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Estimation of Mean Internode Length for GF14 and GF13/LI25 Seedlots Using TreeD Data

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EXECUTIVE SUMMARY

Mean internode length is a variable that has been used to compare the branching characteristics of different seedlots. The data required to estimate mean internode length may be collected using several different techniques. One technique is TreeD, a non-destructive photogrammetric imaging system.

TreeD images of the branching characteristics of radiata pine were collected for a wide a range of site × silvicultural treatment × seedlot combinations between 1999 and 2007. The number of trees imaged for each combination was generally from four to six.

In 2008 some of these TreeD data were used to provide quantitative estimates of mean internode length for a GF14 and a long internode GF13/LI25 seedlot. For some sites, differences in mean internode length were not significant, whereas earlier research suggested that the mean internode length was significantly different between trees selected for their long-internode characteristics and trees representing the “850” series. This raised the issue of appropriate sample size to use if calculating stand average branching characteristics using TreeD images.

FFR supported the collection of a larger sample of TreeD images from selected site × silvicultural treatment × seedlot combinations, in order to investigate the influence of sample size.

TreeD images were collected for trees from GF 14 and GF13/LI25 seedlots in two trials (FR121/2, Kinleith and FR121/3, Gwavas) which had been managed under the silvicultural regime: plant at 500 stems/ha and thin to 200 stems/ha at a mean crop height of 6.2 m.

These new data, and the old data, were analysed to determine whether there was a significant difference in mean internode length between GF 14 and long internode GF13/LI25 seedlots for different stem sections and different sample sizes.

The main results were:

- Due to tree-to-tree variability, there is little differentiation in tree mean internode length between the long internode GF13/LI25 and the GF14 seedlot on the sites considered.
- Average mean internode length is at least 0.1 m longer for GF13/LI25 seedlot than the GF14 seedlot, but the differences were generally not significant even with the larger sample sizes.
- Trees with the longest mean internode length tended to be trees that exhibited previous stem damage. Long internodes may occur after stem damage if a branch takes over as the leader, because branches often have very long internodes.
- An approximate estimation of the sample size required to estimate plot mean internode length to within 0.1 m (assuming random sampling from an infinite population) varied with both the length of stem section considered and the variability between trees.

TreeD is a useful tool for measuring quantitative stem and branching characteristics because a permanent image of the sample tree is archived, and also it avoids health and safety issues associated with tree climbing.

An important issue to emerge from this analysis is the impact of stem defects on the estimation of mean internode length.

Stem damage is a normal occurrence in any forested area, and has an effect on branching patterns of trees.

The variable mean internode length is not used by the processing industry. Rather than attempting to estimate mean internode length in trials designed to measure growth and quality for different seedlots, it is recommended that inventory assessments (that assess both branching and stem form) be carried out in large trials towards the end of the rotation to determine the value of different seedlots and silvicular treatments.

Trees with stem malformations still contribute to the value of the forest, and it is considered that the impacts of stem form (both shape and malformations) need to be incorporated into modelling systems to allow the true value of different silviculture treatments and seedlots to be investigated.

INTRODUCTION

The branch growth model, BLOSSIM was developed by destructively sampling a limited number of trees (usually less than 10) on a range of sites. The TreeD, photogrammetric imaging system[1], was then used as a non-destructive tool to provide quantitative data on branching characteristics to compare with TreeBLOSSIM predictions for a far wider range of sites, silvicultural treatments and seedlots. These analyses highlighted the issue of stem damage and leader changes as features that lead to larger than expected (modelled) branch diameters[2].

TreeD images were collected when the trees were sufficiently tall to obtain a reasonable view of approximately the lower 20 m of the stem. TreeD images are taken at a distance of approximately 15 m from the sample tree. The distance from the tree ensures that the measurement accuracy is not compromised by large angles between the camera position and the measurement point. The height to the base and top of each visible branch cluster, and diameter of the largest branch in that cluster, are measured. The exact portion of the stem measured is influenced to some extent by the density of foliage in the upper crown. These data were then compared with TreeBLOSSIM predictions.

Another potential use for the data extracted from TreeD images is to estimate branching characteristics, such as mean internode length. Internode length is a “compound variable” that results from several more fundamental characteristics of the tree, primarily:

- Annual height extension
- Number of branch clusters formed during the annual height extension
- Angle of branches in each cluster with respect to the stem.

A 1988[3] study of mean internode length for different “breeds” across four sites indicated that mean internode length was significantly longer for trees representing “a long internode breed” than for the “850” breed. This analysis used data from 13- to 15-year-old “crop” trees, where a crop tree was defined as a relatively straight non-malformed dominant. Between 28 and 50 trees were sampled per breed and site, and mean internode length was calculated for the first two 5.5 m logs on the tree. Across sites, the difference in site mean internode length between the two breeds varied between 0.03 m and 0.33 m. At the time of this study, GF ratings were not available, and the data are not available to retrospectively estimate them. However it is considered that the “850” breed would have a rating of around GF 14.

A previous unpublished analysis of some TreeD data (incorporated in this report) indicated that, contrary to perceived expectations, there was generally no significant difference in mean internode length between GF 14 and long internode GF13/LI25 seedlots.

This current study was designed to increase the TreeD sample size available for calculating mean internode length, and examine the role of sample size in characterising mean internode length.

METHODS

Previous TreeD Analysis

The 1990/91 silviculture-breed trials(4,5) are a series of trials that were established to investigate the effects of site, silvicultural treatment and seedlot on tree development. In order to test the performance of TreeBLOSSIM across a range of sites, silvicultural treatments, and seedlots, TreeD images were collected from these trials as they reached a suitable height and funding was available. Under the stand Growth Modelling Cooperative, TreeD images were collected from:

- FR121/1, Tungrove in 2006 (7)
- FR121/2, Kinleith in 2007 (8)
- FR121/3, Gwavas in 2006 (7)
- FR121/4, Tairua in 2004 (6)
- FR121/7, Huanui in 2005 (6)
- FR121/13, Golden Downs in 2007 (7)

A comparison of mean internode length between a GF14 (850 breed) and a long internode GF13/LI 25 seedlot could be made for one silvicultural treatment (plant at 500 stem/ha and thin to 200 stems/ha at a mean crop height of 6.2 m) for four of these trials:

- FR121/1, Tungrove
- FR121/2, Kinleith
- FR121/3, Gwavas
- FR121/13, Golden Downs

The SAS procedure PROC GLM was used to determine whether there was a significant difference in mean internode length between the two seedlots on each site.

Current TreeD Data Collection and Analysis

Two of the previous sites were selected, FR121/3 (Gwavas) and FR121/2 (Kinleith). These were North Island sites where the previous study indicated that there was no significant difference in mean internode length between a GF14 and a GF13/LI25 seedlot.

As stem form and branching characteristics are recorded for all trees in a plot during an inventory assessment, the original intention was to image all trees in PSPs planted with GF14 and long internode GF13/LI25 seedlots and which had received the following silviculture:

- Plant at 500 stem/ha and thin to 200 stems/ha at a mean crop height of 6.2 m

During the planning stage, the question was raised as to whether it was justifiable to collect TreeD images and then extract branching data for trees with major stem malformations (for example, consider a tree with a multi-leader stem above the top-out – mean internode length has not been defined for this situation). If a tree exhibited stem malformation below a height of approximately 10 m, it was decided to take only a single image (as a record), rather than a pair of scaled TreeD images (for extracting data). It is conceivable that some of the trees imaged may not have been defined as "crop" trees in the previous study (3).

