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CRC for Sheep Industry Innovation

Project 2.2 Whiter lightfast wools

Milestone / Task	Description	Due Date
R4.2.3.1	Report on the depth of light penetration into fleece wool	30/09/09

Summary

Wool is a keratinous fibre that yellows and degrades in sunlight. The tips of the wool fibre which receive the maximum exposure to sunlight and weather during growth are significantly more damaged and yellowed than the wool in the remainder of the fleece. Measurement of the penetration of light through a fleece using a fibre optic probe confirms that the root and mid-section of a simulated Merino fleece is somewhat protected from exposure to light when the fleece is sufficiently long and dense. Methylene blue stain was used to visualise the extent of damage to wool staples.

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CSIRO Materials Science and Engineering, Belmont.

30th September 2009

Measurement of light penetration through fleece wool and wool damage

1 INTRODUCTION

Wool is a fibrous protein that yellows and degrades in sunlight. The loss of tensile strength after exposure to UV light below 350 nm is due to oxidation and hydrolysis of the proteins which results in the cleavage of disulfide cross-linkages in the fibre. UV radiation also induces the production of reactive oxygen species which react with certain amino acid residues to form yellow products.

The degree and rate of wool yellowing in sunlight depends on the intensity and duration of exposure, the spectral distribution, and the initial yellowness (Y-Z) of the wool (Lennox and King, 1968). The extent of yellowing and damage also depends on the area on the sheep where wool is grown. The scoured wool colour of wool taken from the back is yellower than wool taken from the flanks (Holt et al., 1994) and wool from the belly has negligible damage when compared to back wool (Holt et al., 1990).

The tips of the fibre receive the maximum exposure to sunlight and the environment and are damaged and yellowed to a greater extent than the root and middle section (Zahn and Blankenburg, 1962). Differences in the depth of wool damage are largely attributed to fleece density since tip damage in open fleeces is more extensive than for denser fleeces (LeRoux, 1958, Review, 1966, Anon, 1966). The portion of the fleece which is close to the skin is protected when the staples grow longer and when the fleece is sufficiently dense to prevent light penetration.

The intensity of midday, midsummer sunlight through a simulated Merino fleece was measured using a fibre optic probe to estimate the penetration of solar radiation along the length of the fibre. The percentage of the total direct sunlight that reaches the base of a 100 mm long simulated Merino fleece was 1%. The section of the fibre from the root to well 60 mm from the root, was protected from exposure. For comparison, light penetration through the wool on the back of a live mature Finn ram, at approximately half the depth of the fleece, was measured and estimated to be 2% of the total sunlight.

The fibre damage of a control wool and 17 samples of fleece wool sourced from the Sheep CRC Information Nucleus (IN) flock was visualized using a methylene blue stain. Weathered tips have a higher concentration of cysteic acid than the remainder of the fibre causing the tips to be more hydrophilic and thus have a greater affinity for the dye (Louw, 1960). Also, some of the disulfide cross-linkages in the cuticle are broken which results in damage to the overlapping scale cells facilitating dye access to the fibre (Holt et al., 1990).

Methylene blue absorption is strongly genetically correlated with suint and moisture indices as well moderately genetically correlated with dust penetration and negatively correlated to wool colour (Dowling et al., 2006). The intensity of staining of wool samples from the IN flock was rated against a colour scale and was positively correlated to the dust score, dust penetration and the calcium and magnesium content.

2 EXPERIMENTAL

2.1 Wool samples

Control wool
A ram's fleece was sourced from Lance Mann, 13 Mayfair Drive, Newtown, Victoria, 3220 has been used as a control wool in this work (King and Millington, 2008).

TMC Wool
Fleece wool, Brand HF/Merton Vale was supplied by The Merino Company (TMC), Melbourne

Sharlea wool
A fleece sample from a coated and shedded Saxon sheep (Sharlea) was supplied by Ms Tricia Pollard of Burrabliss Farms, Box 229. Lake Boga, Victoria 3584.

The staples of control, TMC and Sharlea wool were cut along the length into 3 equal parts representing the tip, mid-section and root of the fibre and were scoured using the method developed for maximizing whiteness described previously (King and Millington, 2008, King and Millington, 2009b)

Sheep CRC Information Nucleus Flock samples
Greasy mid-side wool samples were sourced from the archived samples of the Sheep CRC IN flock retained at the South Australian Research and Development Institute (Darryl Smith, SARDI). The samples were selected based on their trace metal content and included both tip shorn wool from Rutherglen, Cowra, Struan and Katanning and normally shorn wool from Kirby, Turretfield and Hamilton.

