed sought to identify how bias and variance in estimates of stem straightness were influenced by observer, sweep classes used, the degree of sweep of the stem being measured, and the first or second measurements. These analyses was performed in an analysis of variance (ANOVA), using the General Linear Models (GLM) procedure in SAS (SAS Institute Inc. 1986). Differences between group means were tested using Duncan's multiple range test to identify which groups were significantly different. The dependent variables in these analyses used the error in measurements (actual sweep minus estimated sweep), with zero error being used when observers identified the correct sweep class. Bias was calculated as the mean error, and variance was calculated as the square root of variance in error to produce a normalised distribution of variance estimates. The influence of stem straightness on estimates of sweep was explored using the three sweep classes shown in Table 2.

The first ANOVA performed compared the estimates of sweep made in the first and second measurements with the third estimate of sweep made when observers were told the correct location of the plane and height of maximum sweep. This analysis will determine whether or not errors in identifying the plan and height of maximum sweep contribute to the error in stem straightness estimates.

The second ANOVA performed compared the three methods of estimating stem straightness using different sweep classes and techniques for estimating stem diameter, the estimates of sweep made by different observers, and the difference in stem straightness estimates made during the first measurement compared with the second measurement.

A third analysis performed sought to identify how precision in estimates of stem straightness could be improved through repeated measurements by different observers or the same observer. This analysis was performed in a components of variance analysis using PROC MIXED with the RANDOM statement in SAS (SAS Institute Inc. 1986).

A fourth analysis explored the effect of using different stump heights on estimated stem straightness was analysed in a simple analysis of variance using PROC GLM in SAS (SAS Institute Inc. 1986).

Various comparisons of observers, and methods of stem straightness estimation were first made using graphical analysis to check the validity of the data and confirm that more detailed statistical tests would be valid.

RESULTS AND DISCUSSION

The accuracy and precision of estimates of stem straightness are potentially influenced by the following factors:

- stem diameter;
- stem straightness;
- observer;

- type of measurement class, mm or diameter class;
- first or second measurement;
- time of day;
- estimate of plane of maximum sweep;
- estimate of the height of maximum sweep
- stump height;
- estimated stem diameter when using the diameter deviation classes.

The ability of observers to use the different methods of estimating stem straightness was initially tested by plotting the percentage frequency with which each observer using the two methods of sweep estimated which class the tree sweep was in, and comparing these estimates with those made in the initial measurement using the absolute measure (Figures 4 and 5).