Tree mean internode length was calculated for various sections of the stem for both the new data and the old data. Graphs of tree mean internode length were plotted for each stem section and site to illustrate differences between the two seedlots. The SAS procedure PROC GLM was used to determine whether there was a significant difference in mean internode length between the two seedlots on each site. Estimates of appropriate sample sizes to estimate mean internode length to a given precision assuming simple random sampling were calculated.

RESULTS

Previous Analysis

The previous analyses initially examined a larger data set than is reported here. In order to be able to compare mean internode length between the different sites and seedlots, it was necessary to determine the common stem length measured on all images. Due to variable lift pruning and limitations of visibility within the upper crown, the stem section common to all trees was between 5 m and 8 m in height, giving a stem section 3 m in length.

The mean length for internodes whose base was between 5 m and 8 m in height was calculated for each tree. The SAS procedure PROC GLM was used to determine whether there was a significant difference in mean internode length between the two seedlots on each site. While the mean internode length was always longer for the long internode seedlot (by at least 0.1 m), it was only significant ($p<0.05$) at one site, FR121/1. Plot statistics for this analysis are shown in **Table 2** (Appendix). Graphs of mean internode length for individual trees are shown in Figure 1 (Appendix). Examining these individual graphs indicates that there is little visual differentiation in mean internode length for individual trees.

Current Analysis

The number of trees in the selected PSPs in FR121/2 and FR121/3 varied between 16 and 20, but not all trees were imaged due to poor stem form. Some of the trees imaged were noted in the PSP system to have defects, however, in the field, they were still considered reasonable looking trees and imaged (see Table 1 for details).

Table 1. Number of trees in Permanent Sample Plots and number of trees for which TreeD images were collected

Site	Seedlot	Number of trees in PSP	Number of trees with noted defects in PSP	Number of trees imaged
FR121/2	GF14	20	6	19
FR121/2	GF13/LI25	20	2	15
FR121/3	GF14	16	9	8
FR121/3	GF13/LI25	19	6	7

The following variables were calculated for the trees with new TreeD images (i.e. collected in this study)

- The common stem length measured across all trees on a site
- The mean internode length for each tree counting internodes starting within this stem length
- The mean internode length using the common stem section in the previous study, i.e. between 5 m and 8 m.

For these new data and the stem section between 5 m and 8 m, plot mean internode length was at least 0.1 m longer for the long internode GF13/LI 25 seedlot than for the GF14 seedlot. The plot mean internode length for the two seedlots was significantly different ($p<0.5$) at FR121/2, but not at FR121/3. Plot statistics for this analysis are shown in Table 2 (Appendix). Graphs of mean internode length for individual trees are shown in Figure 1 (Appendix). Examining these individual graphs indicates that there is little differentiation in tree mean internode length between the different seedlots.

The common stem length was calculated individually for each site in both the new and previous datasets, and mean internode length was calculated. In this analysis, mean internode length was not significantly different between the two seedlots for any of the six comparisons. Plot statistics for

this analysis are shown in Table 3 (Appendix). Graphs of mean internode length for individual trees are shown in Figure 2 (Appendix). Examining these individual graphs indicates, as previously, there is little differentiation in tree mean internode length between the two seedlots.
An approximate estimate of the sample size required to estimate plot mean value of tree mean internode length to within 0.1 m was calculated using the formula:

$$n = 1.96^2 \times \sigma^2 / E^2$$

Where:

n is the predicted sample size required
s^2 is the observed variance in the current data
E is the required error

This formula assumes random sampling from a large population, which is not strictly true in this instance, but could be in a forest. The estimated values varied widely, from 3 to over 100, depending on observed variability for the particular site and seedlot.

Discussion

TreeD was selected as a non-destructive tool to provide quantitative branching data for testing the branching model BLOSSIM. Major advantages of TreeD are firstly, it provides a permanent record of the tree which may be examined to explain oddities in data, and secondly it avoids the health and safety issues involved with tree climbing.

In this study estimates of tree mean internode length were extracted from TreeD images for a GF14 and a GF13/LI25 seedlot at four widely separated sites that had received the following silvicultural treatment:

- Plant at 500 stems/ha and thin to 200 stems/ha at mean crop height of 6.2 m.

In all analyses the plot mean internode length was at least 0.1 m longer for the GF13/LI25 than for the GF14 seedlot. These differences are of similar size to those reported in 1988 [(3)] where only “crop” trees were measured. Graphs of mean internode length for individual trees (Appendices, Figures 1 and 2) indicated that there was little differentiation in mean internode length between the two seedlots at the sites examined.

An examination of the images for the trees exhibiting very long mean internode lengths indicated that these values could be related to noticeable stem defects. Long internodes may occur after stem damage if a branch takes over as the leader, because branches often have very long internodes. It is therefore considered that the high variability in mean internode length within a seedlot, and consequent lack of significance between seedlots is attributable to stem damage.

An approximate estimation of the sample size required to estimate plot mean internode length to within 0.1 m (assuming random sampling from an infinite population) varied with both the length of stem section considered and the variability between trees. The sample size required decreased as the length of the stem section increased. The length of an individual internode is highly variable, so the smaller the stem section considered, the fewer the number of internodes used in the calculation of mean internode length, and the more variability in mean internode length between trees. The median value using the longest stem section available for each individual dataset (Appendices, Table 3), was 14 trees.

An important question that arises from this study is the role that stem damage plays in the forest and how it should be accounted for in sampling procedures and model development; i.e. how do we ensure that the measures collected and models developed represent the “true” situation rather than a “best case” situation? For example, measuring only “crop” trees is considered to be a “best case” situation.

The above comment applies to more that just branching. For example trees with top-outs are not included in the calculation of height. Also wood property measures such as outerwood density cores and standing tree sonics are generally taken to avoid compression wood, but compression wood is formed to correct for any deviations from vertical and is often present in the stem. Inventory assesses all trees in a plot, and incorporate visual estimates of stem damage and branch size into its assessment of stand value; consequently it is recommended that inventory assessments be carried out in large trials to assess the value of different seedlots and silvicultural treatments.

From a modelling perspective, models need to account for the fact that trees are not “perfect”; stems of rotation-aged trees may incorporate previous leader changes and compression wood.

CONCLUSION

TreeD is a non-destructive tool that provides quantitative branching data. Major advantages of TreeD are firstly, it provides a permanent record of the tree which may be examined to explain oddities in data, and secondly it avoids the health and safety issues involved with tree climbing.

This study used TreeD to examine mean internode length for two seedlots (a GF14 seedlot and a GF13/LI 25 seedlot. While the plot mean internode length was longer for the GF13/LI 25 seedlot, the differences were generally not significantly different. The lack of significance is considered to be due to the occurrence of stem breakage and a previously-formed branch taking over as the new leader.

Stem damage is a factor that needs to be incorporated into modelling systems in order to provide more realistic estimates of the value of different seedlots and silvicultural regimes.

It is also recommended that inventory assessments be carried out in trials to determine the value of different seedlots and silvicultural treatments.

