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Acid Sulfate Soils Centre

Soil patterns on bra fabrics dragged or placed on different soil surfaces using image analyses: Accessory data from field experiments

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Cover image

A human rescue dummy dressed in a clean padded bra is dragged three metres across a natural soil site at the Royal Tasmanian Botanical Gardens during a soil transference experiment. Lifted by the legs, the dummy is dragged on its back in one of two different soil transference experiments.

Photographer: Kathleen Murray @ 2014 Acid Sulfate Soils Centre, The University of Adelaide

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EXECUTIVE SUMMARY

This technical report provides substantial accessory information and data for the following paper submitted to Forensic Science International: "*A study of the patterns produced when soil is transferred to bras by dragging action: the application of digital photography and image processing to support visible observations*".

In a 2012 homicide case, the results of soil examinations became key forensic science evidence. While the source of trace soil evidence was not in question, the method by which soil was deposited on the victim's clothing became a significant factor. It was alleged that the victim was dragged and that this was the mechanism of transfer. However, with no published research available to identify characteristics typical of dragging, the court could not be satisfied that some other mode of transfer, such as placing, had not occurred. The work described in this report was undertaken to provide knowledge that would assist in interpretation of soil transfer in criminal events.

The soil evidence in the homicide case was principally located on the victim's bra. To create the most realistic experiments, a human rescue dummy dressed in a bra was used in these STEs undertaken in the field. The following two soil types were used to conduct the field experiments and corresponding laboratory experiments at the Royal Tasmanian Botanical Gardens (RTBG): (i) anthropogenic soil and (ii) natural soil.

The nylon-elastane bra worn by the rescue dummy was padded with a sock filled with rice (protected by a plastic cliplock bag with the smooth side facing out and all corners taped to the back of the bag). This enabled the fabric surface to be smooth and firm, as if worn by a woman. These experiments explored and documented patterns of soil transference when a female victim is dragged across a soil surface. Soil transferred onto the bras shoulder straps and bra cups became the focus of data analysis. Shoulder straps were chosen because this area retained the most soil evidence in the aforementioned murder case; even after three years of rigorous testing by many forensic science teams. Bra cups provided a large area to recognise and identify different soil transfer patterns; first documented by Murray et al (2015). Forty-eight (48) experiments used anthropogenic and natural soil locations in the field at the Royal Tasmanian Botanical Gardens, Hobart, Tasmania, Australia. Both wet and dry soil at two locations were tested.

Soil transfer patterns produced during experiments that replicated a clothed victim being either placed on or dragged across a soil surface, were first identified in situ by naked eye alone, or with the option of simple light microscopy. It was discovered that photographing soil transfer patterns in situ on clothing, using a basic 14 megapixel digital camera, provided a pristine and reliable forensic scientific record of this trace soil evidence. Once clothing is moved, results indicate that loose soil particles that help define the often very delicate soil transfer patterns will be lost; or end up in the bottom of an evidence bag.

Some soil transfer patterns were present in both transfer methods; whilst others clearly identified an exact method of transfer.

1. LOCALITY, PROPERTIES AND CLASSIFICATION OF SOILS

Summary

This section summarizes the locality, properties and classification of the soil types and soil materials used in the field and laboratory dragging experiments in accordance with The World Reference Base (WRB) and The Australian Soil Classification (ASC).

The following two soil types (two sites and soil profiles) were used to conduct the field experiments and corresponding laboratory experiments at the Royal Tasmanian Botanical Gardens (RTBG), Lower Domain Rd, Hobart, Tasmania, Australia (Figure 1-1):

(i) **Anthropogenic soil from Rose Garden Path:** the original natural soil was excavated and removed before adding 70-80mm of road base followed by a gravel surface layer 40-50mm thick (Reid 2012) and sampled from 0-10cm depth (Figure 1-2 Photograph of the Rose Garden path in the Royal Tasmanian Botanical Gardens.

(ii)).

(iii) **Natural soil near the south east boundary:** the surface layer of the undisturbed soil profile consists of dry fallen undecomposed leaves (0-10cm) and overlies a dark organic-rich mineral soil horizon (0-10cm) (Figure 1-3.