2.2 Measurement of light penetration through fleece wool

The sampling procedure adopted by CSIRO Livestock Industries (Jen Smith) requires collecting 100 g samples of an average staple length of 80 mm from an area of approximately 250 x 250 mm on the midside of a sheep. An estimate of the weight and density of wool required to simulate an average Merino fleece with one year of growth was calculated from this method.

The bottom of a 9.5 cm cubic plastic box was lined with densely woven black fabric to eliminate transmission of light through the bottom of the box. A hole was pierced in the centre of the bottom of the box and the fabric to allow an Avantes AvaSpec 3648-USB2 spectrometer probe to be pushed through the wool (www.avantes.com). The probe was encased in plastic tubing marked in 5 mm increments which protected and supported the probe to maintain a 90^o angle to the base of the box. Eighteen grams of greasy wool with a staple length of 100 mm were collected from a full Merino ram's fleece and were aligned and distributed evenly in the box (Figure 1). The simulated fleece was exposed to full midday midsummer sun in Geelong, Victoria, latitude 38^o 9' 29''S, longitude 144^o 21' 0''E. The light intensity was measured using a fibre optic probe with an Avantes AvaSpec 3648 spectrometer and AvaSoft© 7.2 software in scope mode.

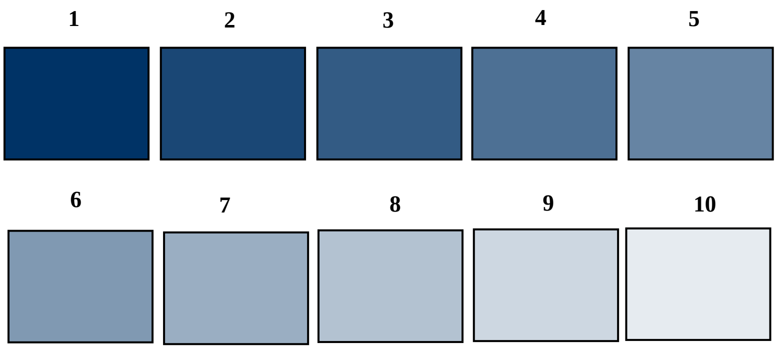
Figure 1 Simulated fleece

The intensity of midday, midsummer sunlight was measured through the fleece of a mature Finn ram with approximately 18 months wool growth. The probe placed on the back, approximately half through the fleece which was approximately 120 mm long.

2.3 Methylene blue staining

Scoured wool was wet out with a solution of Leophen M and the excess fluid was removed before immersion in a 0.1% solution of Methylene blue for 5 minutes. The samples were rinsed in water and air dried.

The intensity of the colour of stained samples was rated against a colour scale from 1-10, each unit representing a colour difference of 10%.



2.4 Colour measurement

The colour of wool samples packed to constant density in PMMA cells was measured using the CSIRO procedure described previously (King and Millington, 2009a)

2.5 Dust scores

Fleeces of sheep in the Sheep CRC IN flock were rated in the field for dust penetration using the scoring criteria outlined in the Sheep Genetics Visual Sheep Scores.
http://sheepgenetics.org.au/ViewImage.aspx?ITEM=105&NAME=VisualSheepScores.pdf

Staples of 17 selected samples from the Sheep CRC IN flock were also rated using this method.

2.6 Trace metal analysis

The method and results of trace metal analysis has been reported previously (King and Millington, 2009b)

3 RESULTS AND DISCUSSION

Fibre damage and yellowing resulting from exposure to UV have been identified as significant problems to the wool industry. The loss of tensile strength due to weathering results in poor fibre quality and the tips of the wool can be weakened to the extent that they are likely to break off during early stage processing (Walls, 1963). The damaged tips are more hydrophilic due to photooxidation of disulphide cross-linkages and have a different affinity for dyes than the root and mid-section of the fibre which can result in uneven (tippy) dying (Holt et al., 1990). Also, wool yellowed by exposure to UV is a poor substrate if bright white, pastel or brightly coloured products are required.

The UV wavelengths of sunlight between 280-380 nm significantly damage wool. Chromophores within the fibre absorb radiation in this range of wavelengths and yield yellow products (Millington 2006). Also, the disulfide bonds of the cystine residues in wool cleave at wavelengths below 350 nm making the wool fibre weaker. The spectral irradiance of terrestrial sunlight is shown in Figure 2.