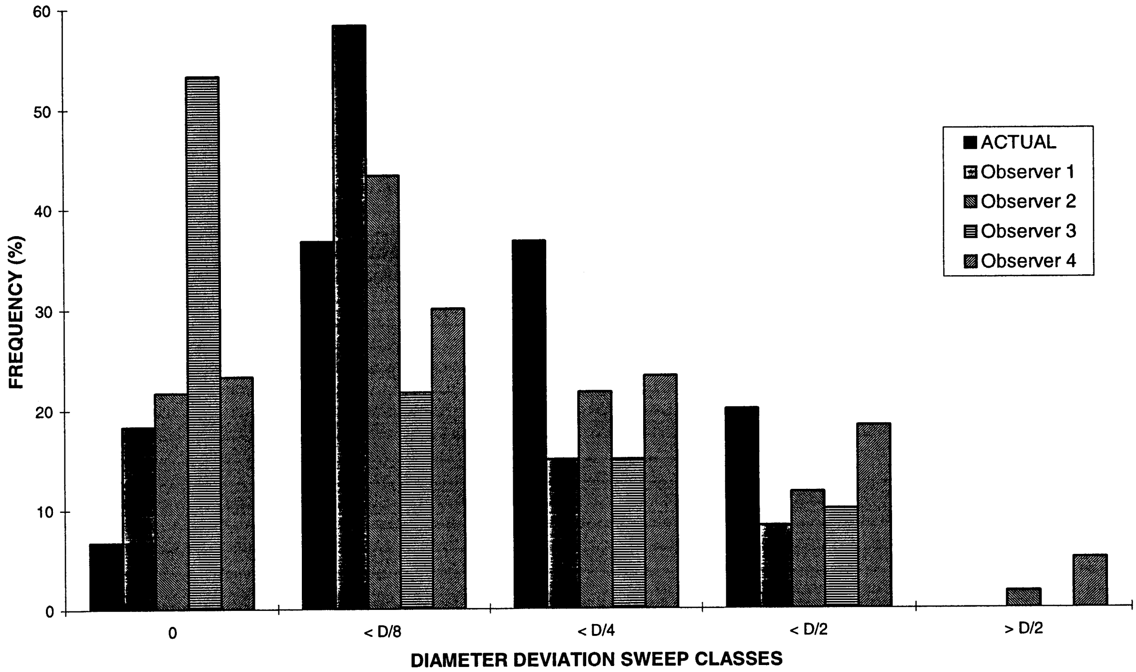

Fig 4: Sweep class distributions by observer for each diameter deviation class, showing the percentage frequency with which each observer assigned a trees sweep to each class.

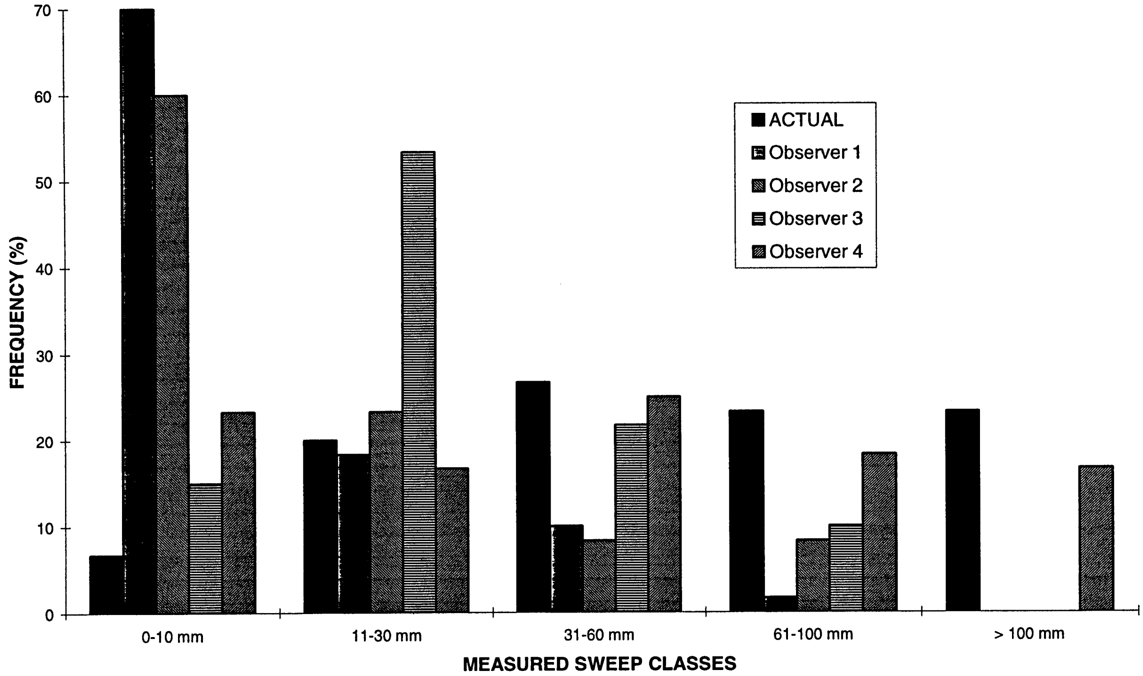

Fig 5: Sweep class distributions by observer for each measured class, showing the percentage frequency with which each observer assigned a trees sweep to each class.

Both the diameter deviation and measured classes were over predicted by observers for low levels of sweep. Slightly higher levels of sweep (the <D/8 and 11-30 mm classes) were the most accurately predicted by all 4 observers, suggesting these levels of sweep are more easily identified and classified. For the greater levels of sweep the use of measured classes proved difficult with only Observer 4 successfully assigning mm classes to these levels of sweep. Other observers tended to underestimate larger degrees of sweep using the mm classes. The diameter deviation classes proved to be more accurately used in identifying larger levels of sweep (Figure 4).