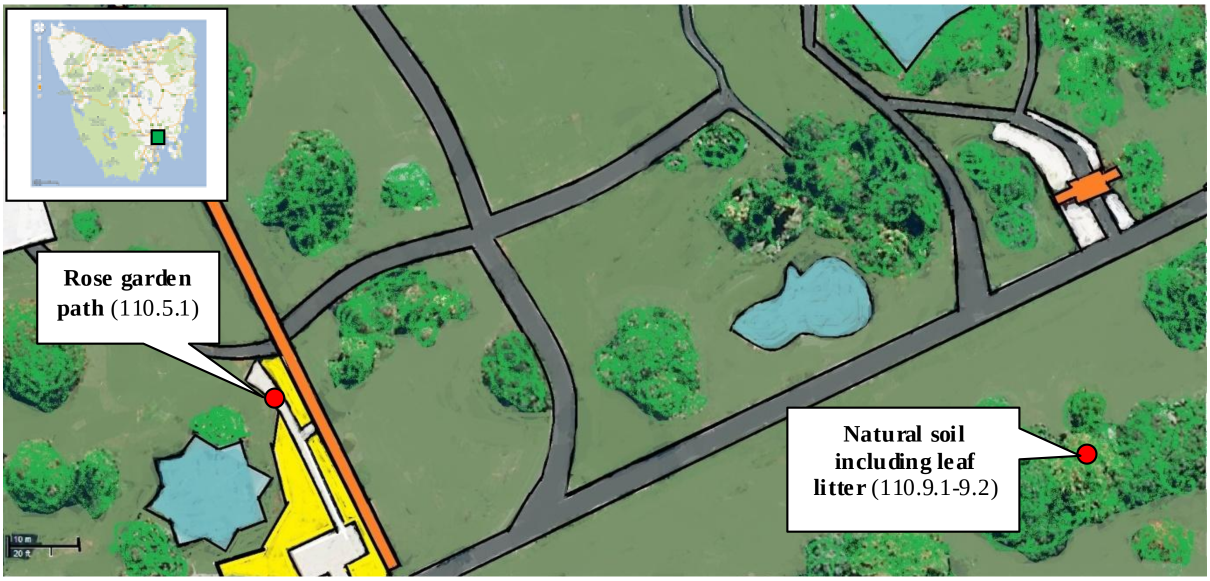

Figure 1-1 Map showing the distribution of the following two sites and soil profiles used to conduct soil transference experiments in the Royal Tasmanian Botanical Gardens: (i) Anthropogenic soil from Rose Garden Path (110.5.1) and (ii) Natural soil near the south east boundary (110.9.1 to 9.2).

Figure 1-2 Photograph of the Rose Garden path in the Royal Tasmanian Botanical Gardens.


Figure 1-3 Photograph of the natural soil under deciduous trees near south eastern boundary of the Royal Tasmanian Botanical Gardens.

Sufficient descriptive, chemical and mineralogical (XRD) data was acquired on three soil samples collected from the two locations to characterise properties and classify the soil materials (Table 1-1). Based on soil morphology and mineralogical data, classification of the 3 soil materials was made according to The World Reference Base for soil resources (IUSS Working Group WRB 2014) and the Australian Soil Classification (Isbell and National Committee on Soils and Terrain 2016).

The soil morphological descriptors of three soil materials and mineralogical data indicate two distinct groups, which are reflected in their soil classification. These two groups of soil materials classify as: (i) natural soil materials or (ii) artefacts[1] or artefact materials (i.e. created or substantially modified by humans as part of an industrial or artisanal manufacturing process to manufacture "roads" e.g. road metal) and classify as Anthroposols or "man made materials" [Urbic Technosols (Ekranic-like)] or Spolic Technosol materials (IUSS Working Group WRB 2014) or Anthroposol materials (Isbell 2016).

Summary description of Technosols (IUSS Working Group WRB 2014): Connotation: Soils dominated or strongly influenced by human-made material; from Greek technikos, skilfully made.

[1]Artefacts Definition (IUSS Working Group WRB 2014): Artefacts (from Latin ars, art, and facere, to make) are solid or liquid substances that are:

1. one or both of the following:
    a. created or substantially modified by humans as part of an industrial or artisanal manufacturing process; ***or***
    b. brought to the surface by human activity from a depth where they were not influenced by surface processes, with properties substantially different from the environment where they are placed; ***and***
2. have substantially the same properties as when first manufactured, modified or excavated.

Technosols Definition (IUSS Working Group WRB 2014): Other soils having :

- 20 percent or more (by volume, by weighted average) artefacts in the upper 100 cm from the soil surface or to continuous rock or a cemented or indurated layer, whichever is shallower; or
- a continuous, very slowly permeable to impermeable, constructed geomembrane of any thickness starting within 100 cm of the soil surface; or
- technic hard rock starting within 5 cm of the soil surface and covering 95 percent or more of the horizontal extent of the soil.

Human-transported material and human-altered material are defined in Chapter 3 of the 12th Ed. of the Keys to Soil Taxonomy, and evidence of their existence provided. If humans levelled the land to produce terraces, creating artificial landforms, it will qualify as human-transported material. If humans altered the soil on purpose beyond standard agricultural practices (such as adding lime), it may qualify as human altered material.

Table 1-1 Soil morphology, Australian Soil Classification of soil materials (Isbell 2016) and the approximate corresponding World Reference Base for Soil resources class (IUSS Working Group WRB 2014).

Locality (depth cm)	**Centre for Aust. Forensic Soil Science (CAFSS) code**	**Munsell[1] soil colour <2mm fraction (wet)** (dry)	**Soil type[2]**	**Brief description**	**The Australian soil classification (Isbell 2016)**	**The world reference base for soil resources (IUSS Working Group WRB 2014)**
Site 1: rose garden path (0-10 cm)	110.5.1	**Dark brown 7.5YR 3/2** Brown 7.5YR 5/2	Anthropogenic, gravelly sandy loam soil	Gravel (90%; arkosic sandstone and andesitic-to-weathered mafic igneous rock) loamy sand, water repellent, 0.7% Carbon (C).	Spolic anthroposol; very gravelly, sandy, very shallow	[3]Spolic technosol (Densic)
Site 2: south-east boundary (5-0 cm)	110.9.1	Leaves not analysed for Munsell soil colour by naked eye	Natural, organic-rich soil	Undecomposed Leaves (60%) and decomposed (40%)	Humose, Mesotrophic, Brown Dermosol; non-gravelly, loamy, deep	[4]Eutric Cambisol (Humic)
Site 2: south-east boundary (0-10cm)	110.9.2	**Very dark brown 10YR 2/2** Very dark brown 7.5YR 2.5/2	Natural, loamy soil	Gravel (2%), loamy sand, water repellent, 23 % C.		

