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Assessing Spiral Grain by Light Transmission – Stage 1: Proof of Concept

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Scion

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EXECUTIVE SUMMARY

Past studies have confirmed the importance of spiral grain in affecting the stability of wood during drying and in use, but have also highlighted the difficulties in obtaining reliable values from wood discs. Traditional methods are time-consuming and subject to a high degree of variation.

A new concept was tested where light is directed through disc samples on a flatbed scanner and the deviation along the grain assessed by means of a template. Conceptually, this should allow the mapping of grain angle variation radially and tangentially within discs. With multiple discs, the 3-D mapping of individual stems should be possible.

This is the first trial designed to test if spiral grain can be estimated using light transmission. This small trial proved that the concept is valid for discs 25 mm thick and small enough to fit on an A4 paper scanner. Comparisons with traditional scribing and cleaving methods were favourable, not least because the traditional methods have acknowledged issues of manpower requirements and accuracy. The light approach should allow much faster and more accurate data accumulation.

Using larger complete discs would improve the ability to assess spatial variation in grain angle, and minimise the effects of sample reference geometry with respect to the tree axis (disc tilt and parallax). Further work would ensure that reliable spiral grain values are obtained from both sapwood and heartwood.

As part of the larger Destructive Sampling Project (F10106), the light transmission approach (compared with scribing and cleaving) should give much more robust values for incorporating spiral grain data into models for predicting wood performance, because values are based on a larger amount of data, covering entire wood discs along the tree stem.

The concept has been shown to be valid for small disc samples. It is now a matter of some urgency to:

1. demonstrate the ability with larger and older samples which contain more resin in the heartwood. This should be done using an A3 scanner;
2. optimise the process by investigating a controlled light system; and
3. design and cost an automatic system for large scale grain assessment in conjunction with other automatic disc measurements.

The new method should fit well with the plans to destructively sample four major wood properties (density, spiral grain, microfibril angle, and chemistry) in an automated process to generate intensive data for stem and product modelling with PQSim.

INTRODUCTION

Distortion is recognised as one of the limiting factors affecting utilisation of plantation softwoods. Twist, crook and bow during drying and use are major issues affecting many species including radiata pine [4, 20]. Specialised kiln drying schedules for twist-prone radiata pine (i.e. juvenile wood), involving high temperatures and stack weighting, have been adopted as the industry standard in Australasia [12].

Among the factors leading to distortion in radiata pine, spiral grain has been strongly implicated [15, 10]. Other lesser contributing factors include growth ring curvature, dimensional shrinkage, distance from the pith, and drying temperature [1, 11, 14].

Due to its importance, researchers have sought to improve methods for measuring spiral grain and predicting distortion.

Traditionally, tree stem grain angles in wood quality and tree breeding studies have been measured on standing trees [9, 13] or from scribing discs removed from stems [7]. These methods have the advantage that samples at equivalent positions on either side of the pith can be averaged to eliminate bias (hence giving 'absolute' values referenced to the vertical axis of the stem). The bulk of studies in New Zealand have used this approach [7, 12, 25, 5].

Discs have given the most reliable and repeatable data, particularly when opposite radii are measured to compensate for disc tilt [2, 17, 10]. Sampling has been done at fixed heights in the stem, often representing commercial log lengths (e.g. 5 m). The method developed by Brazier involved splitting the discs through the pith and measuring the deviation of the split surface of each growth ring from the stem axis. A lot of research has also been done using disc-scribing and splitting methods, and most species have been shown to exhibit left-hand (positive) angles near the pith, decreasing or reversing with age [8, 7, 5, 20].

Most published studies deal with grain angles determined from a rather low level of sampling, which are often averaged over a specified distance or group of growth rings. Wobst *et al.* [26] completed a small study of circumferential variation in discs of Douglas-fir. Their conclusion was that there was significant tangential variation around individual rings, thus complicating analyses of the effects of age, growth conditions, genotypes, etc. Measured values around individual growth rings showed deviations of up to 5 degrees. More recent, detailed studies [21, 22, 16] have indicated that there may be much more variation present within a tree than has been previously reported. An intensive study on a young radiata pine stem also confirmed this high level of spatial variation [5], casting doubt on the dependability of the traditional approach.

Nyström [18] developed an automated method for measuring spiral grain on sawlogs and timber that utilised the light conducting properties of softwood tracheids to measure fibre orientation on the exterior of debarked logs. Its use allowed the possibility of measurement over large areas and segregation of material with high surface grain angles.

Other non-destructive methods for measuring spiral grain in stems or logs have been attempted using x-rays and/or microwaves [3, 23, 24, 16]. These techniques require expensive equipment and powerful mathematical modelling capability and are starting to be adopted in commercial board-scanning systems [16]. Sarén *et al.* [22] used both x-ray and laser methods to investigate within-tree patterns of spatial variation of spiral grain in Norway spruce. Fluctuations were noted to be large (up to 10 degrees), but not in phase with the growth ring boundaries. Importantly, these fluctuations occurred over short distances, e.g. 0.5 mm. The implications of the findings could be dramatic if confirmed in other species, suggesting that the traditional scribing methods based on growth rings may be flawed.

It seems clear that spiral grain, while universally recognised as important for wood behavior, has not been rigorously researched, and that measurement methods may be inaccurate and deficient if the objective is to predict product performance.

Currently there is no accepted method of efficiently collecting data on grain angles, despite the importance for predicting wood performance.

Recent work at Scion (Appendix 1) has indicated that the deviation of natural light along the grain in fresh wood samples may be quantified in a document scanner by placing a light “mask” on the upper surface and calculating the deflection resulting from the grain angle and sample thickness. The benefits of this approach would be that 3-D maps of grain angle could be produced rapidly and economically.

It is well known that light is transmitted some way through wood, particularly in the axial direction [18, 19]. Applying this principle, it was theorised that light contacting the surface of a wood disc would be preferentially directed along the tracheid direction, and thus offer the opportunity of being able to collect data from the whole disc in a two-dimensional fashion.

Using this knowledge, it was hypothesised that by applying a barrier above the disc to block the external light source, the deflection of the light caused by spiral grain could be detected and quantified. Conceptually, the approach could be used to assign grain values across the disc according to distance from the pith, or growth ring number from the pith.

OBJECTIVES

The study is designed to test the following hypotheses:

1. Natural light penetrating wood samples follows the grain direction and the deviation through the thickness can be measured using a light mask on the upper surface, and can be subsequently used to estimate spiral grain in both fresh sapwood and heartwood.
2. This phenomenon can be used to develop a rapid system for mapping 3-D grain deviation in logs and stems, to the degree necessary for predicting product performance.

MATERIALS AND METHODS

In order to refine and test the proposed method, 12 discs were obtained from a single radiata pine tree about 15 years old located near Rotorua, New Zealand. These discs were of varying thickness (15, 25 and 35 mm from adjacent positions at four stem locations) in order to allow the thickness of disc that light could penetrate to be determined and to ensure that some discs contained heartwood, while others contained some compression wood (Figure 1). All discs were evacuated under water to ensure saturation of the heartwood before being scanned using the new method. Spiral grain was also later assessed destructively on all the 25-mm-thick discs using cleaving and scribing methods for comparison.

Figure 1: Disc 1 – Sample with compression wood

Light Transmission

The principle of light transmission through wood samples is shown in Figure 2.