Dependent Variable: BIAS

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	53.94	53.94	0.45	0.5037
OBSERVER	3	5228.32	1742.77	14.69	0.0001
SWEEP CLASS	2	12114.50	6057.25	51.05	0.0001
TIME	2	302.44	151.22	1.27	0.2897
METHOD*OBSERVER	3	2288.41	762.80	6.43	0.0010
METHOD*SWEEP CLASS	2	472.57	236.28	1.99	0.1486
OBSERVER*TIME	6	1441.78	240.30	2.03	0.0824
METHOD*OBSERVER*TIME	8	1421.38	177.67	1.50	0.1858
ERROR	44	5221.09	118.66		

Table 3: Analysis of variance exploring the difference in bias in stem straightness estimates between method, observer, level of sweep, and first or second measurements.

The first set of analyses (Tables 3 and 4) involved the comparison of the first and second measurements, with the third measurement, for the measured class and diameter deviation class methods. The estimate of sweep using stem diameter estimated based on a cone shaped stem was not included in this analysis. There was a significant difference in the level of bias in stem straightness estimates made by the different observers with observer four showing significantly less bias than the other observers (Figure 4). The level of bias for the other three observers was the same whether they were using the measured or diameter deviation classes. The observer which achieved the most accurate estimates of sweep was also the most experienced member of the field crew. This suggests the use of the measured deviation classes for estimating stem straightness may require a greater degree of experience in measuring sweep if it is to be used successfully. Observers tended to underestimate the amount of sweep using the measured classes by between 46 mm/ m and 26 mm/ m (Figure 4).

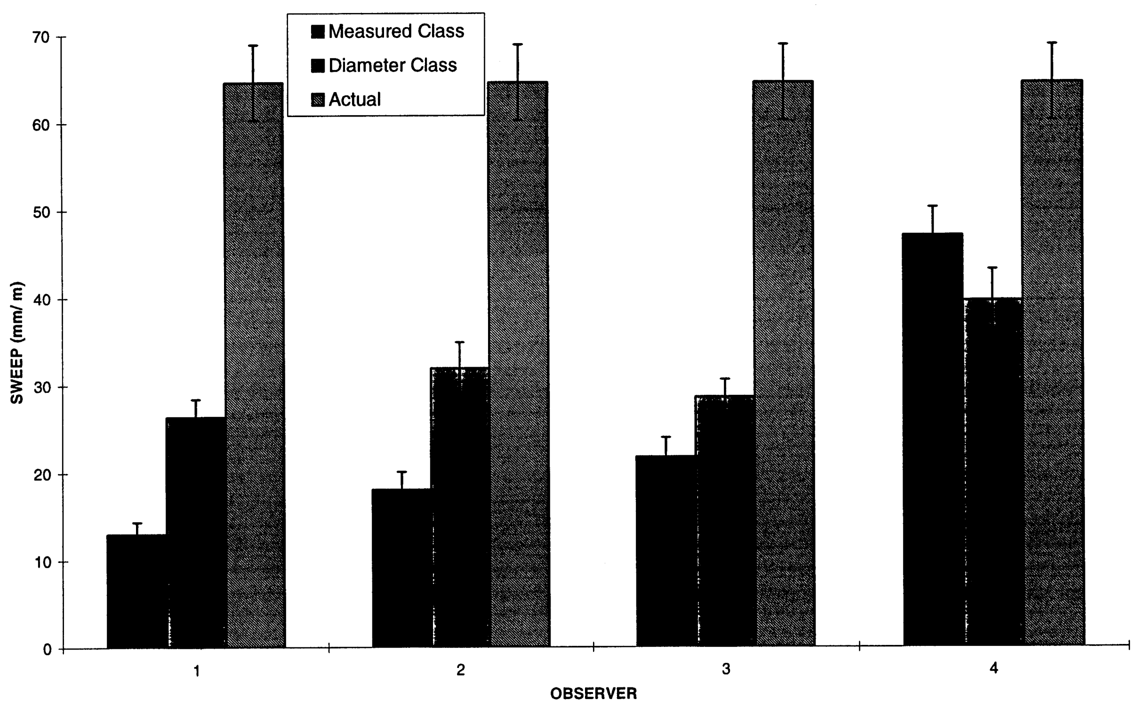

Fig 4: Mean estimates of stem straightness by observer using the measured sweep classes and diameter deviation sweep classes. Error bars shown indicate the standard error associated with the estimate of the mean.