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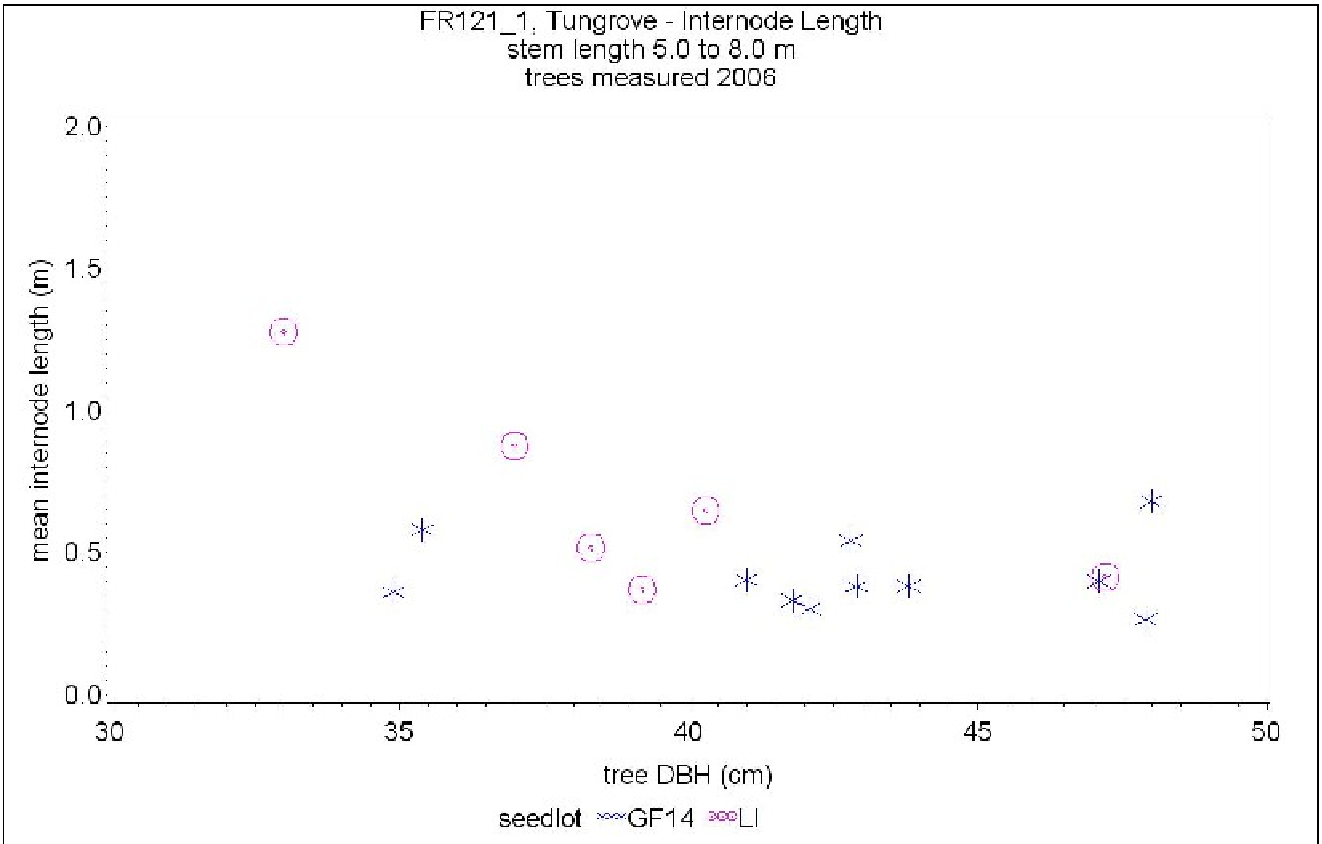
APPENDIX



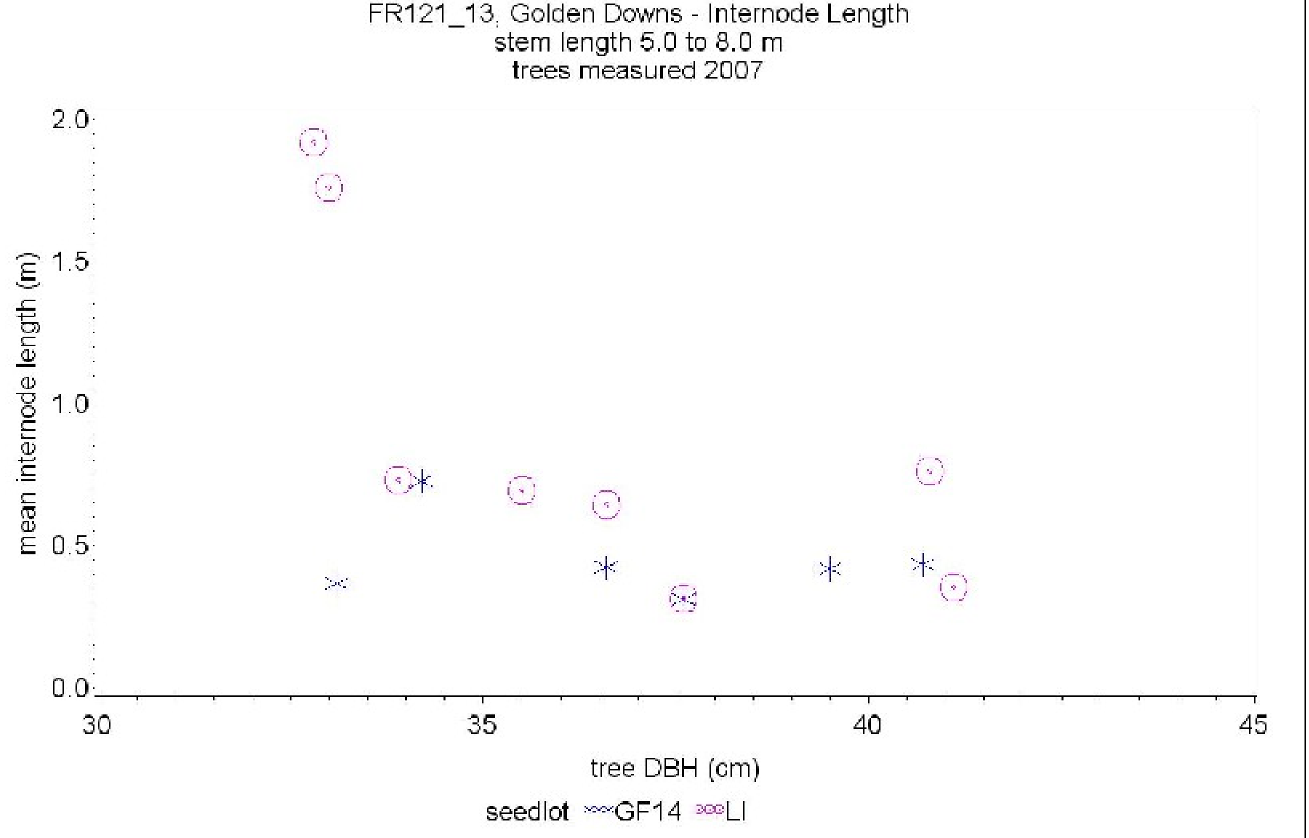
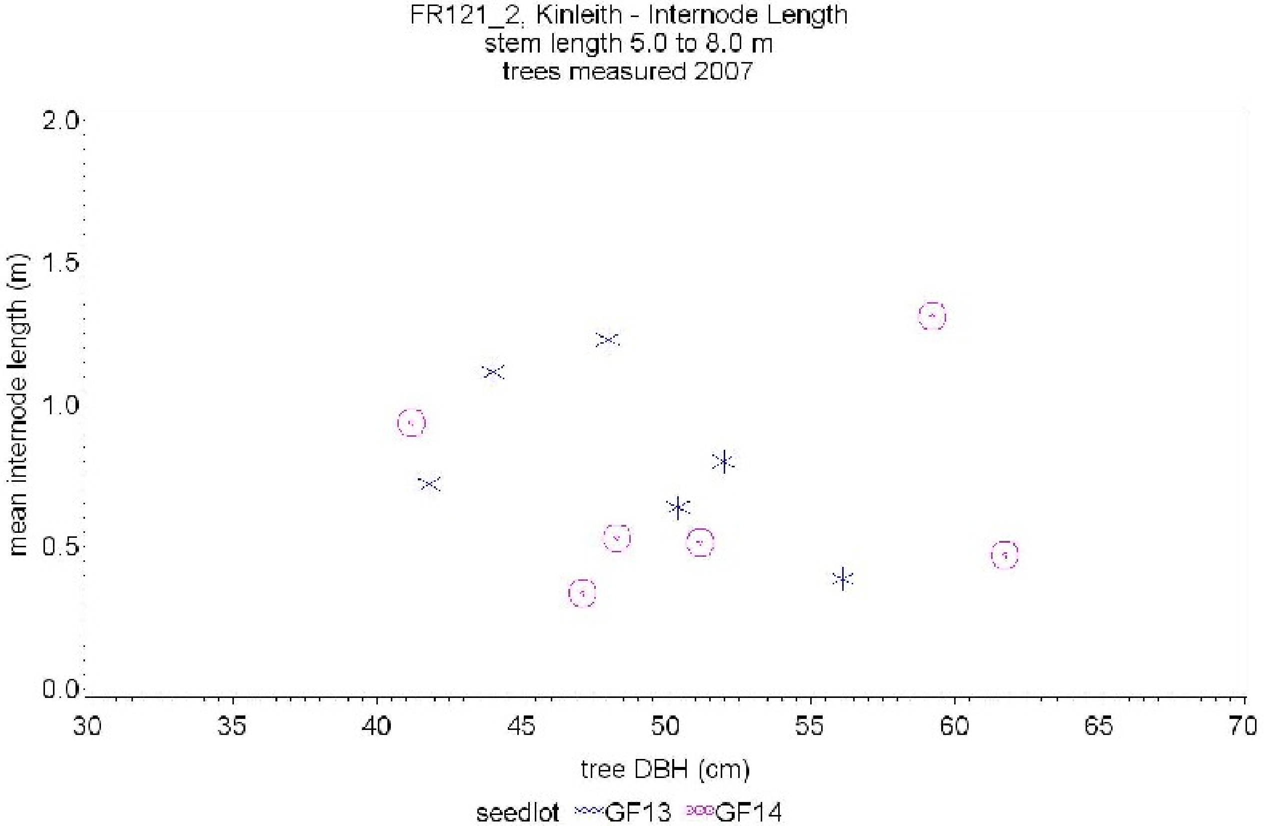