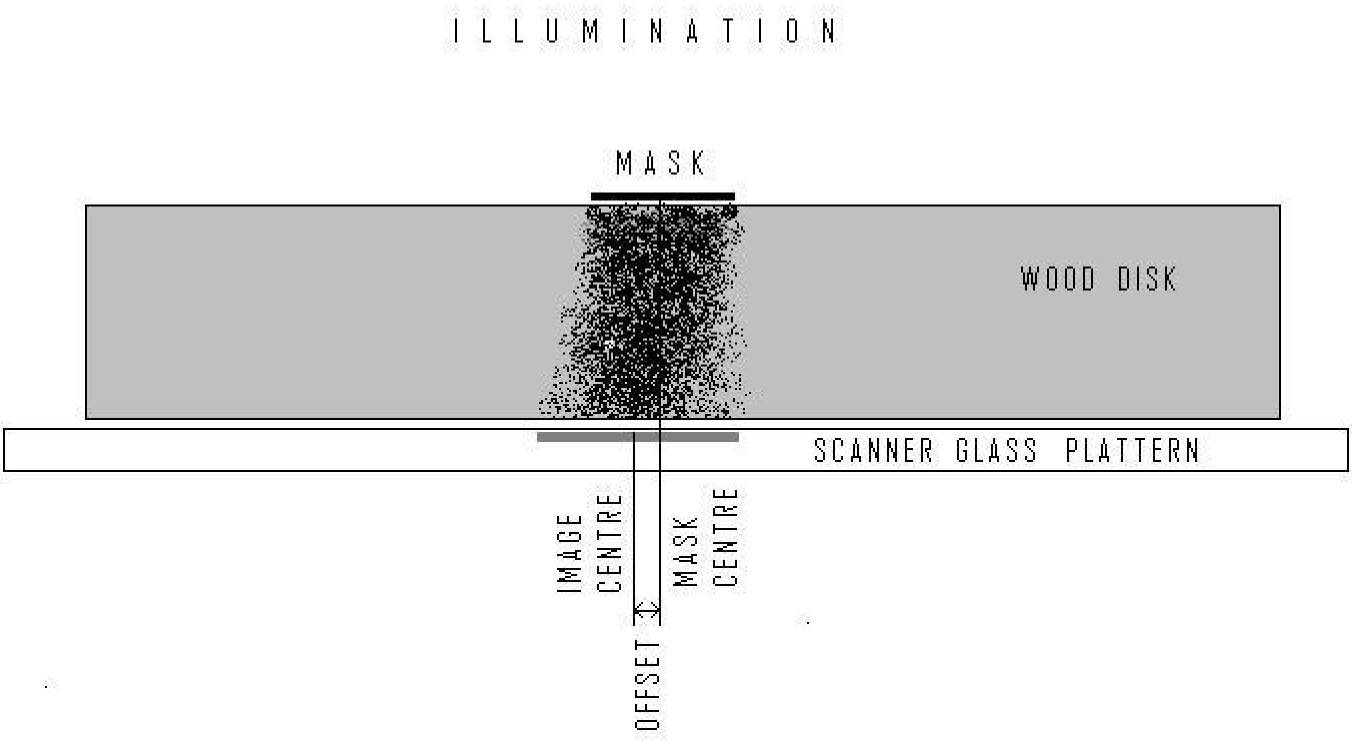

Figure 2: Illustration of light deflection through wood.

The scanner used in this preliminary study was an Epson Stylus Photo RX430. The maximum optical resolution for this model is 1200 DPI (dots per inch), which refers to the hardware resolution of detectors in the direction of the scanner sensor head. The Epson Stylus can move the scanner sensor head in steps of 4800 DPI in the direction of head carriage movement. Higher resolution scans (up to 9600 DPI) are software interpolated values. This model of scanner is designed to scan in reflected mode only where the sample is illuminated from below. Therefore, the scanner cover was removed so that the detector head detects a combination of the reflected light from the under-glass illumination and the light transmitted from above and through the wood sample. The under-glass illumination has a negative influence of reducing the usable dynamic range of the instrument. Preliminary tests established that external light from this system could penetrate wood samples of 20-30 mm thickness, clearly showing the positions of the growth rings due to differential penetration of earlywood and latewood.

The scanner was modified by fixing a right-angled bracket to the glass surface, which enabled a strip template to be placed in the same position on the scanner for each observation. This strip template (50 mm x 240 mm) was constructed from clear acrylic with a central longitudinal channel milled into the centre, which had a 12 mm wide metallic strip inserted flush with the surface. The template was located flush with the bracket and scanned with the metal strip side facing down directly on the glass of the scanner (Figure 3). A scan of the strip template without the sample disc present was used to calculate the reference zero position of the template on the scanner.

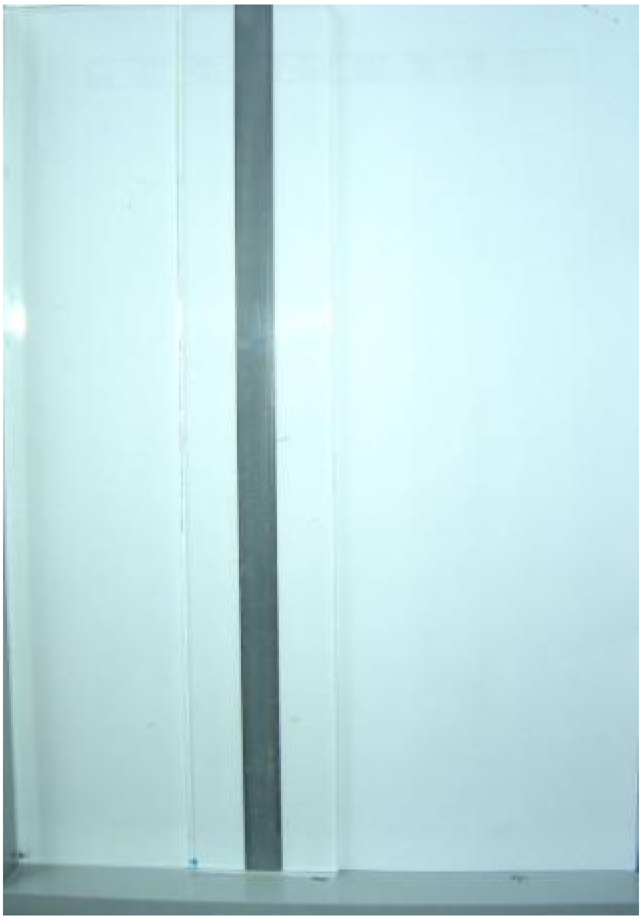

Figure 3: Strip in scanner

Each of the sample discs was then scanned with its upper surface (with respect to stem orientation) facing up and the strip template placed on top of the disc (metal side down) and hard against the edges of the bracket (Figure 4). The strip template was then removed and without moving the disc, a scan of the disc without the template was made (Figure 5). For small discs the whole disc was scanned and additional acrylic strips were used to position the strip template. For larger discs, sets of radial strips, 50 mm wide in the tangential direction, were cut from the disc. Two scans were made on each radial strip in the same manner as for the discs. The lighting used when scanning thin discs (<15 mm) was the ambient daylight present in the room when the window blinds were shut. In this situation light entered the room through a narrow window near the roof and was reflected off the white ceiling. For thicker discs (>20 mm) the same lighting arrangement (daylight with window blinds shut) was adequate for the sapwood, but an additional 25 W incandescent lamp was needed to provide sufficient illumination for light transmission through the heartwood. An artefact of the lamp lighting was a pattern in the scanner head movement direction of varying intensity from the 50 Hz electricity supply.