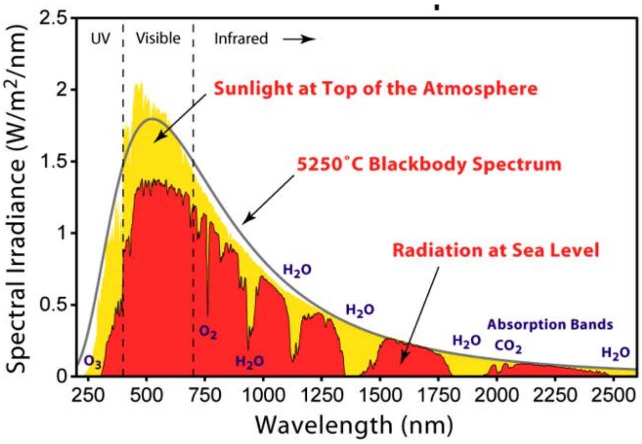


Figure 2 Spectral Irradiance of sunlight

sourced from http://www.globalwarmingart.com/wiki/Image:Solar_Spectrum_png

The yellowness of the tips is greater than the root and mid-section of the fibre (Table 1). The difference in yellowness (Y-Z) in processing lots between whole fibres or fibres with tips removed is significant (Hoare and Thompson, 1974). When wool that was used as a control fibre was scoured with the tips either removed or included, the yellowness (Y-Z) was 3.2 without the tips and 4.4 with the tips. This was confirmed by comparing the yellowness of the root section of the fibre to the colour of the entire fibre using a selection of eight scoured wool samples from sheep in the Sheep CRC IN flock (Figure 3). However, since the majority of the tips are broken off and removed during commercial early stage processing (Walls, 1963), the colour difference may be less when the wool is at the top stage.

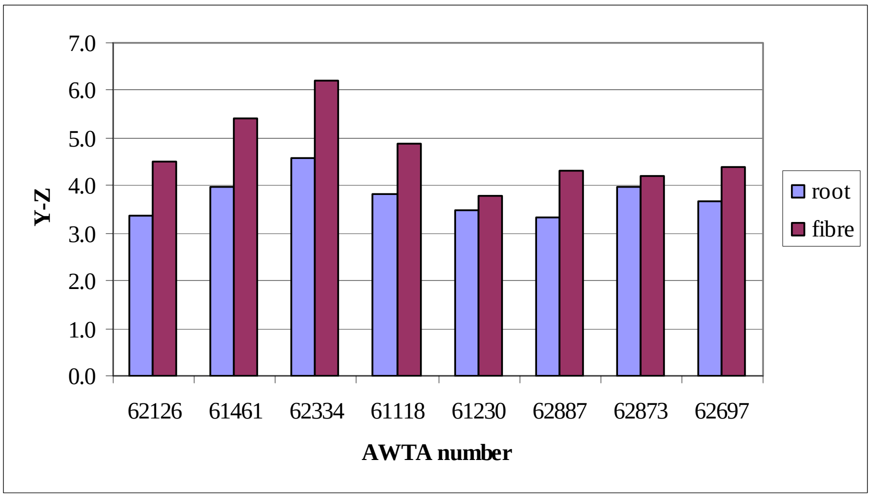


Figure 3 Comparison of the yellowness of the entire fibre and the root section

Coating sheep is a successful method used to protect wool from sunlight and dust penetration and can increase the rating of style by one unit (Hatcher et al., 2003). The wool is whiter with less tip damage and the fleeces are cleaner. Sharlea Saxon sheep (Burrabliss Farms) are rugged and shedded. The wool does not exhibit the same extent of tip damage as pasture raised sheep and the colour of the wool is relatively consistent along the length of the fibre (Table 1).

		Y-Z
Control wool	root	3.8
	mid	3.7
	tip	6.3
TMC wool	root	4.8
	mid	3.8
	tip	6.2
Sharlea wool	root	4.7
	mid	4.4
	tip	3.9

Table 1 Yellowness (Y-Z) of wool from sheep exposed to the environment (control and TMC wool) and from shedded and coated fleece (Sharlea)

While the extent of tip damage is dependant on climate and the duration and intensity of exposure to sunlight, it is also related to the density of the fleece (LeRoux, 1958). When staples form and the fleece is sufficiently dense, the portion of the fibre which is close to the skin is well protected from sunlight. The roots and mid-section of a more compacted fleece are less damaged from sunlight than the tips, whereas a fleece that is more open has less variation in damage along the fibre (Davidson, 1996). The density of the fleece also offers protection from water penetration (Lennox, 1938). Fleece density varies between sheep breeds (Narayan 1960) and between different areas of the body, since the follicle density is greatest at the back of the neck and decreases from anterior to posterior and from the back to the belly