Figure 1. Graphs showing mean internode length for individual trees when mean internode length was calculated for the stem section between 5.0m and 8.0 m in height (i.e. 3 m in length) GF13/LI 25 seedlot labelled LI.



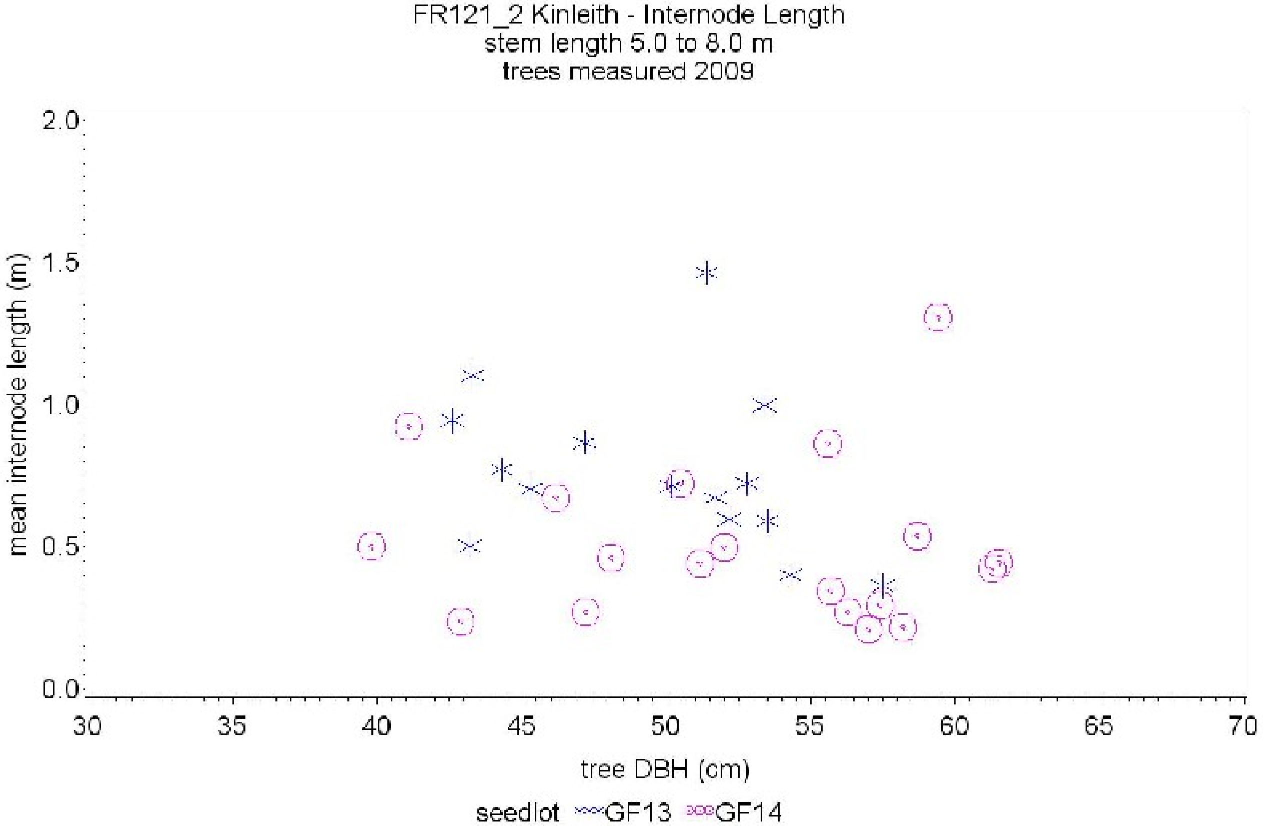
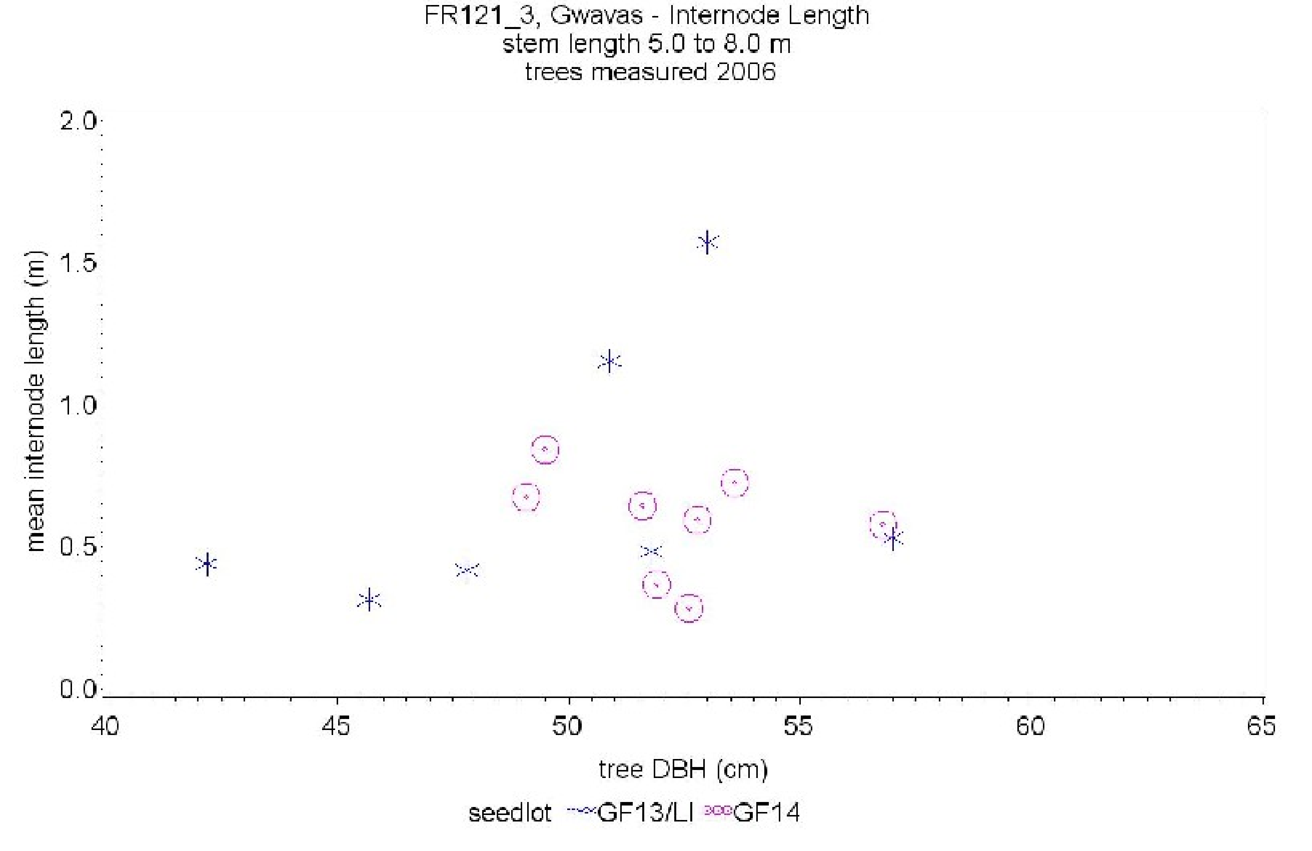