The three levels of actual stem straightness all had significantly different levels of bias with the low sweep class having the least bias and the high level of sweep class having the highest bias. When the bias is expressed as a percentage of the average sweep for the trees in each class the high and low levels of sweep both have bias which is approximately 50% of the average. The medium level of sweep class had bias which was 70% of the average sweep.

There was no significant difference in the estimates of sweep for the three occassions that stem straightness was measured. This suggests that errors in estimating the plane and height of maximum sweep do not result in a significant increase in the error of the estimated stem straightness. Bias in stem straightness estimates, therefore, arise when stem deviation is being estimated.

Dependent Variable: SQRTVAR

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	1693.52	1693.52	16.04	0.0002
OBSERVER	3	423.01	141.00	1.34	0.2751
SWEEP CLASS	2	1229.07	614.53	5.82	0.0057
MEASUREMENT	2	434.87	217.44	2.06	0.1397
METHOD*OBSERVER	3	60.71	20.24	0.19	0.9015
METHOD*SWEEP CLASS	2	879.30	439.65	4.16	0.0221
OBSERVER*MEASUREMENT	6	371.61	61.94	0.59	0.7392
METHOD*OBSERVER*MEASUREMENT	8	783.18	97.90	0.93	0.5039
ERROR	44	4646.46	105.60		

Table 4: Analysis of variance exploring the difference in variance in stem straightness estimates between method, observer, level of sweep, and first, second, or third measurements.

The level of variance in errors in estimating stem straightness differed significantly between methods and the three classes of stem straightness (Table 4). As for bias, there was no significant difference in variance between the three measurements which indicates that estimation of the height and plane of maximum sweep does not significantly contribute to variation in stem straightness estimates. The amount of variance in the error is significantly greater for estimates of stem straightness made using the diameter deviation classes, compared with the measured classes. The high level of sweep class had significantly greater variance in errors that the other two levels of sweep, suggesting estimates of sweep in very swept trees made by the observers was very variable. When variability in sweep estimates was adjusted for the mean by calculating the coefficient of variation (CV), there was in fact significantly greater variability in the estimates of low levels of sweep.

This second set of analyses focuses on the comparison of bias and variance in error of estimates of stem straightness for the three methods of measuring stem deviation, measured classes, stem deviation classes using the taper equation, and stem deviation classes using a cone shaped stem. In these analyses only the first and second measurements were compared.

Dependent Variable: BIAS

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	2	81.97	40.98	0.31	0.7370
OBSERVER	3	4389.71	1463.24	10.98	0.0001
SWEEP CLASS	2	11407.62	5703.81	42.79	0.0001
MEASUREMENT	1	320.63	320.63	2.41	0.1284
METHOD*OBSERVER	6	2595.85	432.64	3.25	0.0103
METHOD*SWEEP CLASS	4	602.65	150.66	1.13	0.3553
OBSERVER*MEASUREMENT	3	695.61	231.87	1.74	0.1735
METHOD*OBSERVER*MEASUREMENT	8	556.50	69.56	0.52	0.8332
ERROR	42	5598.53	133.30		

Table 5: Analysis of variance exploring the difference in bias in stem straightness estimates between method, observer, level of sweep, and first, second, or third measurements.

The results of the analysis of variance (Table 5) show that there is no significant difference in the level of bias between the three methods. This shows that the use of the taper equation to estimate stem diameter does not contribute significantly to bias in estimates of stem straightness (Figure 5). There is again, as was found for the first set of analyses, a significant difference in the level of bias between observers, and levels of sweep. There is also a significant method/ observer interaction for bias, which again indicates that Observer 4 is significantly less biased than the other three observers when using the mm classes.