Where: [1]Munsell Soil Colour (Munsell 2009): measured on the fine earth fraction (<2mm). [2] Special-purpose technical soil classification system (Fitzpatrick 2013), which uses plain English language places strong emphasis on being either an anthropogenic soil or natural soil, soil texture (e.g. gravelly, sandy, sandy loam) and presence of high amounts of organic carbon (>10%; organic-rich).

[3]Classification of Technosols (IUSS Working Group WRB 2014): Connotation: Soils dominated or strongly influenced by human-made material; from Greek *technikos*, skilfully made. They contain a significant amount of *artefacts*.

[4]Classification of natural soils: Connotation: Soils with substantial soil formation such as Dermosols (Isbell 2016) or Cambisols (IUSS Working Group WRB 2014).

2. FIELD AND LABORATORY METHODS

Summary

This section outlines the methods used to sample and analyse representative natural and human made soil samples from soil profiles.

2.1 Total carbon and sulfur

The carbon and sulfur content of the soil samples were determined using Nondispersive infrared (NDIR) analysis.

The carbon and sulfur contents of the soil samples were determined by Nondispersive infrared (NDIR) analysis using a Bruker G4 Icarus analyser, in the MRT laboratories, Rosny Park. The following standards were run during analyses to check calibration: AR4005 (C=1.42%, S=1.41%), AR4013 (C=2.93%, S=0.020%), AR4014 (C=5.87%, S=0.029%), AR4007 (C=7.27%, S=3.26%) and AR4024 (C=11.72%, S=0.418%).

2.2 Mineralogical analyses by x-ray diffraction

Analysis of the XRD patterns were performed using CSIRO XRD software: "VisualXRD" , "PW1710 for Windows" and "XPLOT for Windows". Mineralogical phase identification were made by manually comparing the measured XRD patterns with a series of similarly-prepared standards of the more common minerals to enable some semi-quantitative analysis. Quartz, if present, is used as an internal standard. If quartz is not present, it is routinely added to the sample for a supplementary scan. The semi-quantitative results are calculated using single-peak calibration factors derived from scans of known mixtures of minerals. This follows the methods of Maniar and Cooke (1987) and Chung (1974); which are variants of the internal standard and matrix flushing method of Klug and Alexander (1954).

2.3 Sports bra

The unpadded, underwire, sports bra used in all these experiment has three hook-and-eye back fasteners, underwires rising high between the cleavage, unpadded cups, and sliding shoulder-straps with metal buckles. The bra’s fabric is nylon-elastane. A DD-cup size provided a large fabric area for experiments and the white fabric made it easier to locate and identify trace soil transferred. To smoothly stretch the bra-cup fabric with a replication of a human breast, the bra was padded with a sock filled with rice (protected by a plastic cliplock bag with the smooth surface facing out and all corners taped securely to the back of the bag).

2.4 Soil transference experiments to test the transfer method of placing or dragging a human rescue dummy dressed in clothing (bra) across soil surfaces

Experimental design

A life-like rescue dummy from LifeTec came dressed in waterproof overalls and gumboots. A waterproof nylon-reinforced PVC bag was then duct-taped over its head and two ‘sacrificial’ plastic clip-lock bags duct-taped over this and secured to the collar of the overalls. Two plastic clip-lock bags were also duct-taped to each hand. The entire hand was then duct-taped over and attached to the cuffs of the overalls. A clean bra was firmly fitted and removable ‘breast implants’ positioned deep within each cup. Each implant consisted of a sock filled with 700g of rice. This was knotted, excess sock material removed and then firmly enclosed in a plastic bread bag. The end of the plastic bag was tied, cut and smoothly secured with duct-tape. The implant was always fitted with the knotted side pressed against the dummy. Fully attired, the rescue dummy weighed in at 55kg with ‘breast implants’.

To identify the soil transfer patterns that occur when a body wearing clothing (a bra) is placed on a soil surface, the dummy wearing a clean bra is placed on its back on the target soil for 2 minutes. The placing STE is then repeated with the dummy turned onto its front for a further 2 minutes, whilst detailed photos are taken of the STE just completed on the back of the bra. Then once the second STE is completed, the dummy is gently placed on its back on a clean plastic groundsheet; whilst extensive photos are taken of the front of the bra. This test was run three times each on the front and back of the bra; first using dry, then wet soil.

In order to identify the soil transfer patterns that occur when a body wearing clothing is dragged across a soil surface, the rescue dummy wearing a clean bra was first placed on its back for a 5 second count. During this time, the assistant dragging the dummy takes a firm grip on its legs. The dummy is then dragged for 3m. During a final 5 second count, two attendants take one dummy arm each and then lift the dummy’s torso in unison. It is vital to raise the bra cleanly from the soil without smudging the soil transference patterns. The dummy is then placed on its front on a clean plastic groundsheet whilst detailed photos are taken of soil transference patterns on the back of the bra.

The dragging STE is then repeated with the dummy dragged on its front, before being gently placed on its back on the clean groundsheet to photograph these new soil transference patterns. This test is run three times each on the front and back of the bra; first using dry, then wet soil.

The same assistant was used for all 24 dragging STEs to keep results consistent. At 174cm tall and weighing 67kg, the 66 year old assistant dragged the 55kg dummy at a consistent speed for a total of 36 metres. He also helped a second assistant to place and manoeuvre the rescue dummy in another 24 placing STEs.

The results of all STEs were photographed in situ with a Sony Cyber-shot DSC-W530 14.1 megapixel camera.