Figure 1 cont. Graphs showing mean internode length for individual trees when mean internode length was calculated for the stem section between 5.0m and 8.0 m in height (i.e. 3 m in length) GF13/LI 25 seedlot labelled GF13



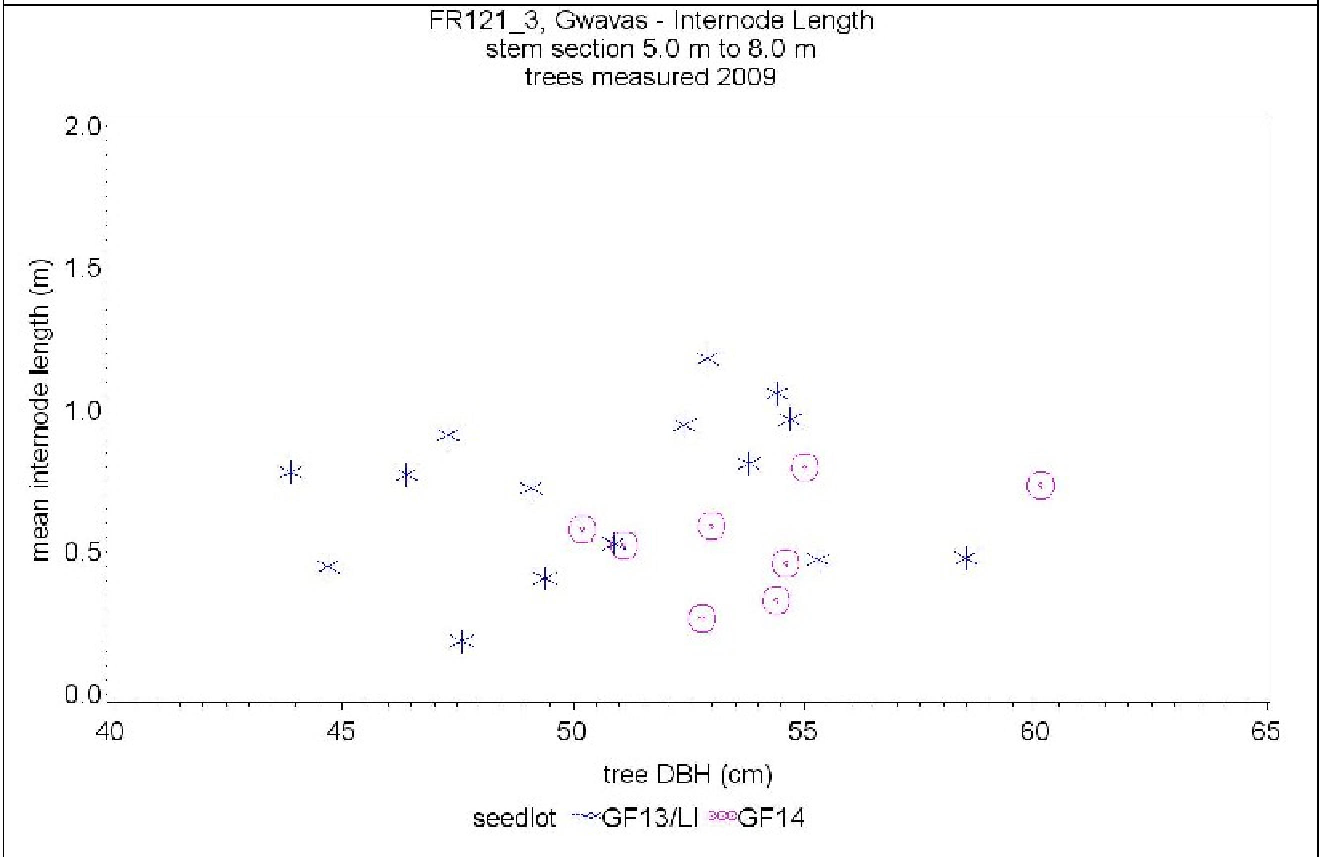
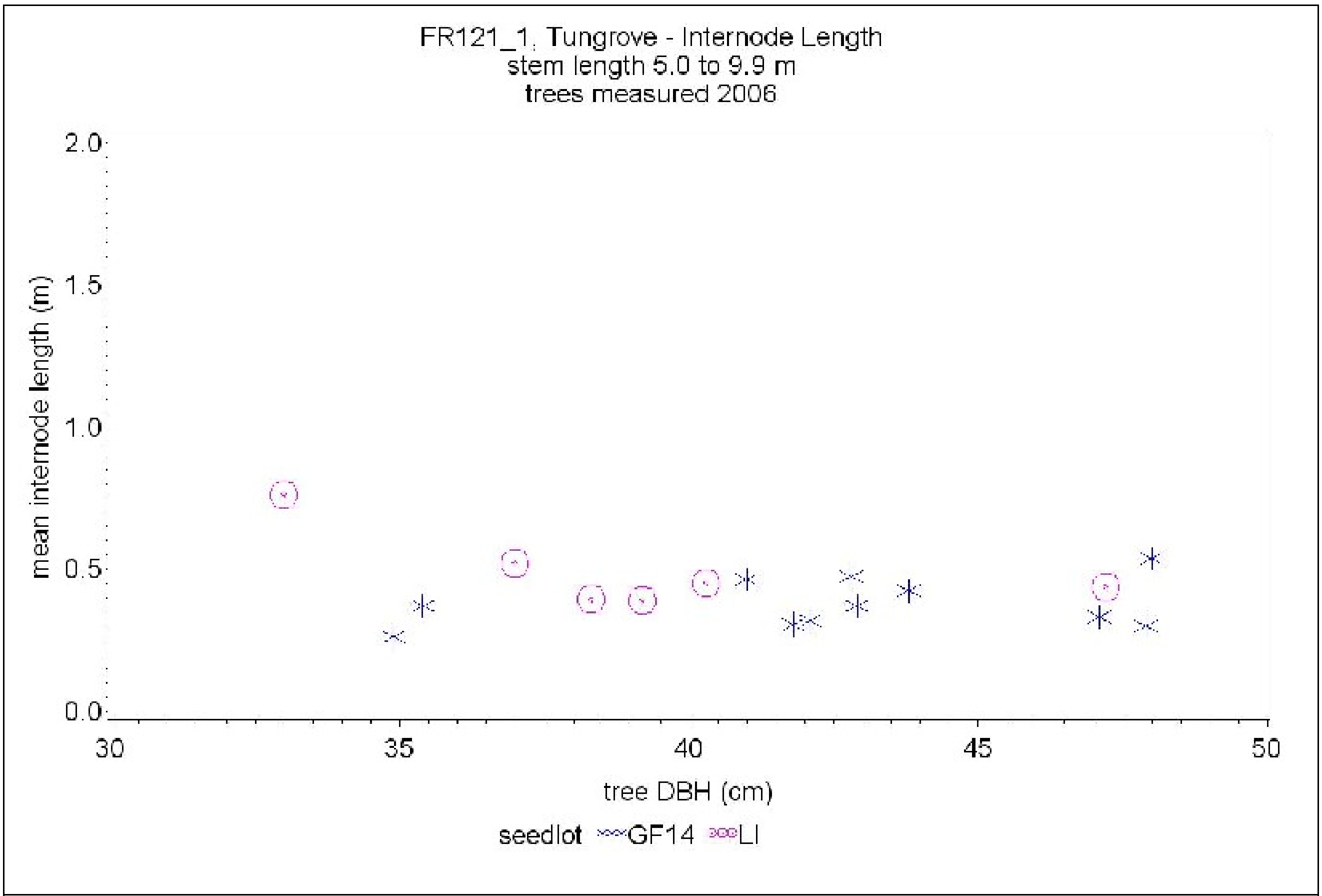