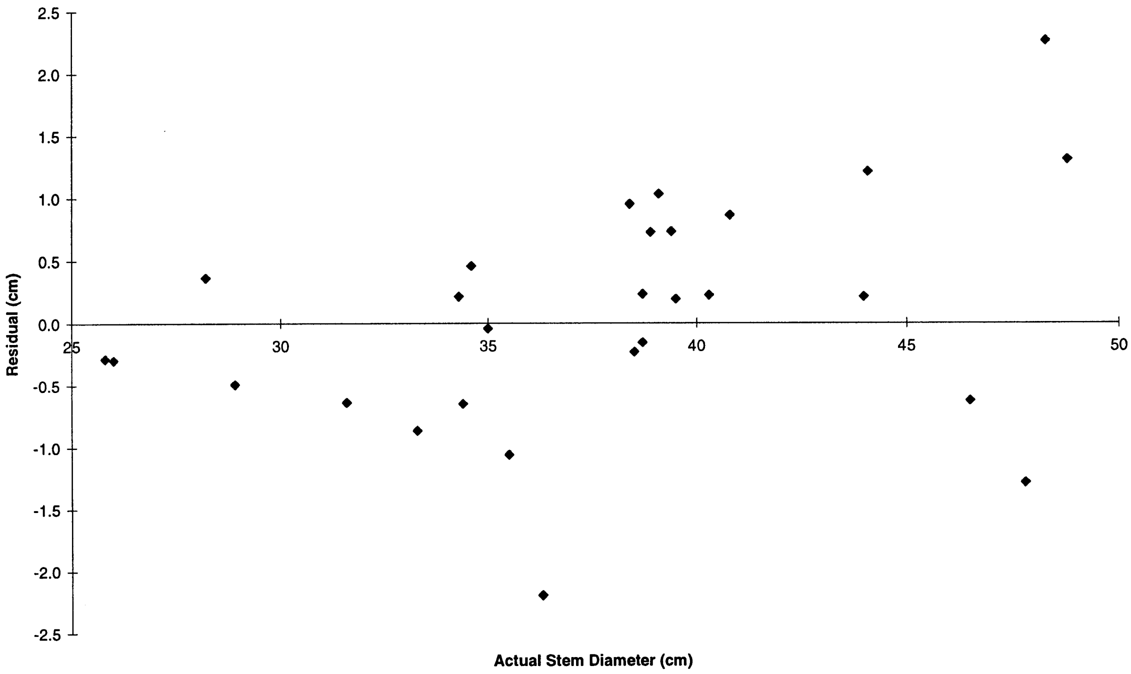

Fig. 5: Error in estimated diameter at height of maximum sweep against the actual diameter at the height of maximum sweep.

Dependent Variable: SQRTVAR

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	2	1233.11	616.55	3.97	0.0264
OBSERVER	3	713.76	237.92	1.53	0.2202
SWEEP CLASS	2	3510.35	1755.17	11.30	0.0001
TIME	1	1.76	1.76	0.01	0.9156
METHOD*OBSERVER	6	131.32	21.89	0.14	0.9899
METHOD*SWEEP CLASS	4	1193.81	298.45	1.92	0.1246
OBSERVER*TIME	3	364.39	121.46	0.78	0.5106
METHOD*OBSERVER*TIME	8	480.53	60.07	0.39	0.9216
ERROR	42	6522.76	155.30		

Table 6: Analysis of variance exploring the difference in variance in stem straightness estimates between method, observer, level of sweep, and first, second, or third measurements.

The analysis of variance (Table 6) indicates that there is a slightly significant difference in the variability of sweep estimates made using the three methods, with the measured class estimates of sweep being less variable than those made using the diameter deviation classes. There was also a significant difference in the variability in sweep estimates for the three levels of sweep, with there being more variability in estimates for the higher levels of sweep. When variability in sweep estimates was adjusted for the mean by calculating the coefficient of variation (CV), there was in fact significantly greater variability in the estimates of low levels of sweep.

Improvements in Precision

A components of variance analysis was performed to identify how precision in sweep estimation for a single tree were influenced by the number of observers, and the number of measurements performed. The results of this analysis indicate that the number of observers has the greatest influence on the precision of sweep estimates (Table 7), with most variance being apportioned to the observer component. This indicates that improvements in precision of sweep estimates may be best achieved through the use of more than one observer (Figures 6 and 7). It must be noted that the identification of the effect of observer number on precision is limited in this case because of the small number of observers and the result being unique to the four observers used in this study.