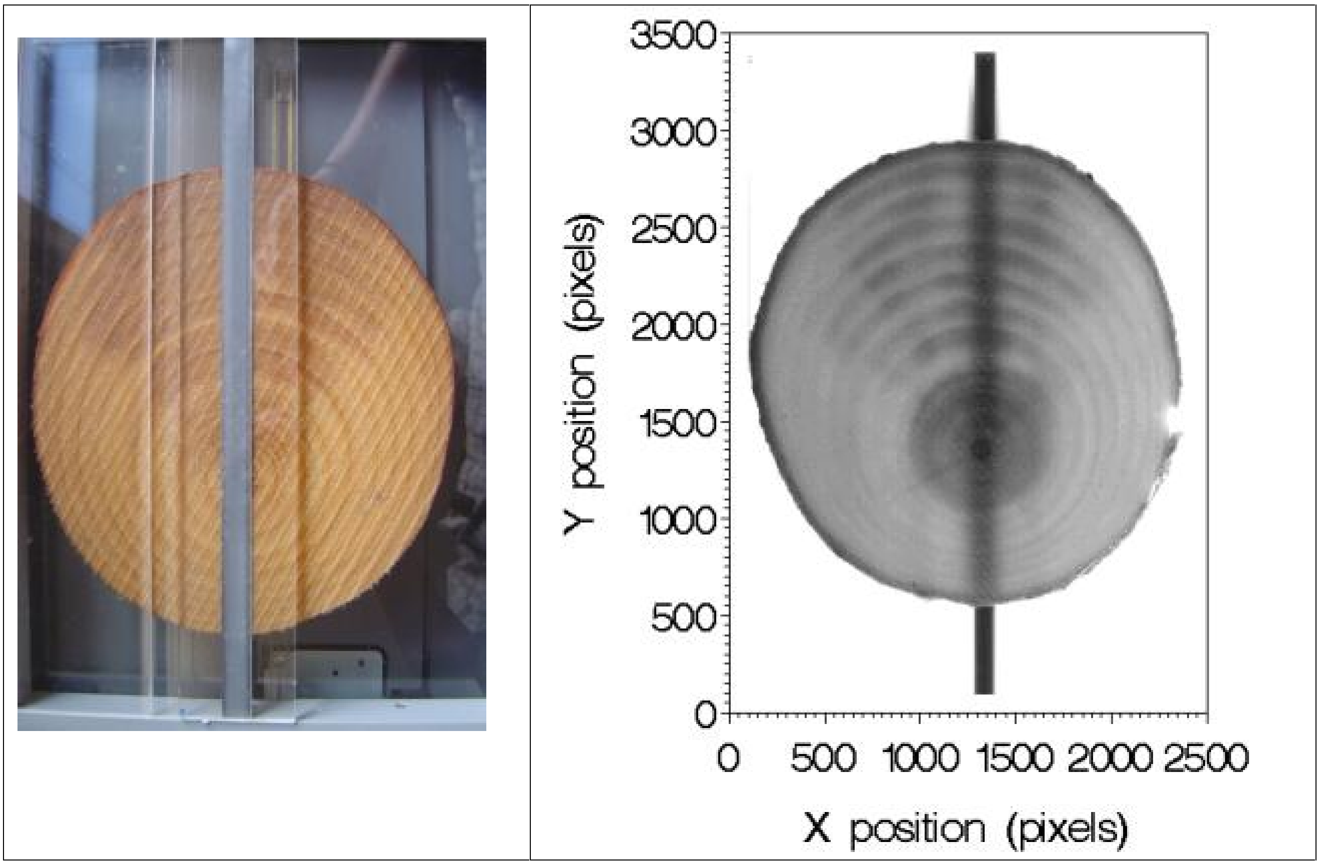

Figure 4: Disc image with template (scanned image on right)

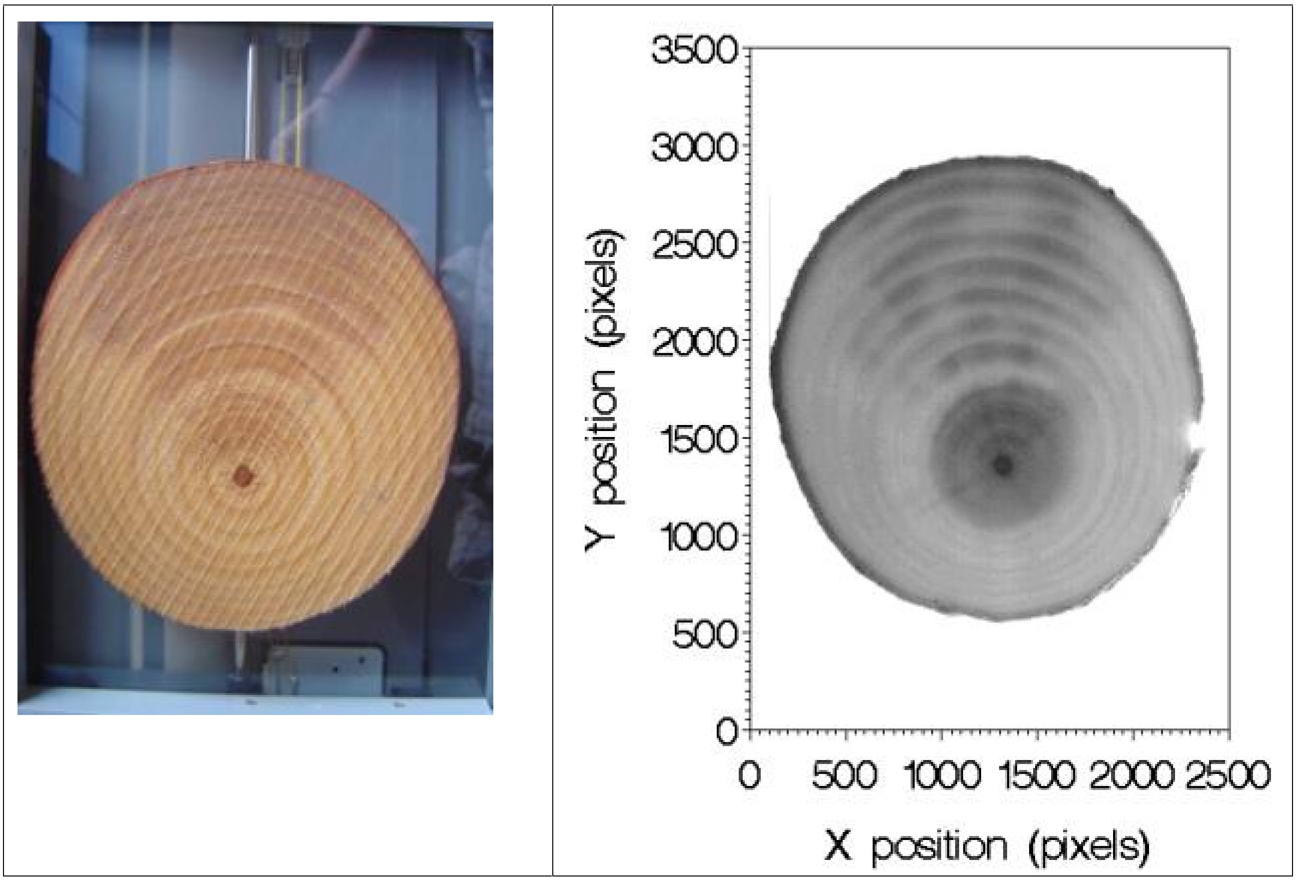

Figure 5: Disc image using natural light (scanned image on right)

For all scans the detected intensity was saved as a 24-bit colour image (3 channels (RGB) with 8 bits per channel). The image of the disc with the template was then subtracted from the image of the disc without the template. This yielded the “difference image” which showed how much lighter (more intense) each pixel is without the template present (Figure 6).

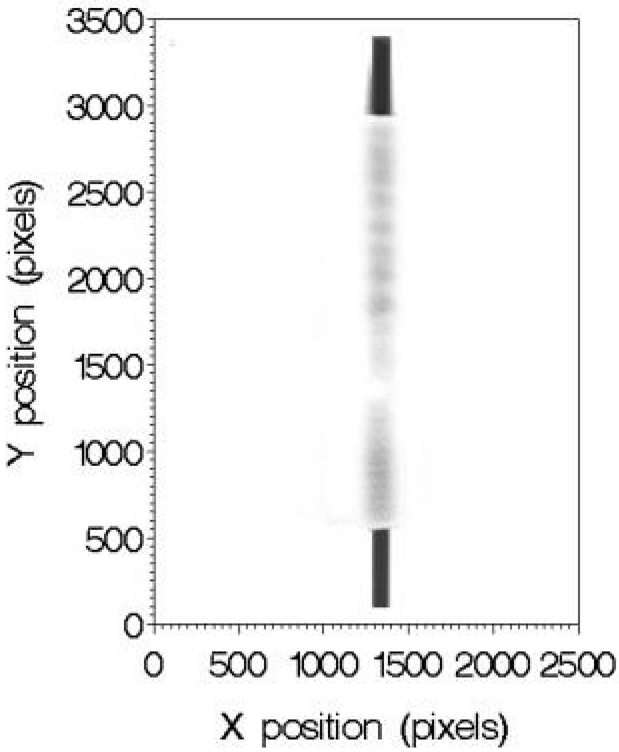

Figure 6: Subtraction of images

Software was developed to eliminate data where the light did not transmit through the sample (e.g. the pith area or where the disc edges included bark). This program checked the image intensity values and merged data appropriately when two different levels of illumination were required for the heartwood and sapwood regions of a disc. To calculate the spiral grain offset a centre of mass algorithm was applied to a radial transect of data. This algorithm calculated the intensity weighted X position at each point along this transect (Y position - Figure 7).