Low-powered binocular microscopy using a WILD Heerbrug M5-53707 microscope was undertaken on bulk soil samples taken from the RTBG and on 48 trace soil samples from 48 bras used in the STEs. Digital photomicrographs were taken using the Leica DFC-425 and the Leica Application Suite, Version 3.6.0.

In order to hold the fabric flat whilst it is photomicrographed back in the laboratory, the bra was secured to a flat 2kg weight by a rubber band (Figure 2-1). This process alone dislodged an unknown amount of transferred soil particles from the surface of the fabric; as did removing the bra from the rescue dummy and transporting it to the laboratory by motor vehicle.

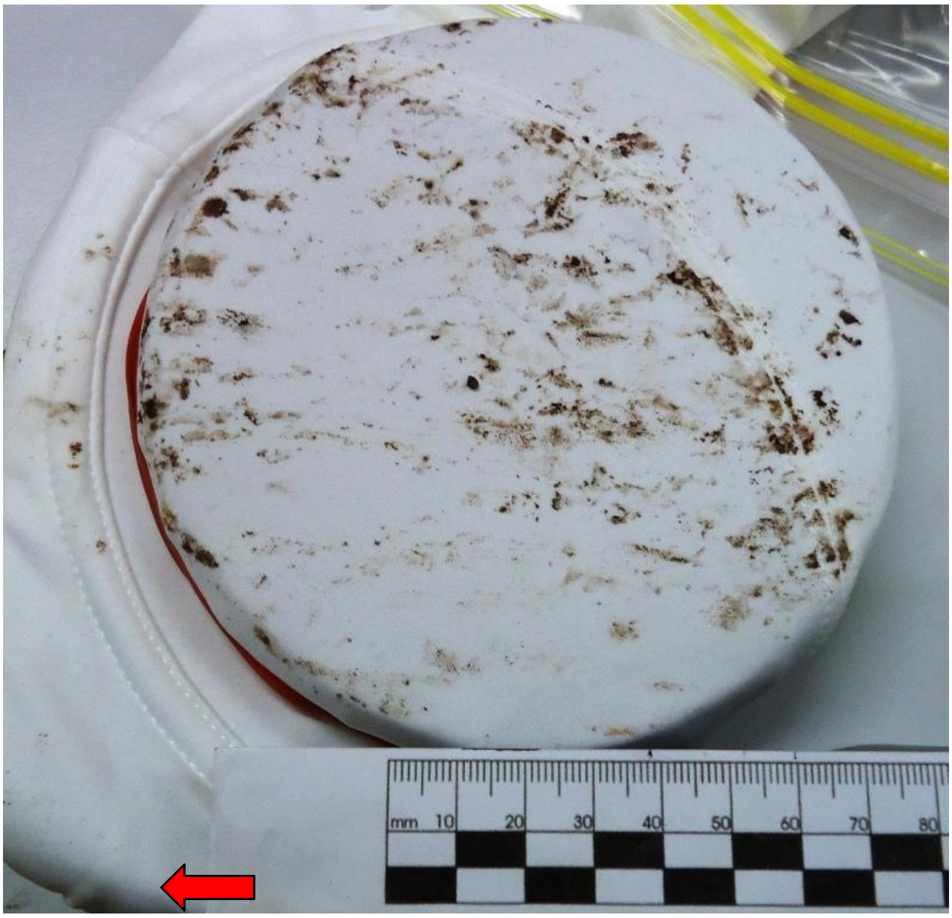

Figure 2-1 Before being photomicrographed back in the laboratory, the bra is secured to a flat 2kg weight by a rubber band (Direction of movement = right to left).

In preparation for the wet runs, the soil surface at each location was sprayed with a hose with a spray attachment until the soil colour changed evenly and water beaded. Between each run, at the natural soil site covered with dry leaves, the soil surface would be gently levelled by hand without compacting the soil surface.

3. MINERALOGY, CARBON AND SULFUR ANALYSES

Summary of mineral, carbon and sulfur analyses of all soil samples used in dragging STEs in the laboratory; to further investigate the universality of transference patterns across all soils.

3.1 Mineralogy

In order to ascertain how soil's unique mineralogy, carbon and sulfur content influenced subsequent soil transfer patterns seen across the two soil types tested, mineralogy, carbon and sulphur analyses were undertaken (Bottrill and Woolley 2014).

The semi-quantitative determination of minerals in the whole soil by X-ray diffraction (XRD) is presented in Table 3-1. XRD analysis of soil samples from the Royal Tasmanian Botanical Gardens revealed quartz as the major mineral in these soils. Smectite is of secondary importance in the Rose garden and soil on the SE boundary. X-ray diffraction (XRD) diagrams are presented in Appendix 5. The sample composed entirely of undecomposed leaf litter (110.9.1) was omitted from XRD analysis because it lacked any mineral content.

Table 3-1 Results of X-Ray Diffraction (XRD) analysis and organic carbon on soil samples from the Royal Tasmanian Botanical Gardens (approximate weight %)

Sample	**110.5.1**	**110.9.2**
Location	**Rose Garden Path**	**Natural Soil near SE boundary**
Quartz	40±4	32±3
Organic		38±2
Plagioclase	19±3	7±2
Smectite	19±3	20±3
K-Feldspar	1±0.5	3±1
Halloysite	3±1	
Clinopyroxene	3±1	
Hematite	8±2	
Ilmenite	1±0.5	
Laumontite	4±1	
Stilbite	1±0.5	
Apatite	1±0.5	

A range of results was given for each mineral detected, to compensate for a possible 'peak overlap' that may interfere with identifications and quantitative calculations; such as can occur between Potassium Feldspar and Clinopyroxene.