Figure 1 cont. Graphs showing mean internode length for individual trees when mean internode length was calculated for the stem section between 5.0m and 8.0 m in height (i.e. 3 m in length) GF13/LI 25 seedlot labelled GF13/LI.



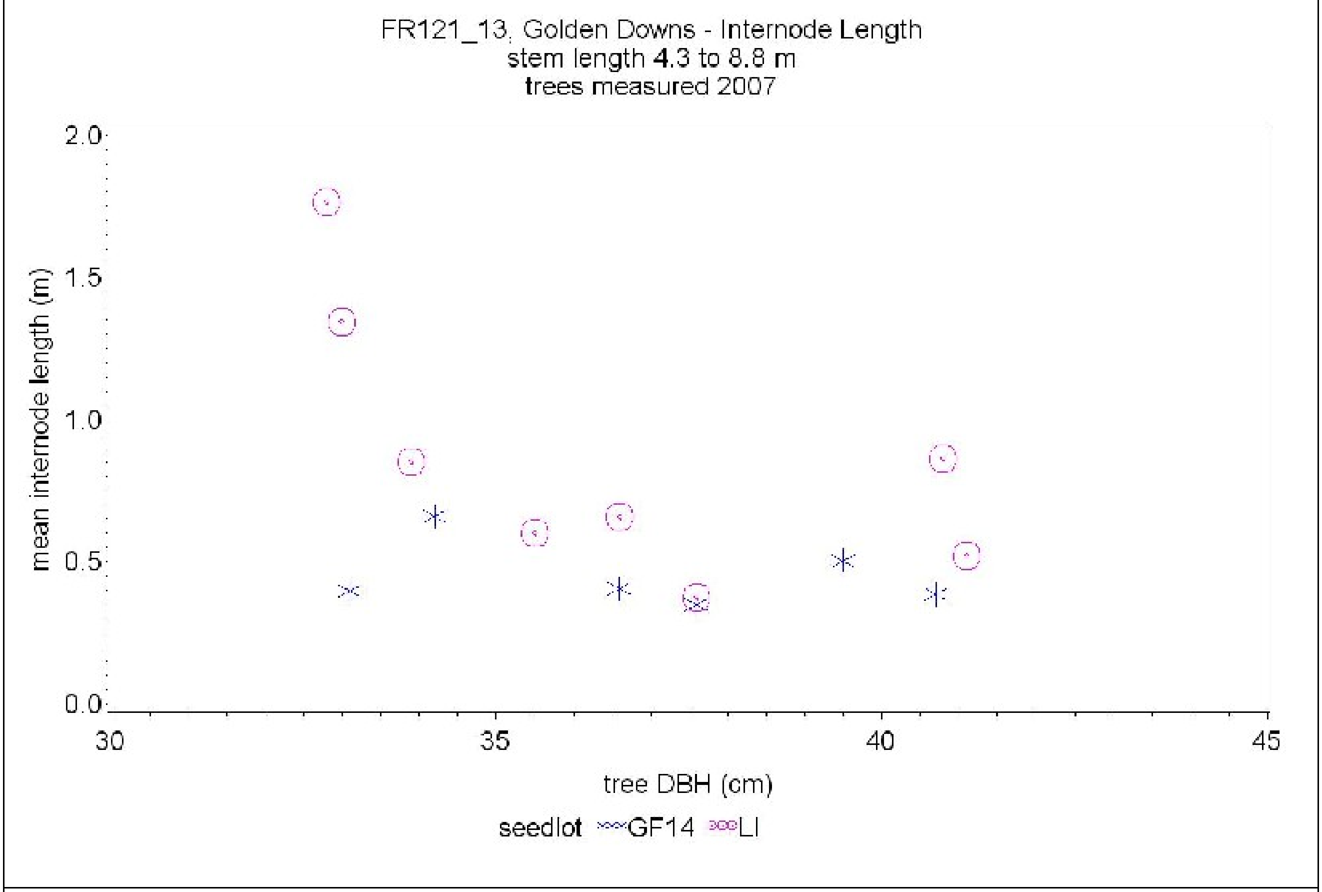
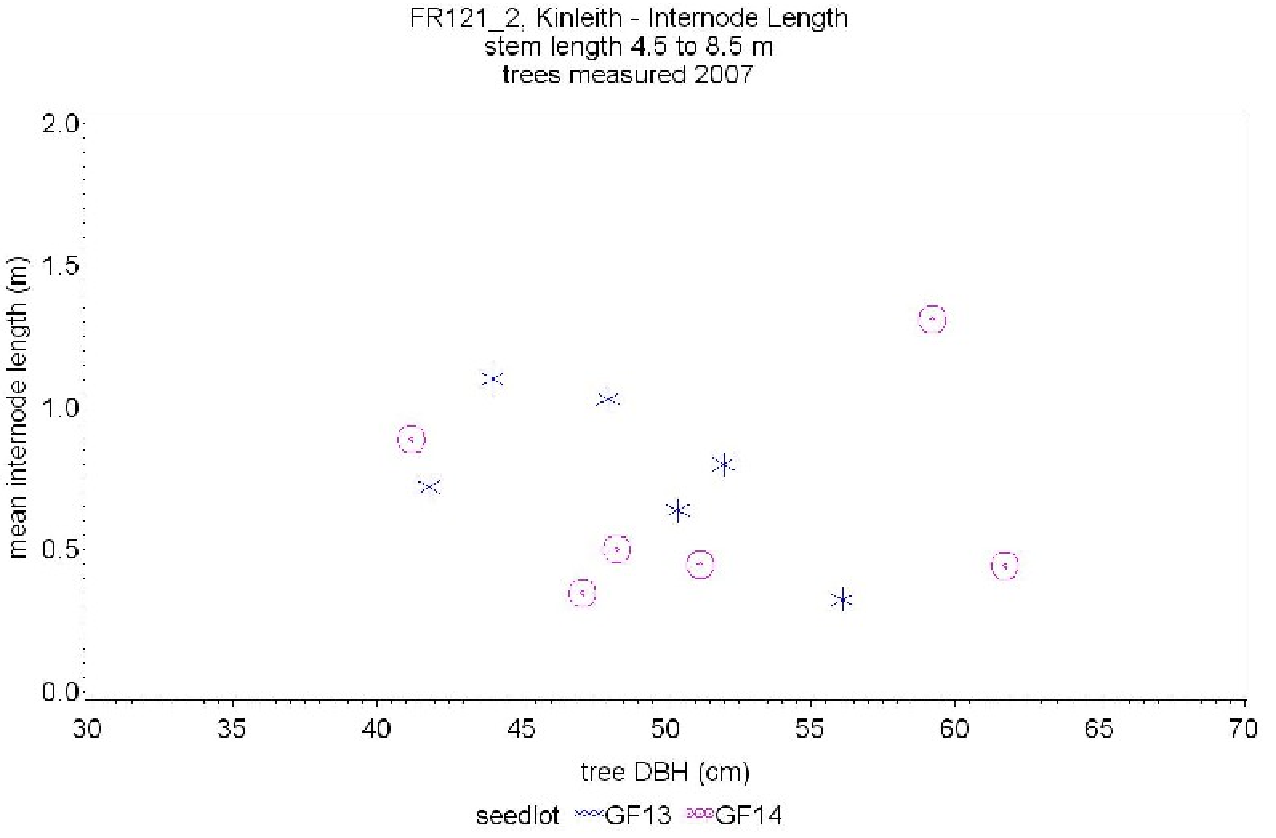