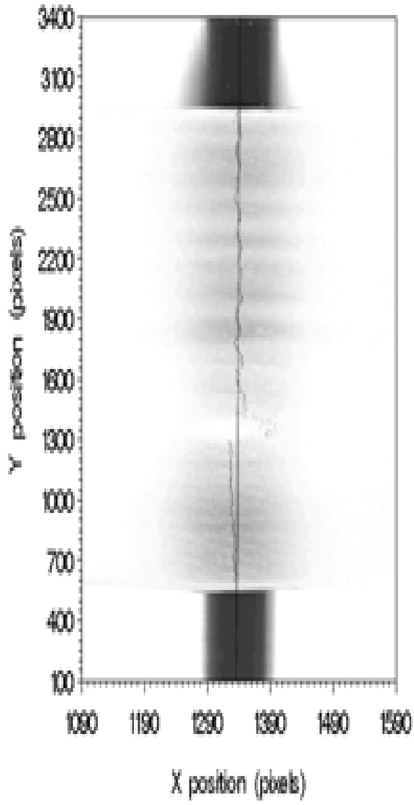

Figure 7: Centre of Mass Algorithm

Subtracting the reference zero position from this weighted X position gave the offset value in number of pixels. This was converted to an actual distance by multiplying by the resolution of the scanner, and the spiral grain angle was then calculated as:

$$arctan\left(\frac{o}{t}\right) \qquad [1]$$

where: *o* is the offset distance (mm) and *t* is the disc thickness (mm). For example, when scanning a disc that is 25 mm thick at 1200 DPI (47 dots mm^{-1}) resolution, a grain angle of 1° would result in a deflection in the position of the template of 21 pixels (Table 1).

Table 1: Offset distance in pixels for a grain angle of 1° for differing disc thicknesses and common scanner optical resolutions

Disc Thickness (mm)	Scanner Optical Resolution (DPI)			
	300	600	1200	2400
10	2	4	8	16
15	3	6	12	25
20	4	8	16	33
25	5	10	21	41
30	6	12	25	49
35	7	14	29	58

While grain angles can be assessed continuously from bark to bark with this approach, for the purpose of the present study they were summarised according to individual annual rings in order to allow comparison with values obtained by scribing and cleaving.

Cleaving

The fresh discs were cleaved across two diameters by loading in the compression tester in the Timber Engineering Laboratory, yielding four radii exposed (Figure 8). Annual ring boundaries will be marked and grain angles measured by Spiralite on the radial/longitudinal surfaces at each ring boundary.

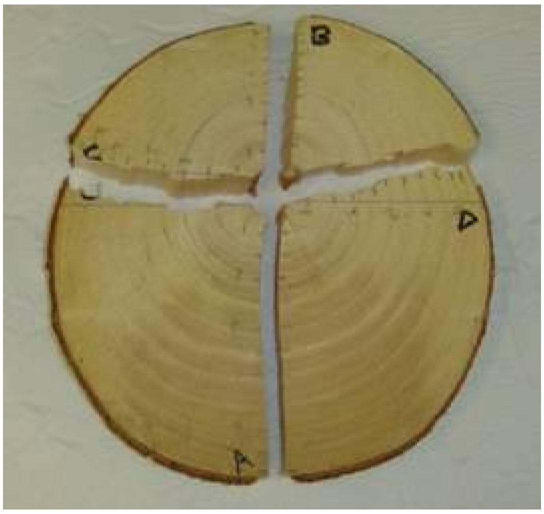

Figure 8: Disc 1 prepared for spiral grain measurements

Photographs of the cleaved discs 2-4 are shown in Appendix 2.

Scribing

The four segments resulting from the cleaving process had wood removed at the annual ring boundaries from the bark side and the grain highlighted by scribing the tangential/longitudinal surfaces (Figure 8). Grain angles will be measured with the Spiralite, using the convention of positive angles representing grain sloping upwards to the left as viewed from the bark side.

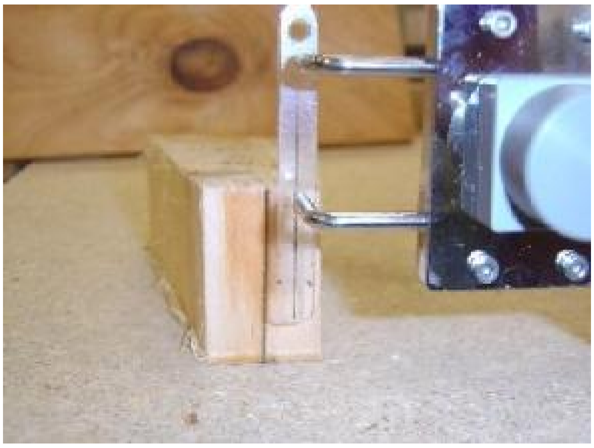

Figure 9: Spiralite

RESULTS AND DISCUSSION

Appendix 3 presents the results of the scribing, cleaving and light transmission studies graphically.

Light Transmission Method

It was possible to scan thin discs (≤15 mm) using only the ambient daylight present in the room when the window blinds were shut. In this situation light entered the room through a narrow window near the roof and was reflected off the white ceiling. For thicker discs (>20 mm) the same lighting arrangement (daylight with window blinds shut) was adequate for the sapwood, but an additional 25 W incandescent lamp was needed to provide sufficient illumination for light transmission through the heartwood. An artefact of the lamp lighting was a pattern in the scanner head movement direction of varying intensity from the 50 Hz electricity supply. It was also found that: (1) ambient external light was much better than fluorescent bulbs; (2) light penetration through heartwood was best when the wood was saturated; and (3) light penetration was better through 25-mm-thick discs than through thicker discs. It was also observed that in order for the background subtraction to work without wood features such as rings or compression wood influencing the difference image, the illumination level had to be adjusted so that there was no blooming (intensity higher than 255 on this scanner). In addition, the image with the template could not be too dark or the difference image could again be influenced by wood features.

Comparison Between Methods

All three methods yielded similar radial trends in spiral grain angle for each of the discs (Figure 10), despite measuring different parts of the annual rings.

Legend:

1,2,3,4 –	**Disc No.**
C –	**Cleaved**
S –	**Scribed**
A,B,C,D –	**Disc Radii**
M –	**Transmitted Light**
m –	**35 mm thick**
t –	**25 mm thick**