Amorphous material and trace amounts of minerals not detected are shown as blanks.

3.2 Organic carbon and sulfur

Table 3-2 contains the results of NDIR analysis of soils undertaken at MRT. Organic content of soil samples was calculated using NDIR measurements. No sulphur-containing minerals were identified in any sample. Due to its lack of mineral content, the soil sample composed entirely of undecomposed leaf litter (110.9.1) was omitted from NDIR analysis.

The Carbon contents were converted to approximate Total organic matter, by multiplying the total organic carbon content by 1.7, a standard figure (Howard, 1965).

Small Sulfur contents were noted in most samples but no Sulfur-bearing species were identified; appearing to correlate with organic matter.

Table 3-2 Nondispersive Infrared Analysis (NDIR) of Carbon and Sulfur Content of soils from the Royal Tasmanian Botanical Gardens (RTBG

Sample	Location	Carbon (%)	Sulphur (%)	Analyses
110.5.1	**Anthropogenic soil from Rose Garden Path in RTBG**	0.70	0.09	2
110.9.2	**Natural soil near SE boundary of RTBG**	22.8	0.54	3

Standards run during analyses to check calibration: AR4005 (C=1.42%, S=1.41%), AR4013 (C=2.93%, S=0.020%), AR4014 (C=5.87%, S=0.029%), AR4007 (C=7.27%, S=3.26%) and AR4024 (C=11.72%, S=0.418%)

4. IMAGE PROCESSING CONDUCTED ON DIGITAL PHOTOGRAPHS TAKEN OF SOIL TRANSFER PATTERNS

Summary

Summary of image processing conducted on digital photos recording the soil transfer patterns produced when the rescue dummy was either placed or dragged across a soil surface at two locations in the RTBG.

Image processing software analysed digital photos taken of every soil transfer experiment (STE). Quantifiable statistics were collected regarding the abundance of soil transferred, percentage of individual soil objects and aggregates, Munsell soil colour range and directionality of soil transferred. These statistics were then combined by soil sample, method of transfer and whether soil was wet or dry when the test was run; producing the following graphs and Rose diagrams.

4.1 Abundance of soiled areas on fabric compared to clean areas of fabric

Soil objects recognised by image processing software as areas in pixels were categorised as pale smears, brown smears, organics as well as areas of clean fabric. Due to the software's difficulty in recognising organic objects, the true area of this category is not realistically represented in the following graphs (Figure 4-1 to Figure 4-4).

It must also be noted that the image processing software could not reliably recognise soil objects <100 microns. Anthroposol soil samples from the Rose Garden gravel path (110.5.1) produced marked differences in the area of clean fabric remaining if the fabric had been placed or dragged across the soil surface in the field. A wet soil surface produced a greater area of fabric with pale brown or dark brown smears (Figure 4-1).

These differences between placing and dragging fabric across soil in the field was dramatically increased; compared to fabric dragged across soil samples from the same location in laboratory experiments (Murray et al. 2015).