Figure 2. Graphs showing mean internode length for individual trees when mean internode length was calculated using the common stem section for each dataset as noted on the individual graphs. GF13/LI25 seedlot labelled as LI.



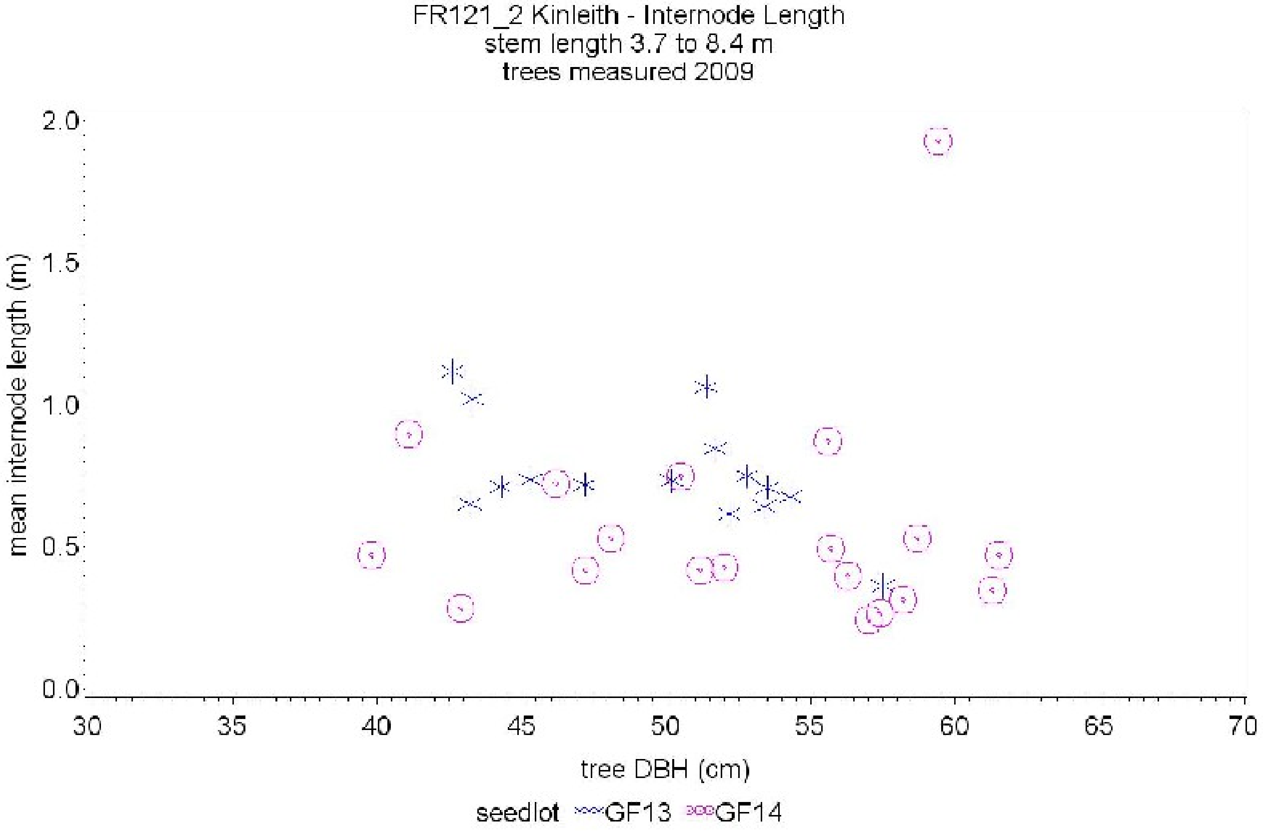
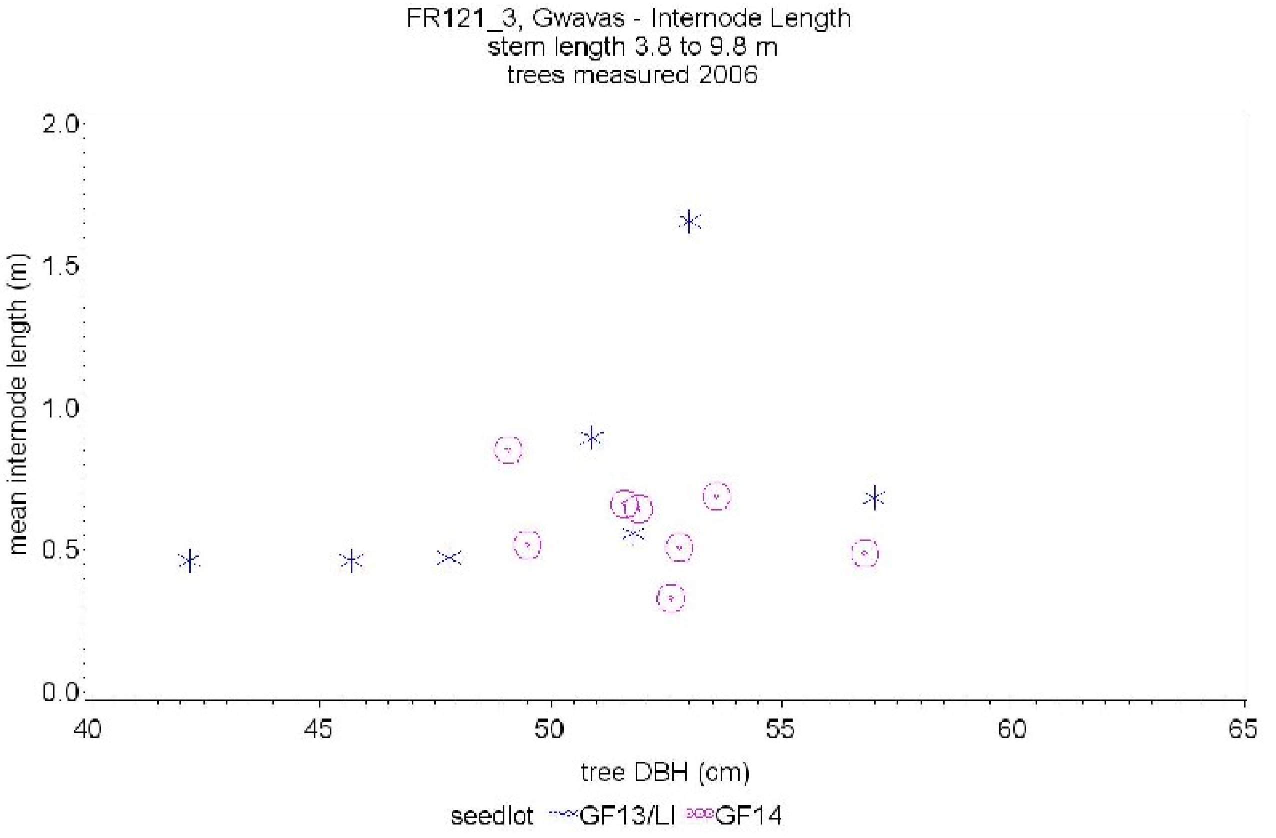


Figure 2 cont. Graphs showing mean internode length for individual trees when mean internode length was calculated using the common stem section for each dataset as noted on the individual graphs. GF13/LI25 seedlot labelled as GF13.