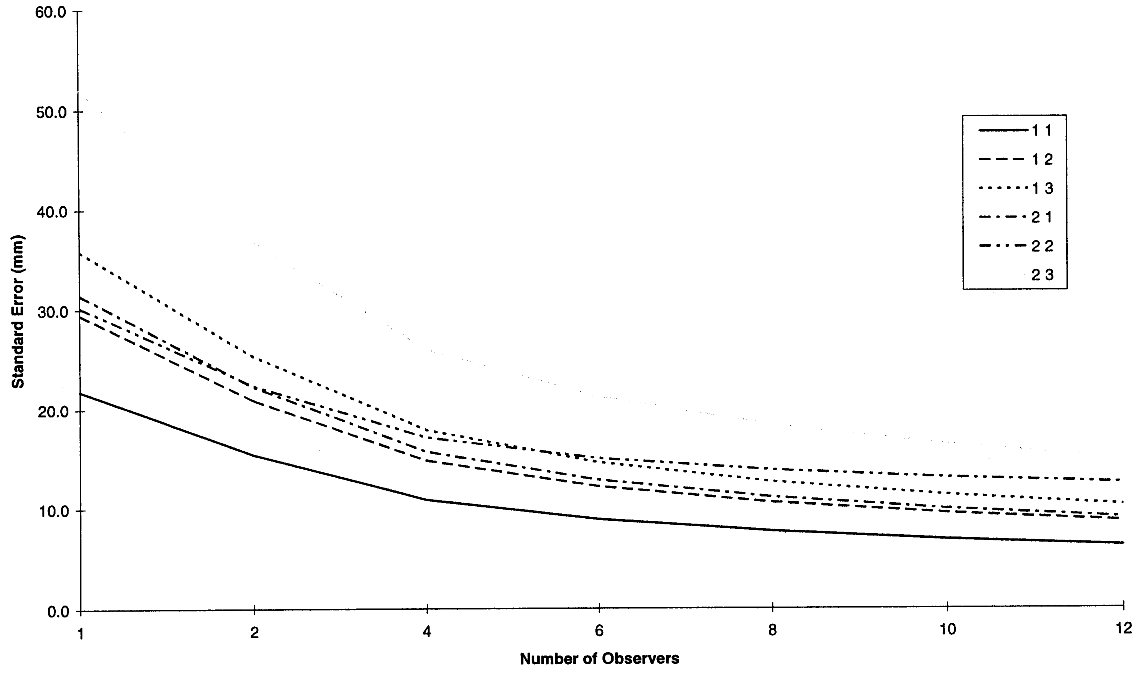

Fig. 6: Improvement in the level of precision for sweep estimate for a single tree with the addition of extra observers. Line 11 refers to sweep measured using method 1 (mm classes) on trees in sweep class 1 (least sweep).