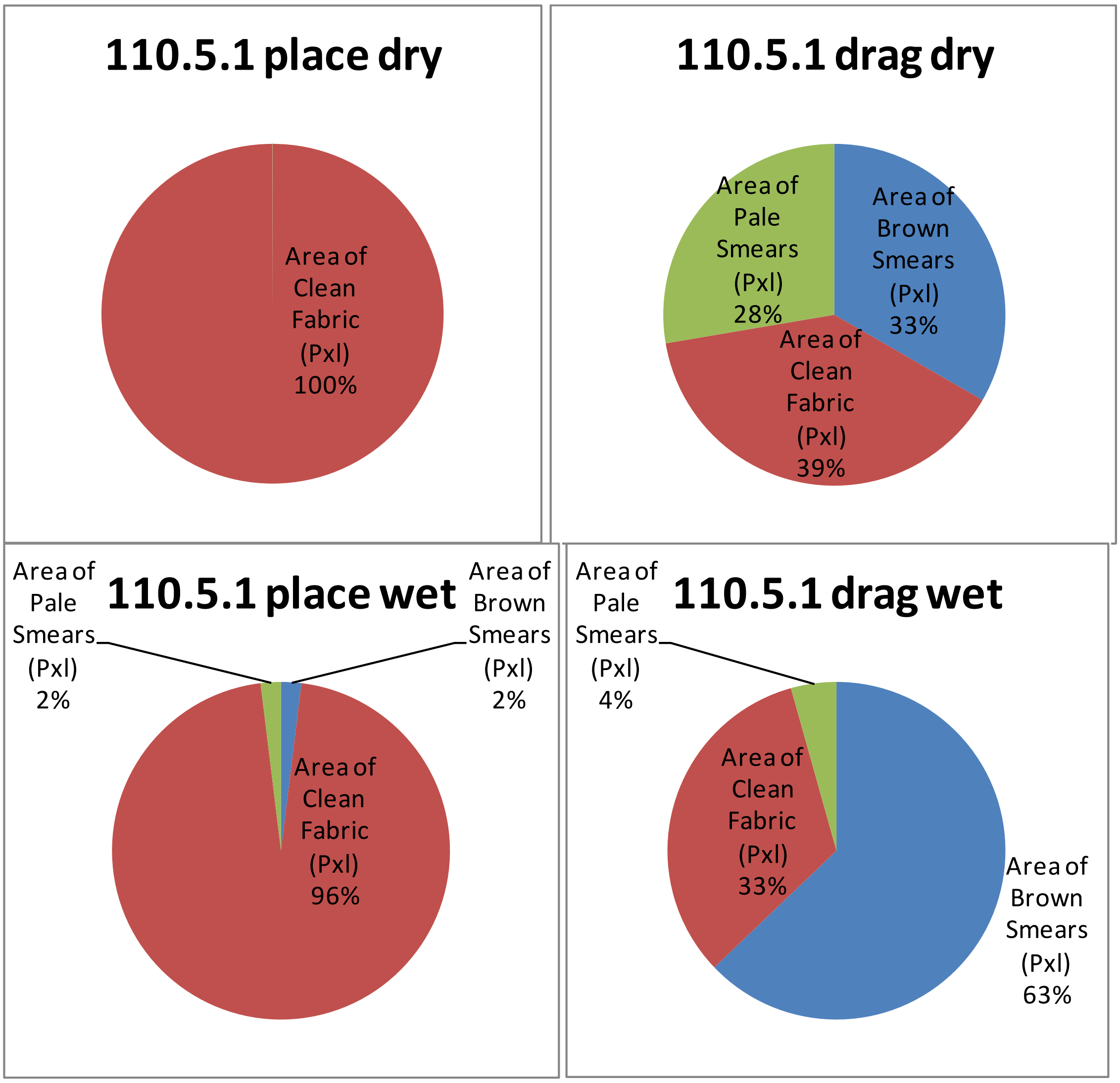

Figure 4-1 Abundance of dry and wet soil transferred to fabric from the Rose Garden path (110.5.1), RTBG. Image processing showed these results as areas in pixels.

Natural soil under deciduous tree leaves from the southeast boundary of the RTBG produced a similar difference in the abundance of soil transferred when wet or dry soil was used, as shown by the gravelly soil surface of the anthroposol Rose garden path (Figure 4-2). This natural soil was composed of undecomposed leaf litter (soil sample 110.9.1) covering dark organic-rich undisturbed soil (110.9.2). Using this natural soil sample, image processing software detected no soil transferred to the bra fabric area when the clothed body was placed on the dry soil surface. When this same soil surface was wet, 10% of the fabric had soil objects transferred. When the body was dragged across a dry soil surface, 89% of the bra fabric surface appeared clean; with any soil objects transferred being below 100 microns. When the soil surface was wet, only 45% of the bra fabric area was recognised as clean; with 55% of fabric analysed as soiled.