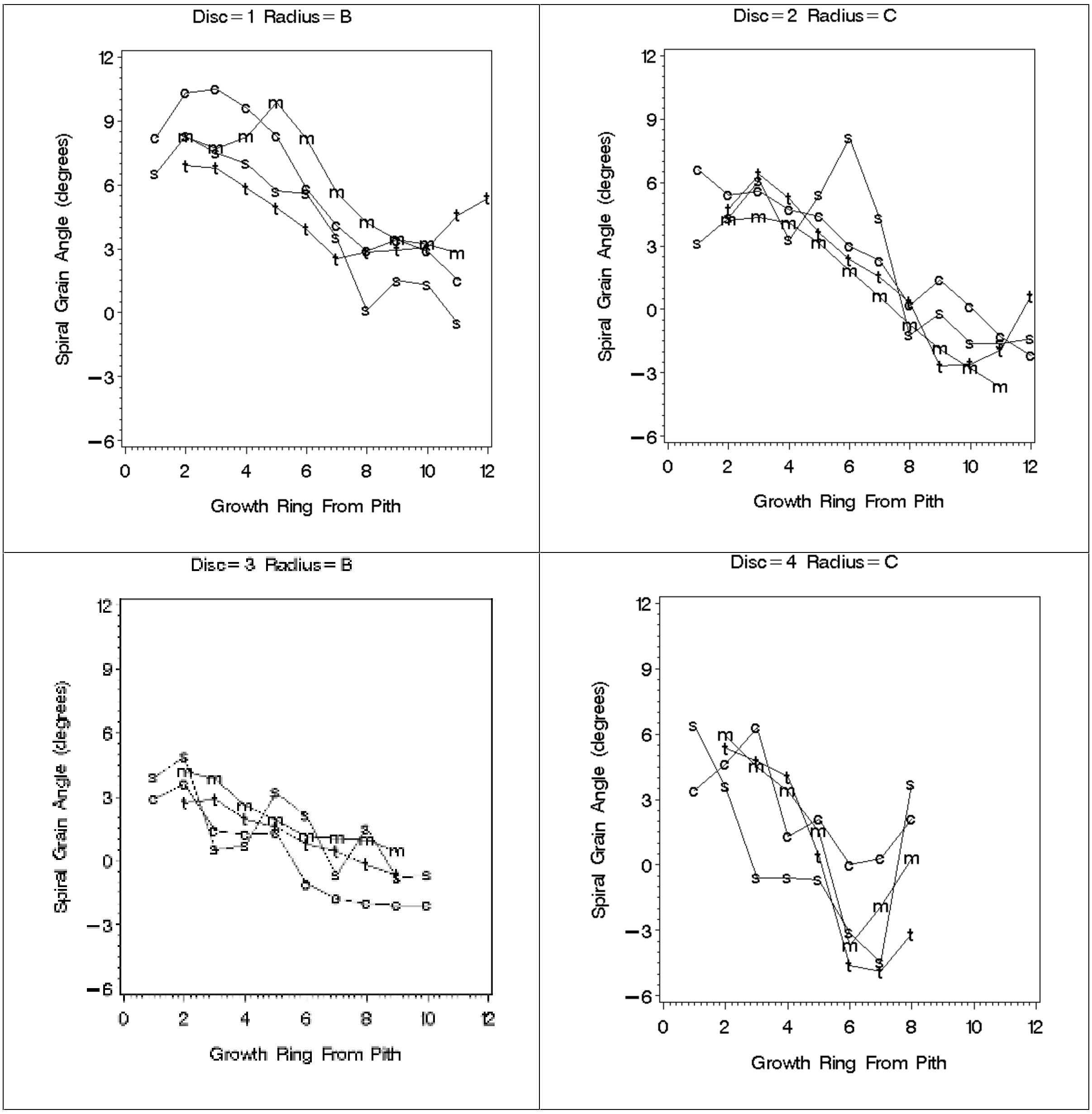

Figure 10: Comparison of Transmitted light and scribed and cleaved values from 4 discs

Overall, the concordance between spiral grain angles obtained from scribing and cleaving was 0.74, while the concordance between values obtained by cleaving and light transmission through 25 mm thick discs was 0.76 (Figure 11).

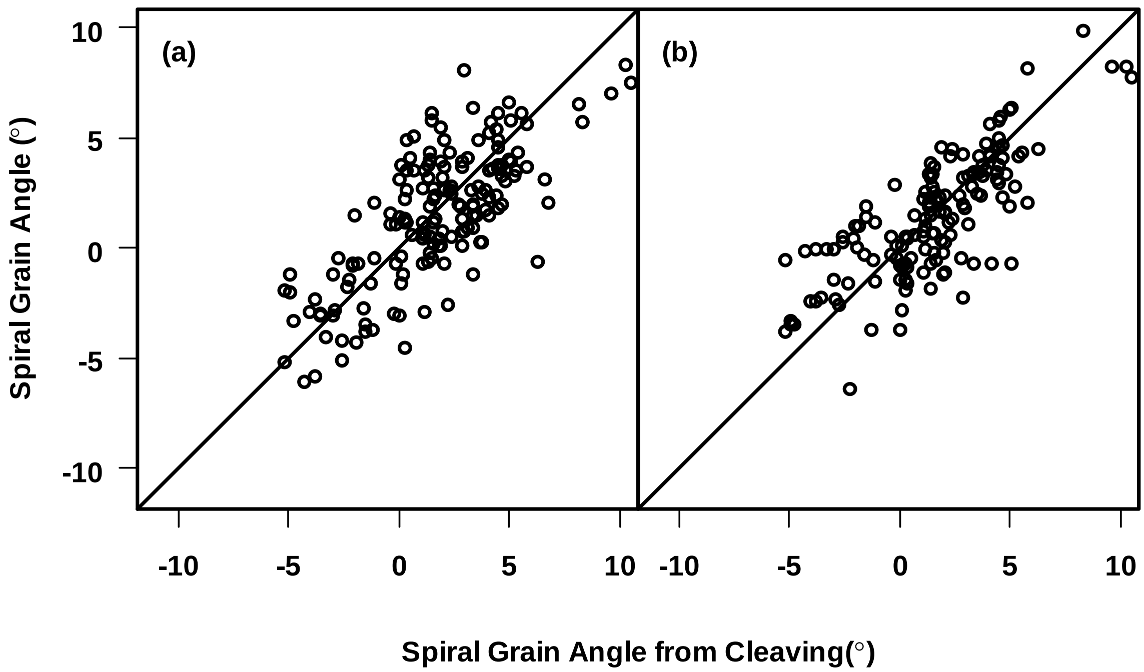

Figure 11: Correspondence between values of spiral grain angle determined from cleaving and those determined from (a) scribing and (b) light transmission. Data are from all radii on the 25 m-thick discs. The diagonal line indicates a 1:1 relationship.

On individual radii the concordance between values obtained by cleaving and light transmission was generally good (>0.7), with the most notable exceptions being radius C and D from disc 4 and radius D from disc 1 (Table 2). The concordance between values obtained by light transmission and those obtained by scribing was considerably lower (0.53). There was a moderate concordance (0.76) between the result obtained from scanning the 25-mm-thick discs and those obtained from the 35-mm discs. These discs were sampled from adjacent positions along the stem, and this result potentially serves to highlight the variation in spiral grain angle that exists over a small distance within the stem. Some caution should be exercised when interpreting these concordance values, as none of the three methods used are considered to be the definitive standard for spiral grain measurement. However, the results do show that the level of agreement between values obtained by light transmission and those obtained by cleaving is similar to that between values obtained by scribing and those obtained by cleaving. This indicates that the light transmission method yields values of spiral grain angle that are consistent with the other two approaches that are commonly used. Qualitatively, there appeared to be a greater amount of ring-to-ring variation in the values of spiral grain angle obtained from scribing than in those obtained from either cleaving or from light transmission, suggesting that they are most susceptible to operator bias. However, both scribing and cleaving are subject to errors due to: (1) alignment of the discs not necessarily being perpendicular to the stem axis; (2) increasing instability of the base of the scribed sample as sections are removed to expose the next ring to be assessed; and (3) measurement at specific points on the annual rings – tangential latewood for scribing and radial latewood for cleaving. Because of the high spatial variation in spiral grain angles[5], the scribing and cleaving methods, which measure spiral grain angle at specific points, often exhibited differences of up to 2 degrees. In this preliminary study, spiral grain angles were calculated for the entire annual ring using the light transmission method. Better agreement with the results obtained from scribing and cleaving may have been obtained if the spiral grain angle was determined only for the latewood portion of the annual ring.

Previous studies have shown high spatial variation in spiral grain angles [5] where it was concluded that using current methods – scribing and cleaving – differences of up to 2 degrees were common. In both cases the overall pattern corresponds to a reduction from pith to bark.

Cleaving is much more rapid than scribing (by a factor of about 10), but gives broadly similar within-disc patterns (Appendix 3).

Figure 10 and 11 show that all three methods are capable of yielding similar grain patterns for the discs, despite measuring different parts of the annual rings. Overall, the scribed values seemed to be more variable than either the cleaved or those derived from light transmission, (Appendix 3 – full data) suggesting scribed data are most susceptible to operator bias.