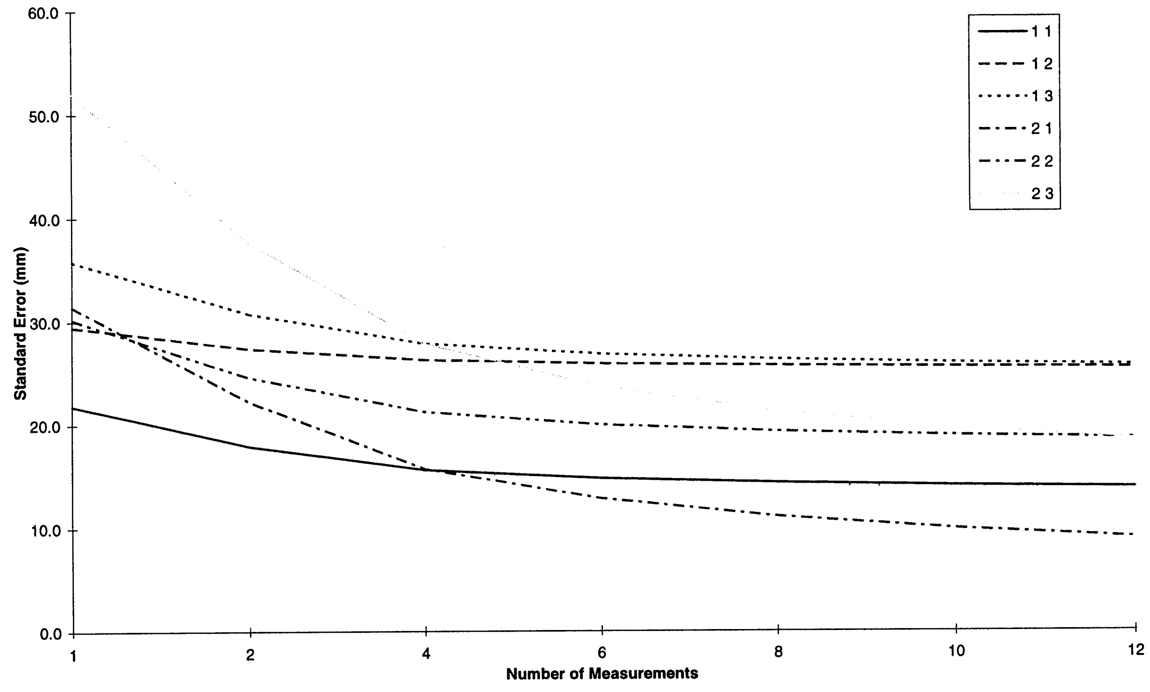

Fig. 7: Improvement in the level of precision for sweep estimate for a single tree with additional measurements of the same tree.

Time of Day

The time of day at which estimates of stem straightness were made did not influence the accuracy with which the estimates were made (Figure 8).

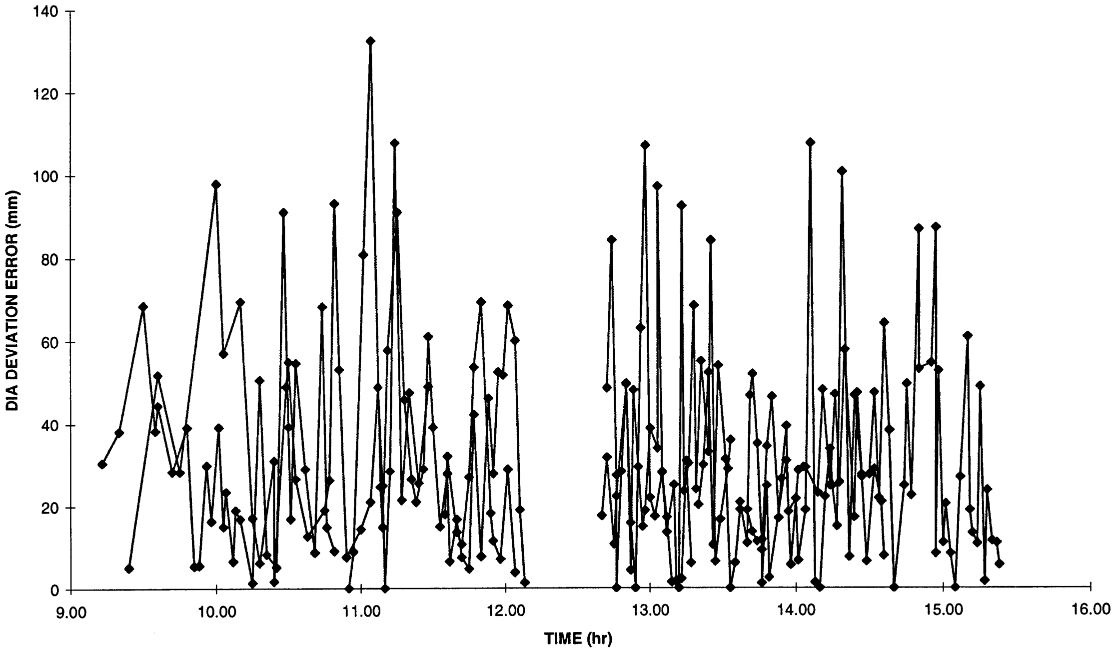

Fig. 8: Error in stem straightness estimate using the diameter deviation classes. All observers and first and second measurements are aggregated.

Stump Height

The use of three different stump heights (0.1, 0.2 and 0.3 m) for estimating sweep using the centre to centre method with string appeared to have no effect in an analysis of variance, on the stem straightness measured for the 30 trees in the study (Table 7).