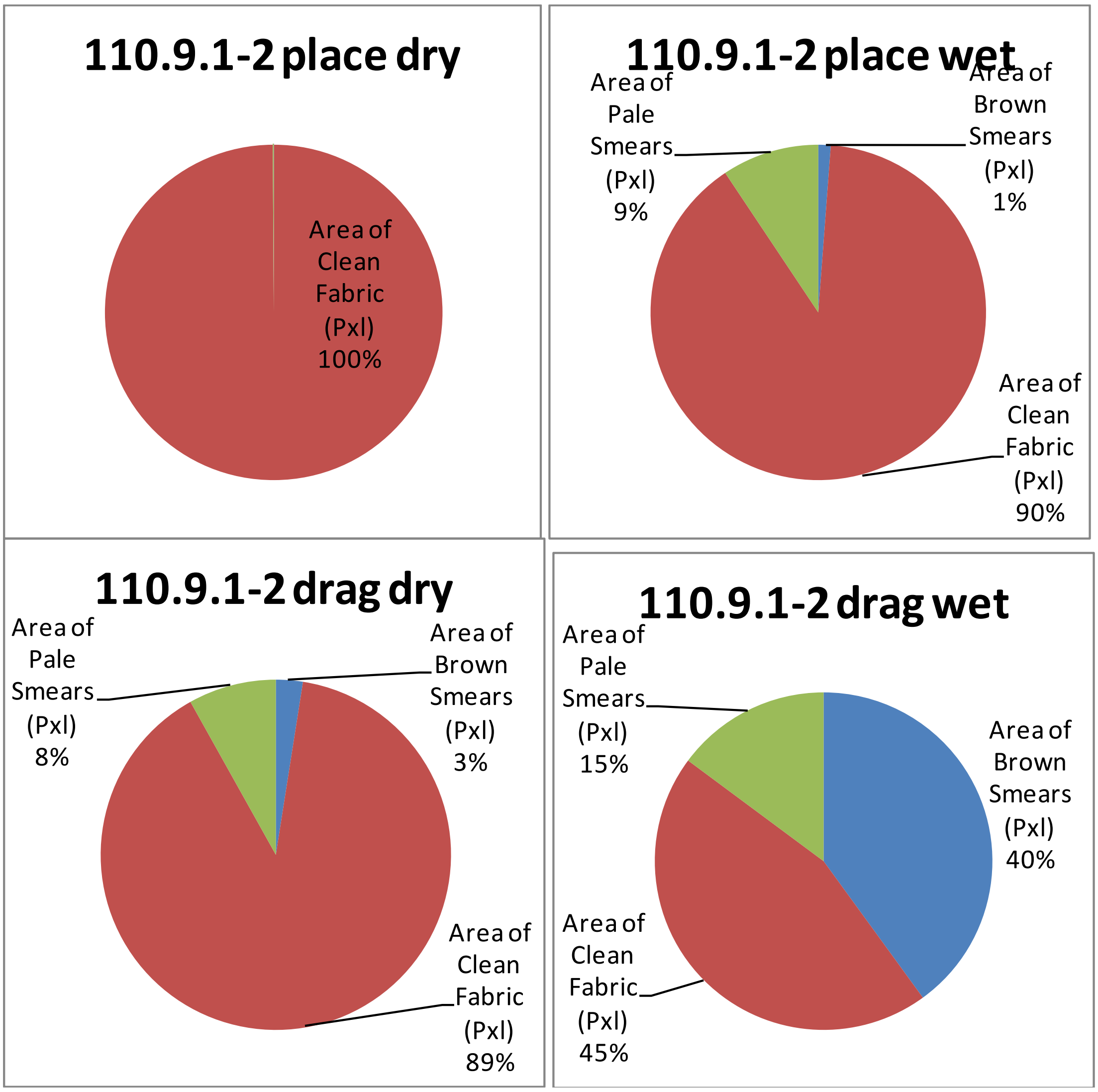

Figure 4-2 Abundance of dry and wet soil transferred to fabric from natural soil near the south eastern boundary fence (110.9.1-2), RTBG. Image processing showed these results as areas in pixels.

4.2 Individual soil objects and aggregates of soil objects transferred to fabric

Soil samples from the Rose Garden path (110.5.1) showed the transfer of 30-35% of individual soil objects and 70-65% of aggregates of soil objects onto bra fabric when placed on dry soil (Figure 4-3). When wet soil is used, 20-70% of individual soil objects and 80-30% of aggregates are transferred onto fabric.

When the rescue dummy is dragged across dry soil, bra fabric shows 10% of individual soil objects and 90% of soil aggregates transferred. When soil is wet, an overwhelming 98-100% of soil aggregates are transferred.

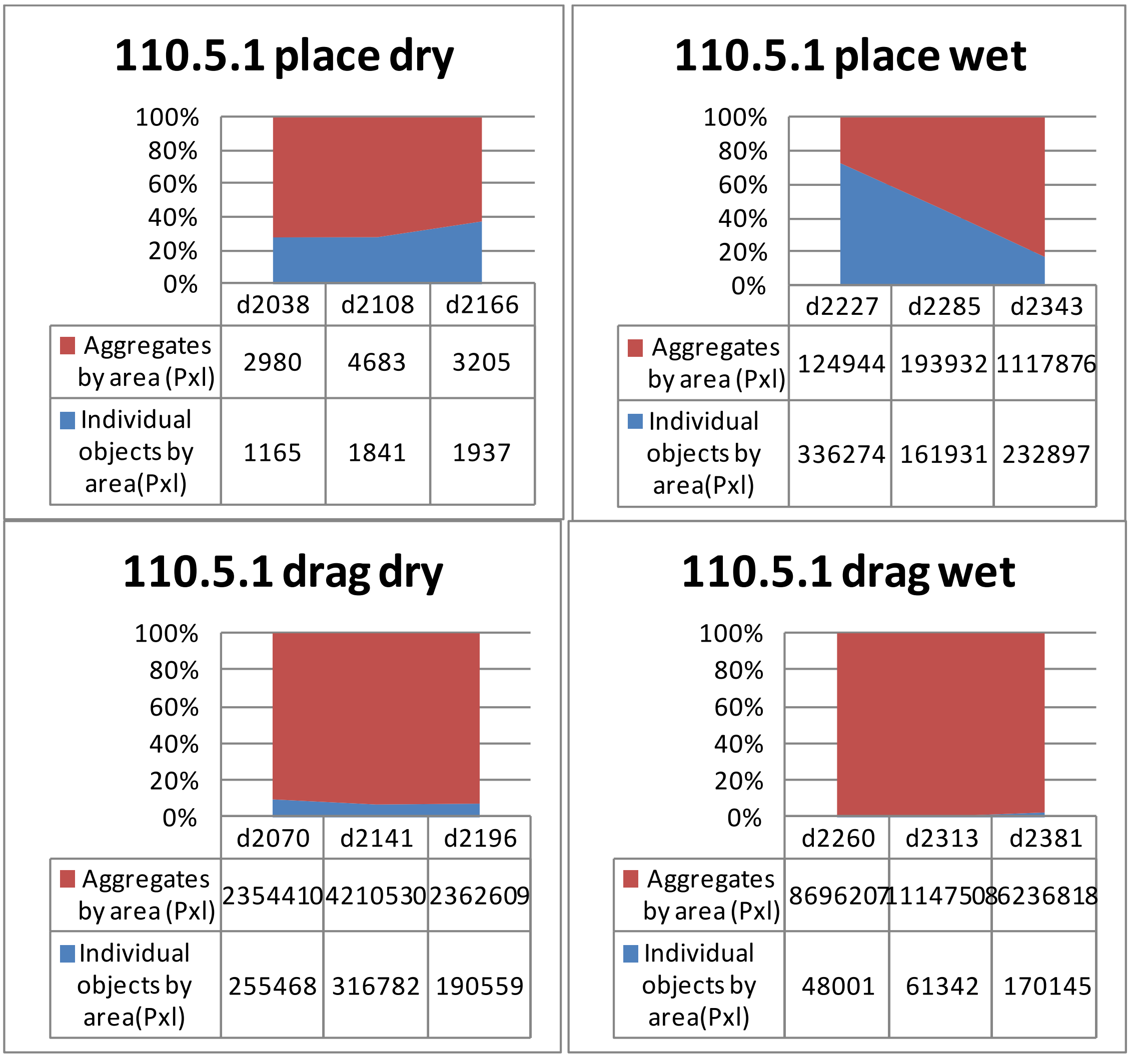

Figure 4-3 Individual soil objects and aggregates of soil objects transferred to fabric, shown as an area of pixels, from the Rose Garden path (110.5.1), RTBG.