CONCLUSION AND RECOMMENDATIONS

During this development phase, only radial strips were used for the comparison of methods because of the size limitation in the A4 scanner – thus only four relatively small disc samples were used as source material. Nevertheless, the study enabled a number of conclusions to be reached:

1. The concept of using light penetration to assess spiral grain angles in discs (25 to 35 mm thick) was proven, at least under the conditions tested (natural light).
2. The comparisons of light penetration with scribing and cleaving were favourable, not least because the traditional methods have acknowledged issues of manpower requirements and accuracy. The light approach should be capable of allowing much faster and more accurate data accumulation.
3. The possibility of using complete discs would enhance the ability to assess spatial variation in grain angle, and minimise the effects of sample reference geometry with respect to the tree axis (disc tilt and parallax).
4. Disc thickness appears to be critical, and a 25-mm disc (with minimal thickness variation) has been shown to be required to allow light to penetrate the heartwood, although some samples still show discrepancies (disc 1D – Appendix 3). Further work will be required to ensure that reliable spiral grain values are obtained from both sapwood and heartwood.
5. The light transmission approach should give much more robust values for incorporation into models for predicting wood performance, because values are based on a larger amount of data, covering the entire growth ring along a chosen radius.
6. Spatial resolution can be altered by using different masks.

In order to further develop and refine the approach, the key priorities are: (1) demonstrate the ability to obtain results from larger and older disc samples which contain more resin in the heartwood (using an A3 scanner); (2) optimise the process by investigating a controlled light system; and (3) design and cost an automatic system for large scale grain assessment in conjunction with other automatic disc measurements.

ACKNOWLEDGEMENT

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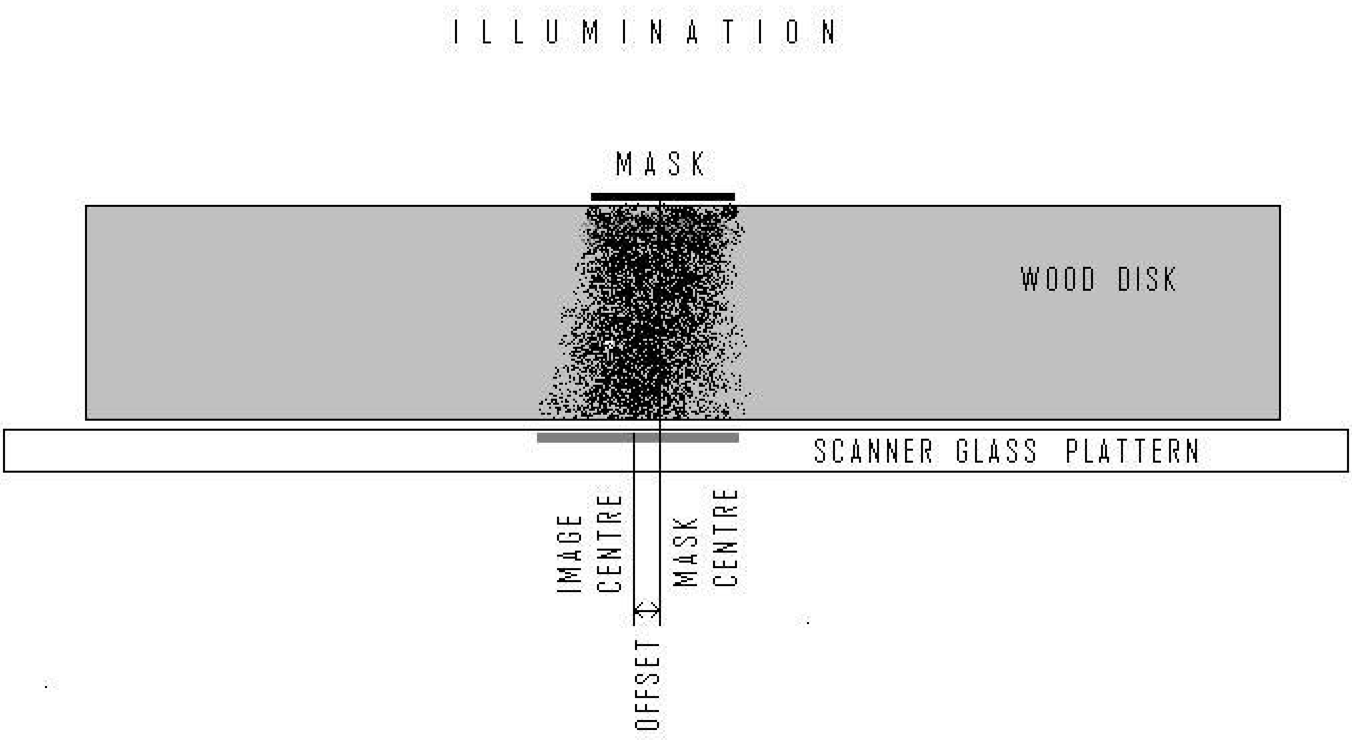
APPENDICES