(Young and Chapman, 1957). Merinos have the fullest fleeces of all sheep breeds with a follicle density of 88 per mm^2 for a medium wool sheep (19.6-22.9 μm MFD) compared to Corriedale sheep which have a follicle density of 31 per mm^2 and Scottish Blackface with 7 per mm^2 (Carter and Clarke, 1957a, Carter and Clarke, 1957b). High fleece weight, clean scoured yield and low fibre diameter are genetically related to follicle density (Hynd et al., 1996). Selection for these desirable traits will also ensure the that the effect of weathering is minimized.

3.1 Light penetration through a fleece

The penetration of midday midsummer sunlight through a simulated fleece was measured using a fibre optic probe between 290-750 nm, which includes most of the visible spectrum (400-800 nm), the wavelength of maximum sunlight intensity (531 nm) and some of the UVB region (280-320 nm) (Figure 4). The required weight per unit area of 100 mm long fleece wool was estimated from the method used by CSIRO Livestock Industries when collecting midside samples from Merino sheep. Light intensity was measured incrementally along the fibre as the probe was drawn down through the fleece. This method was employed because wool tangled in the probe assembly and masked the sensor when the probe was pushed upwards through the sample. The wool was repositioned after the probe was initially drawn down to simulate a closed fleece and to prevent the formation of a tunnel. The simulated fleece was in the upright position during Trials 1 and 2 to estimate the penetration of light through the back wool of the sheep and then tilted to directly face the sun for Trials 3 and 4, to guarantee the maximum possible exposure to light. The percentage of the total direct sunlight that reaches the base of a 100 mm length fleece is 1% and approximately 5% at 60 mm from the root end of the fibre. The light penetration was also measured in Trial 4 while the simulated fleece was facing the sun and when the wool was left open as the probe was drawn down to approximate the parts of the fleece on a live sheep that open as the sheep moves. While light penetration is greater under these conditions than in a closed fleece, the intensity of light at 20 mm from the root is approximately 20% that of the tip.

The fibre optic probe was placed on the back of a live Finn ram approximately 60 mm from the tip of the 120 mm fleece. Although the percentage of the total sunlight reaching the mid section of the fleece varied from 0 to 9% over the range of 260-800 nm, the average was 2%. Finn sheep have a fleece density of approximately 20 follicles per mm^2 (Fahmy, 1987) therefore the penetration of light through a denser Merino fleece is likely to be less.

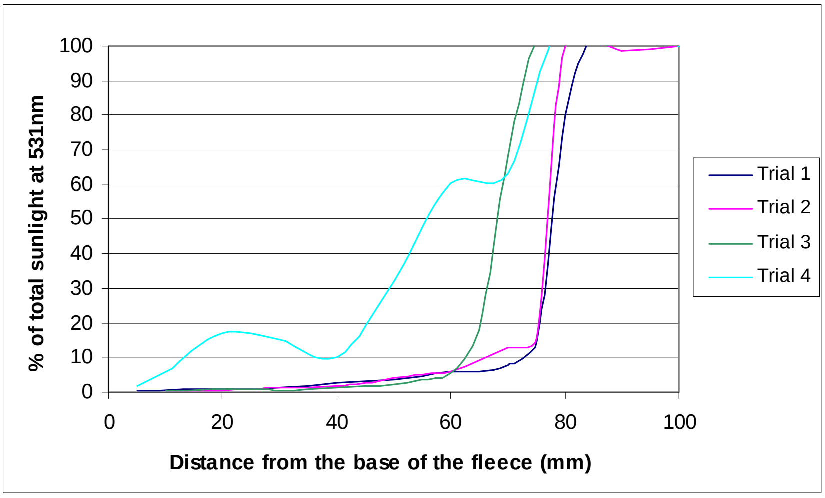


Figure 4 Penetration of sunlight through a simulated Merino fleece

In contrast, sheep that had shorter fleeces over the summer period had wool that was less weathered than wool on sheep that were shorn in the winter months since a longer fleece is more likely to fall open and expose more of the fibre to weathering (Steenkamp et al., 1970).