Dependent Variables: STUMP HEIGHT

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREES	29	83.090	2.868	121.24	0.0001
STUMP HEIGHT	2	0.022	0.011	0.47	0.6280
ERROR	58	1.371	0.0236		

Table 7: Analysis of variance to analyses the effect of stump height on the estimate of stem straightness.

With increasing stem deviation, using a 0.2 m stump, there was an increasing difference in the stem deviation measured between the 0.2 m and 0.3 m stump heights, indicating that choice of stump height becomes important when there is a high degree of sweep (Figure 9).

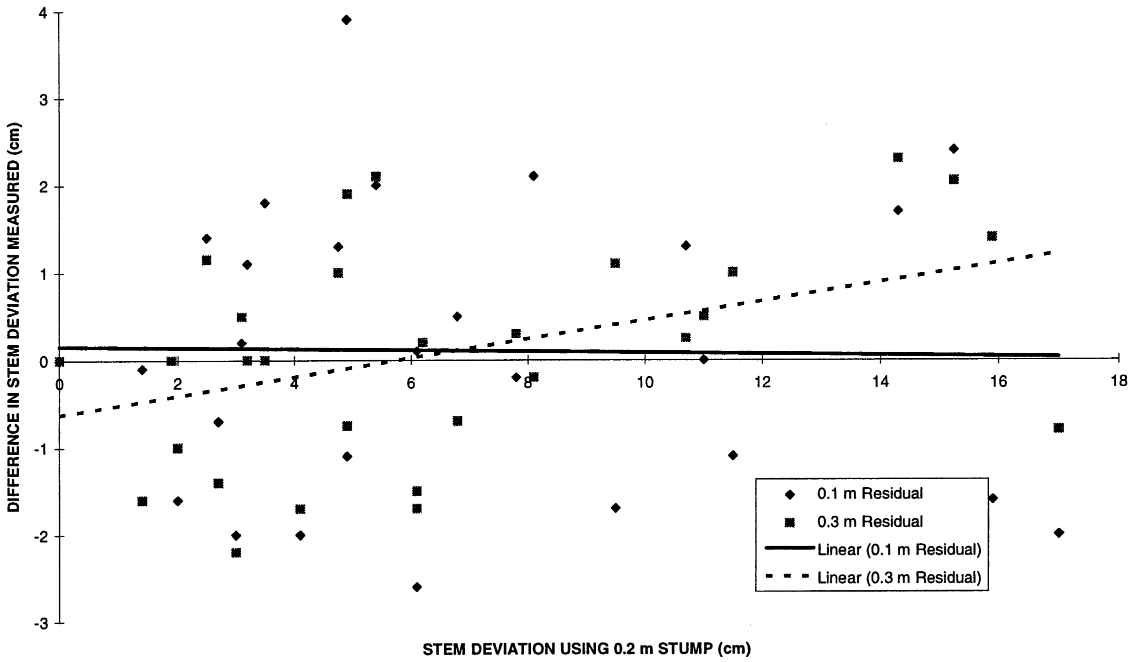

Fig. 9: Difference in stem deviation measured using 0.1 and 0.3 m stump heights compared with the stem deviation measured using a 0.2 m stump height against stem deviation using a 0.2 m stump height.

CONCLUSION

The analyses of influences of observer, method of stem straightness assesment, level of stem straightness, time of measurement, and estimation of plane and height of maximum sweep, on the level of bias and variance in stem striaghtness estimates indicate that observer is a strong influence on the precision and accuracy of stem deviation estimates. All observers using both methods underestimate sweep, with underestimation greater for a greater degree of sweep. There was a significant difference in bias of stem straightness estimates using different methods for only one observer, who gave a lower bias when using the measured classes. For the remaining three observers both methods resulted in the same level of bias. There was a significant difference in the level of variance in estimates between the two methods, with the measured classes proving to give less variable estimates of stem straightness than the diameter deviation classes. Incorrectly estimating the plane and/ or height of maximum sweep was found not to significantly contribute to bias in the estimation of stem straightness suggesting that bias in estimates arises when determining deviation of the stem. The components of variance analysis indicates that the greatest improvement in precision of stem straightness estimates may be achieved by increasing the number of observers.

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