Appendix 1 – Use of Scanner for Light Penetration Through Discs

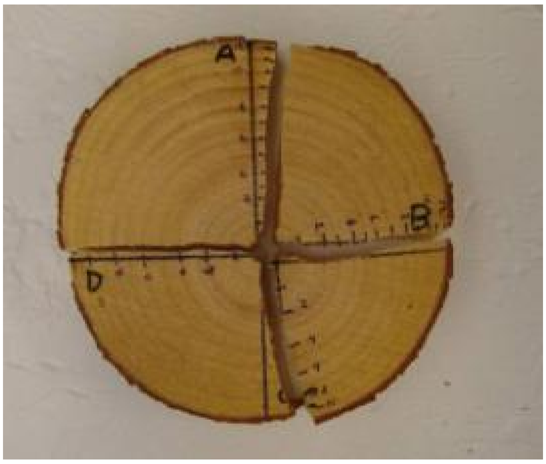
Principle



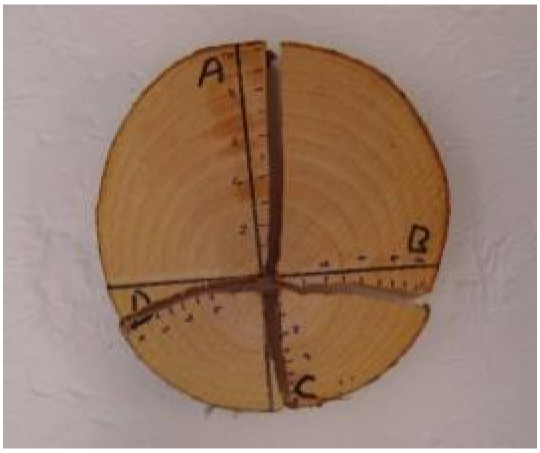
Appendix 2 – Disc Photos

Disc 1- a) Freshly Cut **b Dried, Marked and Cleaved**

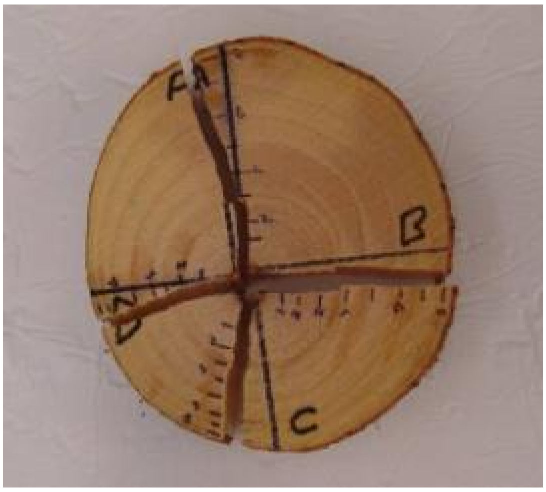
Discs 2-4 Freshly Cut



Disc 2 – Marked and Cleaved



Disc 3 – Marked and Cleaved

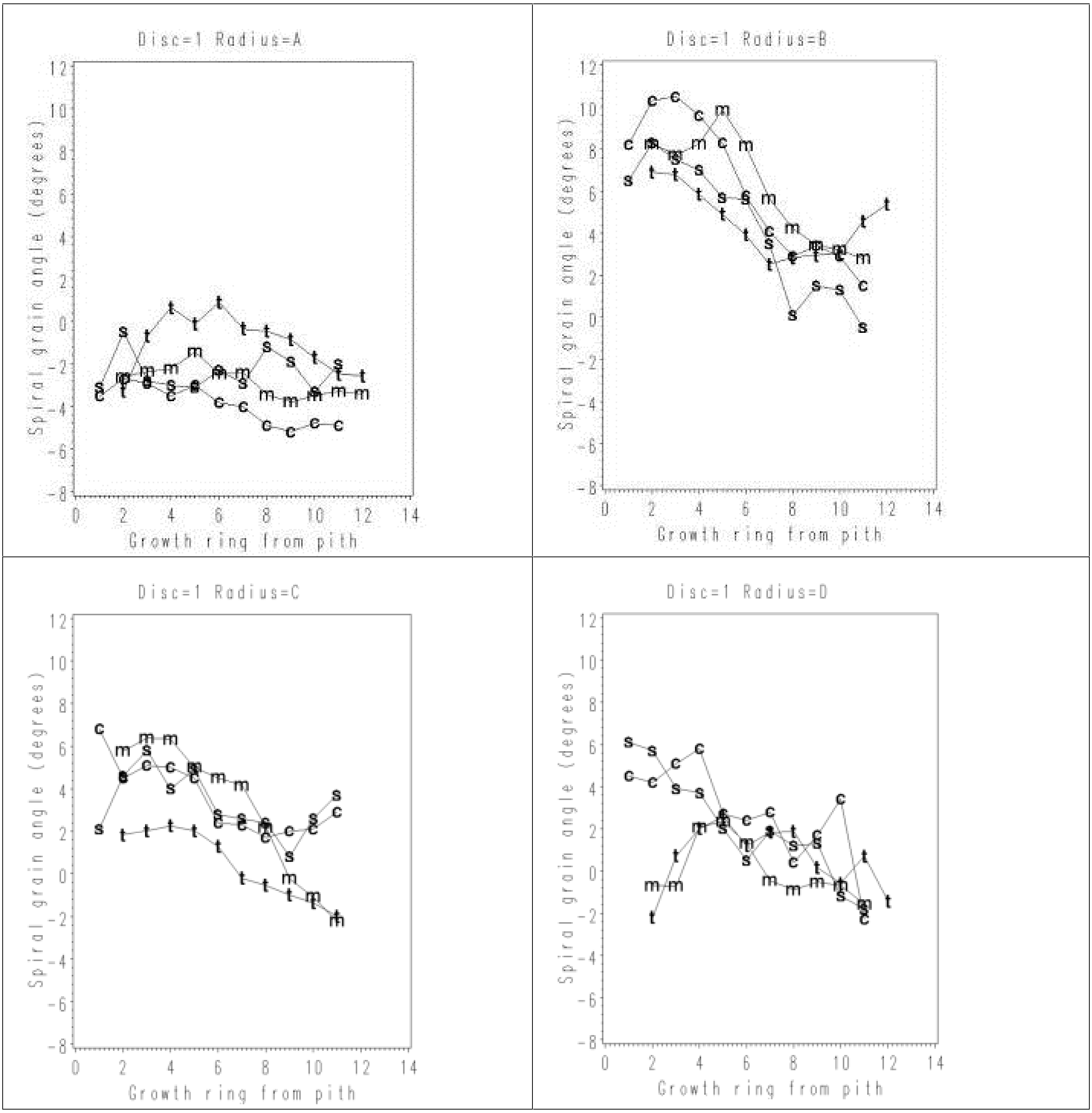


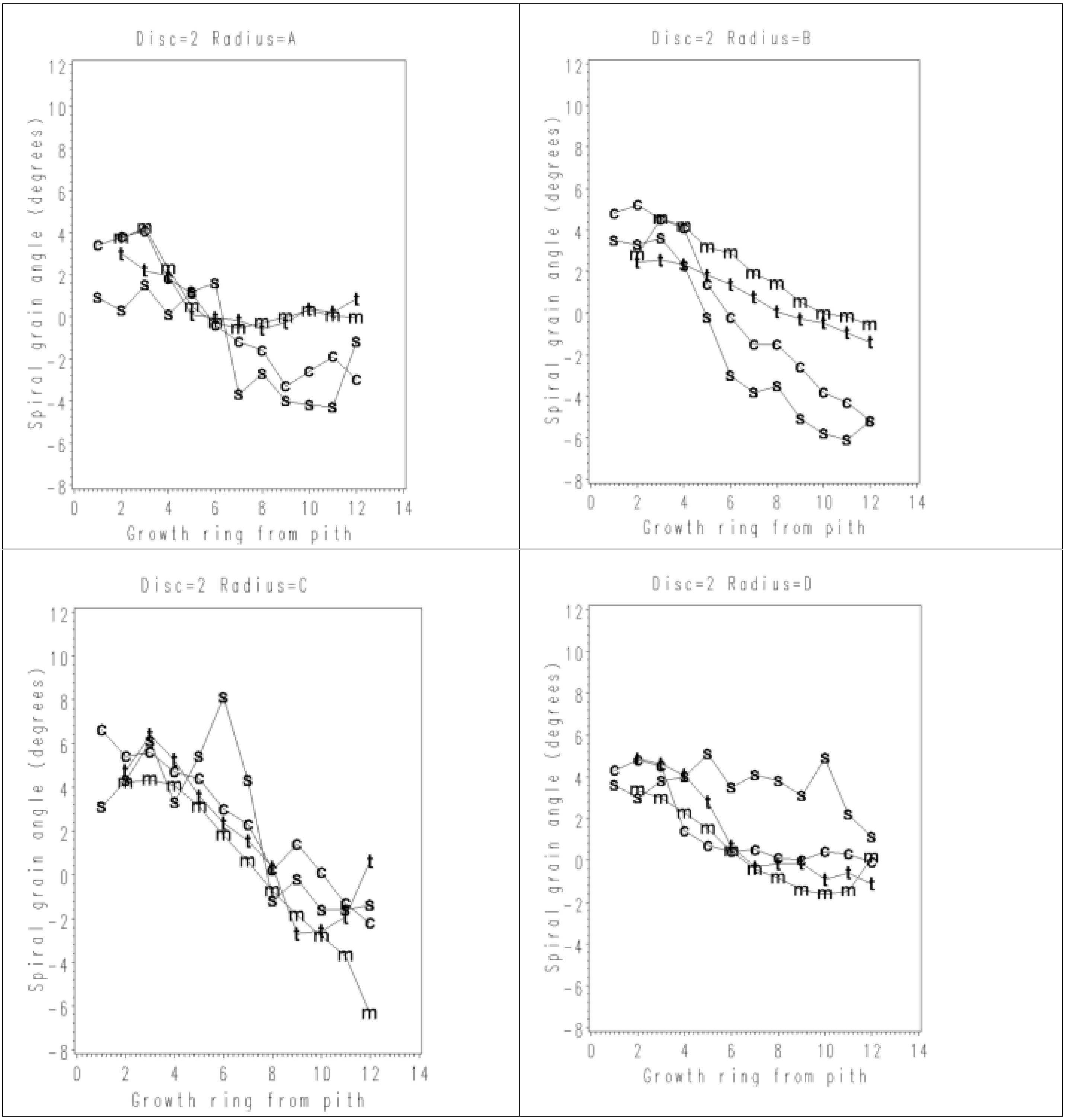
Disc 4 – Marked and Cleaved

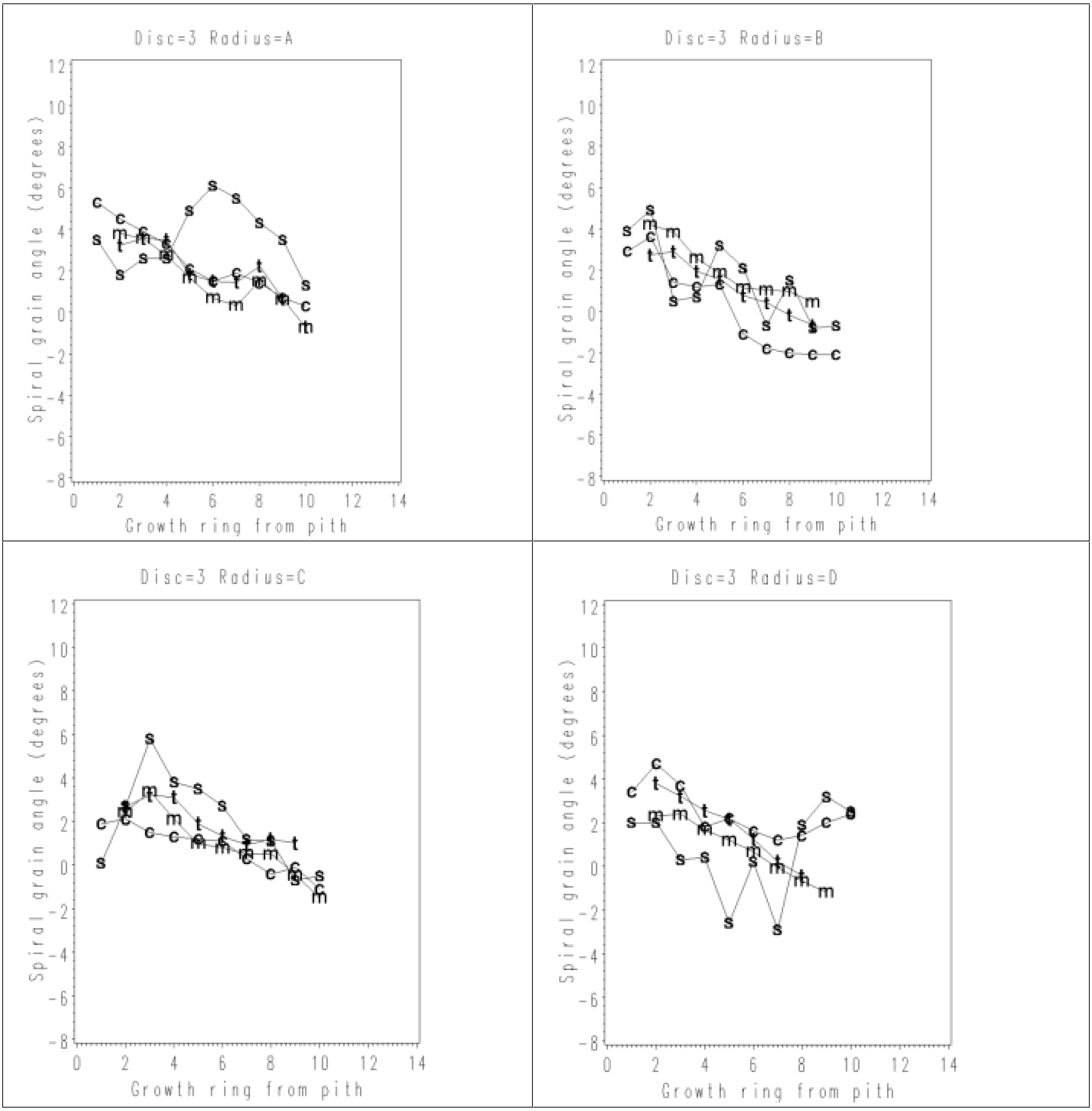
Appendix 3 – Disc Evaluations (Light Transmission, Cleaving, Scribing)

Legend:

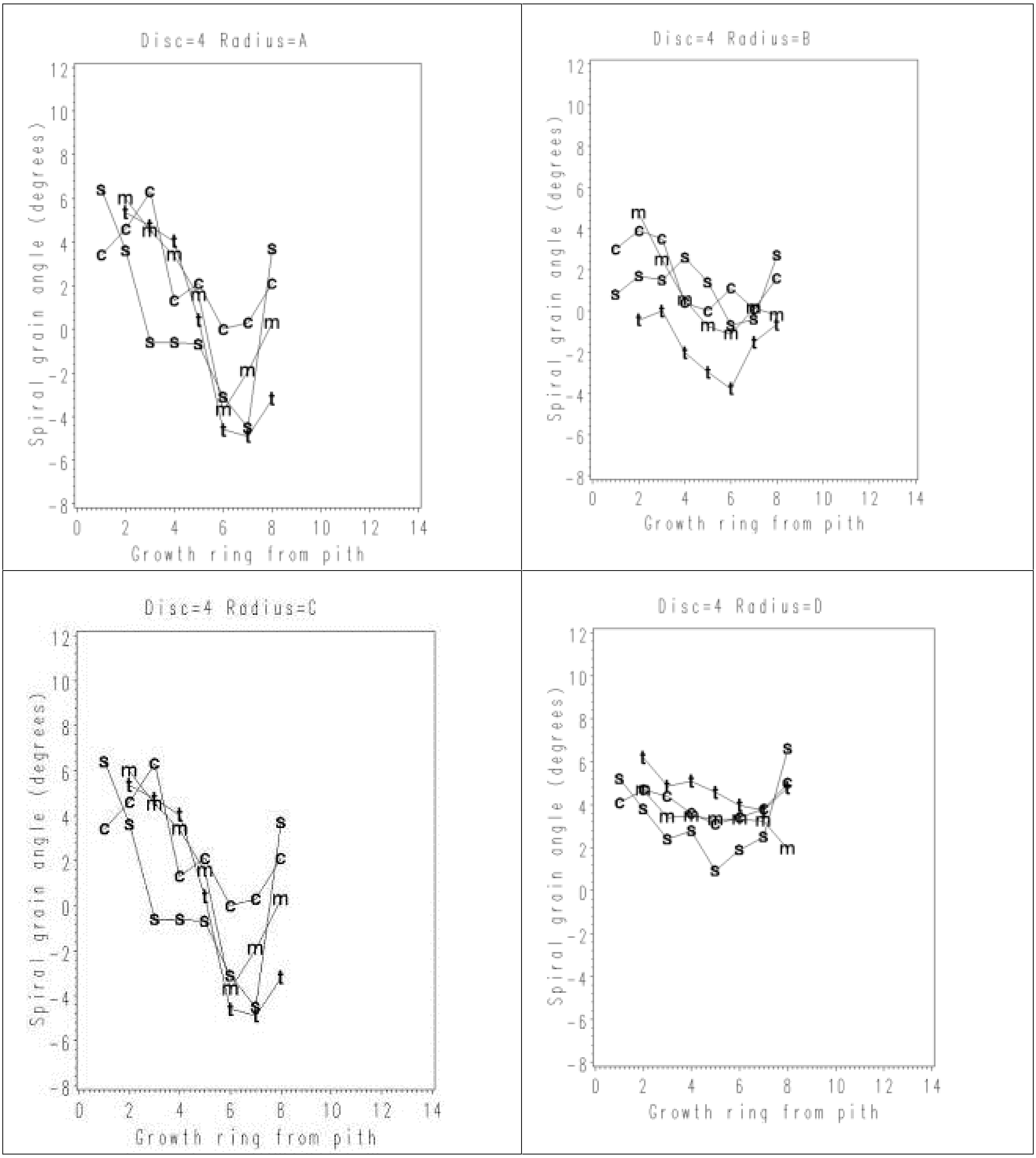
1,2,3,4 –	**Disc No.**
C –	**Cleaved;**
S –	**Scribed;**
A,B,C,D –	**Disc Radii**
M –	**Transmitted Light;**
m –	**35 mm thick;**
t –	**25 mm thick**




Disc=2 Radius=A
Disc=2 Radius=B
Disc=2 Radius=C
Disc=2 Radius=D
Spiral grain angle (degrees)
Growth ring from pith
12
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14



Disc=3 Radius=A
Disc=3 Radius=B
Disc=3 Radius=C
Disc=3 Radius=D
Spiral grain angle (degrees)
Growth ring from pith


Disc=4 Radius=A
Disc=4 Radius=B
Disc=4 Radius=C
Disc=4 Radius=D
Spiral grain angle (degrees)
Growth ring from pith