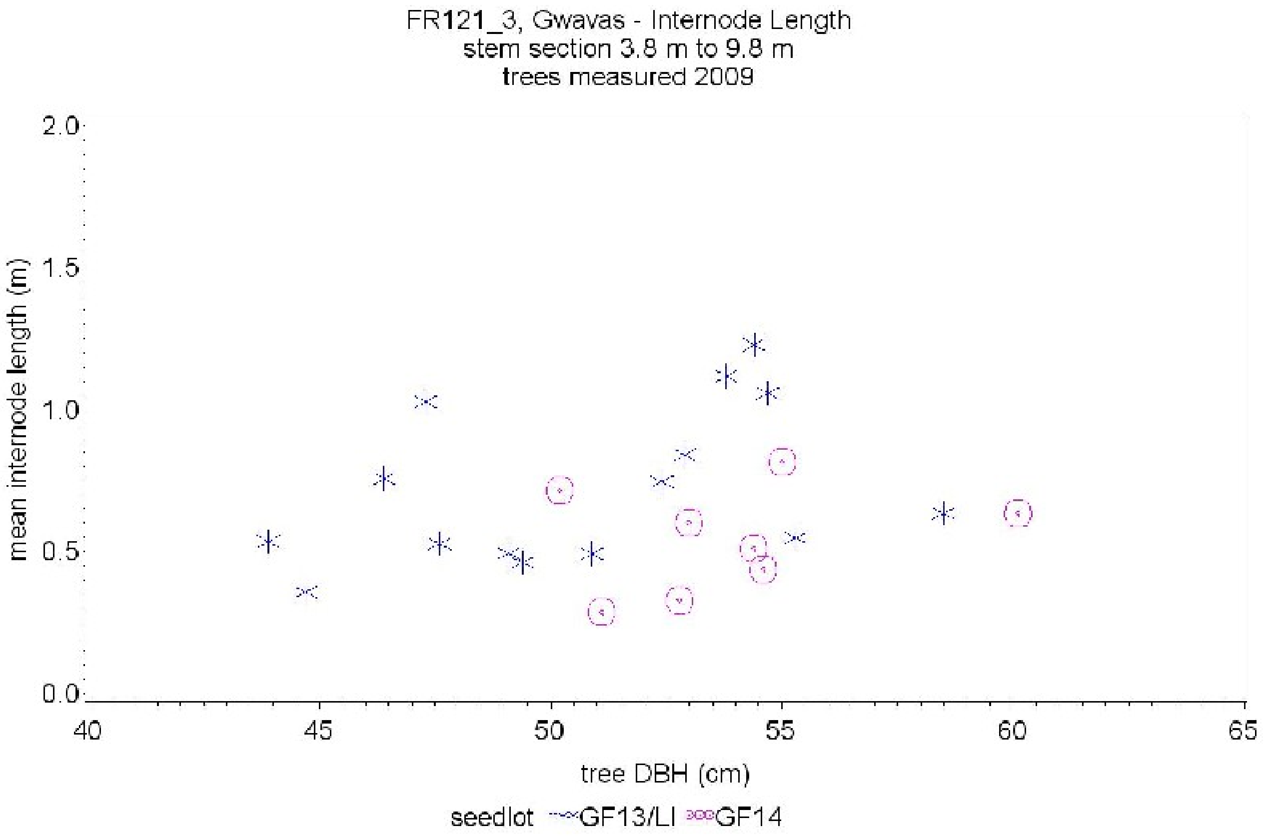


Figure 2 cont. Graphs showing mean internode length for individual trees when mean internode length was calculated using the common stem section for each dataset as noted on the individual graphs. GF13/LI25 seedlot labelled as GF13/LI.

Table 2. Descriptors for mean internode length for the common stem section between 5.0 m and 8.0 m (i.e. 3 m in length)

GF rating	Minimum	Maximum	Mean	Variance	Actual sample size	Estimate of sample size
FR121/1, Tungrove, measured 2006						
GF14	0.27	0.68	0.42	0.02	11	7
GF13/LI25	0.37	1.28	0.68	0.12	6	46
FR121/2, Kinleith, measured August 2007						
GF14	0.34	1.31	0.68	0.13	6	52
GF13/ LI25	0.39	1.23	0.81	0.10	6	38
FR121/2, Kinleith, measured March 2009						
GF14	0.21	1.31	0.51	0.08	19	32
GF13/LI25	0.36	1.46	0.76	0.08	15	32
FR121/3, Gwavas, measured November 2006						
GF14	0.28	0.84	0.59	0.03	8	13
GF13/LI25	0.31	1.57	0.70	0.22	7	86
FR121/3, Gwavas, measured March 2009						
GF14	0.27	0.80	0.54	0.03	8	13
GF13/LI25	0.19	1.18	0.71	0.08	15	31
FR121/13, Golden Downs, measured 2007						
GF14	0.31	0.73	0.45	0.02	6	9
GF13/LI25	0.32	1.92	0.90	0.37	8	142

Table 3. Descriptors of mean internode length for common stem length between seedlots for a given site.

GF rating	Minimum	Maximum	Mean	Variance	Actual sample size	Estimate of Sample size
FR121/1, Tungrove, measured 2006 section considered 5.0 to 9.9 m (length 4.9 m)						
GF14	0.26	0.54	0.38	0.007	11	3
GF13/LI	0.39	0.76	0.49	0.02	6	8
FR121/2, Kinleith, measured August 2007, section considered 4.5 to 8.5 m (length 4 m)						
GF14	0.5	1.31	0.66	0.14	6	53
GF13/ LI25	0.32	1.10	0.77	0.08	6	31
FR121/2, Kinleith, measured March 2009, section considered 3.7 to 8.4 m (length 4.7 m)						
GF14	0.25	1.93	0.57	0.15	19	56
GF13/LI25	0.36	1.12	0.76	0.04	15	15
FR121/3, Gwavas, measured November 2006, section considered 3.8 to 9.8 m (length 6 m)						
GF14	0.33	0.85	0.59	0.03	8	10
GF13/LI25	0.46	1.66	0.74	0.18	7	73
FR121/3, Gwavas, measured March 2009, section considered 3.8 to 9.8 m (length 6 m)						
GF14	0.29	0.82	0.54	0.03	8	13
GF13/LI25	0.36	1.23	0.72	0.08	15	28
FR121/13, Golden Downs, measured 2007, section measured 4.3 to 8.8 m (length 4.5 m)						
GF14	0.35	0.66	0.45	0.01	6	6
GF13/LI25	0.37	1.77	0.87	0.21	8	83