3.2 Methylene blue staining

Methylene blue (CI Basic Blue 9) is a biological stain and has been used to visualize the extent of damage to the tips of wool fibres (Lennox, 1938, Elmquist and Hartley, 1935) and the degree of damage to the entire fibre caused by high levels of suint (Dowling et al., 2006). The oxidised tips have a greater affinity for the dye and are stained to a greater extent than the root and mid-section of the fibre (Zahn and Blankenburg, 1962). However, methylene blue absorption is also positively correlated with suint and moisture indices and an increase in the uptake of the dye in the mid section and root of the fibre has been attributed to alkaline damage from high levels of suint (Dowling et al., 2006). Suint content is also genetically correlated to wool colour (James et al., 1990) and with the propensity for wool to yellow (David and Lead, 1980, Aitken et al., 1994).

Wool that was designated as control wool, and which was used to prepare a simulation of a Merino fleece, was scoured and then stained with methylene blue (Figure 5). The staples were randomly selected from the entire fleece and the location of where the wool was grown on the sheep was unknown. The intense blue colour extended approximately 30 mm from the tip of the 100 mm staple and represents the portion of the fibre that receives the maximum amount of sunlight exposure (Figure 4). For comparison, seventeen samples from the Sheep CRC IN flock were also scoured then stained with methylene blue. The depth of intense staining of the tips ranged from 7.5 to 30 mm (Appendix 1 and 2). Tips of normally shorn wool representing 10-11 months of wool growth were more damaged than tip shorn wool with 6-7 months of growth. An alkalii solubility test that is used to evaluate the degree of damage to wool confirms that damage to a typical Merino fleece extends to 13mm (0.5in) from the tip and can extend to 38 mm (1.5in) in fleeces of lower densities (LeRoux, 1958).

Figure 5 Control wool stained with Methylene blue

The depth of colour of the stained mid-section of the wool fibres was rated from 1-10 against an arbitrary colour scale. There was variation in the extent of intense staining along the tips as well as the intensity of the colour of the mid-section of the fibre.

The positive correlation of yellowness (Y-Z) with magnesium, calcium and manganese has been reported previously (King and Millington, 2009b). This study of 17 wool staples indicates a correlation between yellowness and dust score and the intensity of staining of the mid-section of the staples (Table 2). If trace metals present in dust catalyse photoyellowing, dust penetration and fleece density are important wool traits. The results also concur with the observation that methylene blue staining is an indicator of suint content which is phenotypically correlated to yellowness (Dowling et al., 2006). The minerals calcium and magnesium are major components in suint (Table 3) (Aitken et al., 1994) and are highly correlated to yellowness, suggesting that suint content strongly influences the colour of wool in the mid-section of the fibre.

	Y-Z	Sheep dust score	Staple dust score	Dust penetration (mm)	Extent stain (mm)	Stain rating of tips	Stain rating of mid fibre
Ca	0.86	0.40	0.56	0.77	-0.16	0.34	0.68
Cu	-0.13	-0.06	-0.01	-0.15	-0.09	0.26	0.24
Fe	-0.23	0.02	0.05	-0.05	0.32	-0.06	0.02
Mg	0.88	0.36	0.52	0.80	-0.05	0.30	0.58
Mn	0.57	0.67	0.62	0.55	-0.27	0.22	0.47
S	-0.42	-0.10	-0.13	-0.25	-0.26	-0.30	-0.40
Zn	-0.41	-0.26	-0.22	-0.15	-0.08	-0.41	-0.38
Y-Z		0.52	0.64	0.83	-0.09	0.40	0.59
CRC dust score			0.72	0.43	0.03	0.43	0.62
Staple dust score				0.67	-0.20	0.39	0.61
Dust penetration (mm)					0.01	0.42	0.60
Extent of tip stain (mm)						0.21	-0.09
Stain rating of tips							0.43

Table 2 Correlations of trace metal content, dust score and penetration, and extent and rating of Methylene blue staining. Highlighted data indicates are correlation >0.5

(mg kg^{-1})	Mean	s.e.m	Range
K (g kg^{-1})	6.09	0.971	0.41-19.92
Na	354.4	53.5	72.0-1616.0
Ca	109.7	12.6	29.0-365.0
Mg	21.64	4.16	3.0-108.0
Cu	0.395	0.020	0.16-0.72
Zn	0.969	0.106	0.08-2.96

Table 3 Concentration based on greasy wool weight of minerals of fresh suint from wools with a range of resistance and susceptibility to yellowing (n=36) (Aitken et al., 1994)

4 CONCLUSIONS

Approximately 60% of the wool fibre on a Merino sheep with 12 months wool growth is protected from the damaging effect of sunlight. The extent of damage to a selection of wool staples from the midside samples of Merinos in the IN flocks was visualized using methylene blue stain, and measured to be 10-30 mm from the tip.

The intensity of methylene blue staining of the mid-section of the fibre was correlated with yellowness (Y-Z), calcium and magnesium contents and the dust score and dust penetration depth.

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APPENDIX 1

	Sheep ID	AWTA ID	Source	Ca	Cu	Fe	Mg	Mn	S	Zn	MFD	Y-Z	Wool growth (months)	Staple length (mm)	CRC dust score	Staple dust score	Dust penetration (mm)	Depth of tip stain (mm)	Stain rating of tips	Stain rating of mid fibre
normal shear	26IN012007070547	61118	Kirby	174	6	9	10	0.8	32500	93	19.9	9.3	10-11	70	2	2	20	10	10	5
	26IN012007070717	61127	Kirby	45	6	19	2.7	0.5	31750	119	14.1	6.9	10-11	65	2	1-2	<10	15	9	2
	26IN012007070432	61230	Kirby	52	5	22	5.9	0.7	35450	126	15.8	6.6	10-11	60	2	2	10	10-15	8	2.5
	26IN052007070393	62056	Hamilton	45	6	14	2.8	0.1	33600	115	15.6	8.1	10-11	65-70	3	3	30-40	20-30	10	5
	26IN052007070412	62091	Hamilton	173	8	29	11	1.3	36150	123	13	6.3	10-11	50-60	3	3	20-30	15-20	10	4
	26IN052007070438	62126	Hamilton	215	8	59	32	1.9	31500	133	15	7.5	10-11	65	3	3	25	20-25	10	3
	26IN072007070300	62334	Turretfield	534	11	36	48	2.9	30150	89	20.9	9.7	10-11	90	4	5	20	20-15	10	7
	26IN072007070138	62424	Turretfield	1036	7	25	122	6.2	29050	95	17.7	13	10-11	70	3,2	4	50	15-20	10	5
	26IN072007070202	62440	Turretfield	1028	6	16	120	5.6	28950	85	19.1	15	10-11	90	4	4	50	10-15	10	7
tip shorn	26IN032007000974	61461	Cowra	43	4	9	2.2	0.8	31650	84	19.5	10	6-7	50	3	4	25-30	10-20	10	2
	26IN032007000888	61481	Cowra	536	5	8	46	13	38750	122	20.3	11	6-7	60	5	5	35	7.5	10	5
	26IN042007071161	61553	Rutherglen	23.5	7	16	1.5	0.7	34550	102	15.1	7.3	6-7	40-45	2	3	15-25	10	10	2.5
	26IN082007070793	62685	Katanning	134	7	23	7.8	0.7	38300	139	14.8	6.7	11-12	60	1	3	25	7.5-1	9	2.5
	26IN082007070216	62688	Katanning	833	8	13	114	1.5	34600	133	17.7	14	11-12	70-75	none	4	40-45	15	10	4
	26IN082007070410	62697	Katanning	311	6	8	22	0.6	31700	99	27.7	9.3	11-12	100	3	4	30	10	10	5
	26IN062007077730	62873	Struan	484	15	20	35	0.7	32800	124	15.5	7.1	10-11	60-70	2	2	10-15	7.5-10	10	4
	26IN062007077792	62887	Struan	51.1	6	9	3.8	0.1	34500	98	16.9	7.3	10-11	70-75	2	1	10	25	10	2

Highlighted data indicates the criteria for sample selection

APPENDIX 2

ID 26IN072007070300
Turretfield, AWTA ID 62334

ID 26IN072007070138
Turretfield, AWTA ID 62424

ID 26IN072007070202
Turretfield, AWTA ID 62440

ID 26IN062007077730
Struan, AWTA ID 62873

ID 26IN012007070432
Kirby, AWTA ID 61230

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Kirby, AWTA ID 61127

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Kirby, AWTA ID 61118

ID 26IN032007000974
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Cowra, AWTA ID 61481

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Struan, AWTA ID 62887

ID 26IN082007070216
Katanning, AWTA ID 62688

ID 26IN082007070410
Katanning, AWTA ID 62697

ID 26IN052007070438
Hamilton, AWTA ID 62126

ID 26IN052007070393
Hamilton, AWTA ID 62056

ID 26IN052007070412
Hamilton, AWTA ID 62091

ID 26IN082007070793
Katanning, AWTA ID 62685

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