The natural soil sample composed of leaf litter and organic soil (110.9.1-2) transferred 0-20% of individual soil objects and 100-80% of aggregates when the body was placed on dry soil; and 0-10% of individual objects and 100-90% of aggregates when soil was wet (Figure 4-4).

When the body was dragged across the dry natural soil surface, 8-25% of individual soil objects 92-75% of soil aggregates were transferred to the bra fabric. When soil was wet, 5-12% of individual soil objects and 95-88% of aggregates were transferred to bra fabric.

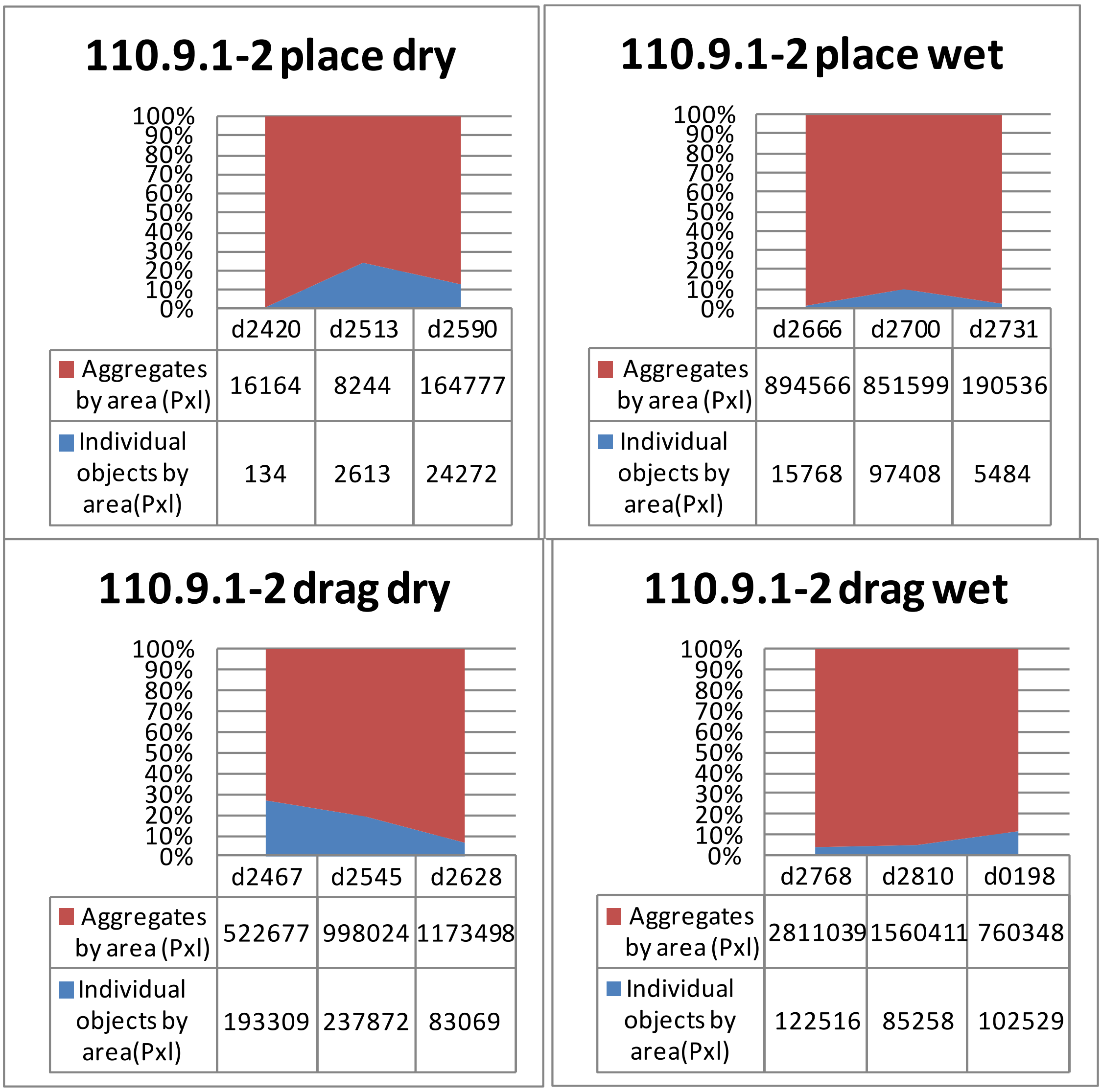

Figure 4-4 Individual soil objects and aggregates of soil objects transferred to fabric, shown as an area of pixels; from natural soil under trees from the southeast boundary of RTBG, composed of leaf litter (110.9.1) and undisturbed organic-rich soil (110.9.2).

4.3 Munsell soil colour range of soil transferred to fabric in pixels

The fine (<2mm) dry and wet fractions of each soil sample had their Munsell soil colour analysed by naked eye outside under natural daylight. Twenty-five different Munsell colours were recognised in wet and dry samples from an original collection of 21 different soils. When image processing software analysed digital photographs taken in the field at RTBG, this limited range of Munsell colours were used to match the computer softwares RGB values to the standard Munsell soil colours used by forensic and agricultural soil scientists.

For each soil sample, using either dry of wet soil, a set of three STEs was combined to produce a single graph (Figure 4-5 to Figure 4-8). Original Munsell colour analysis of a fine (<2mm) fraction of soil taken from the Rose Garden path (110.5.1), under natural daylight, showed a Munsell colour of 7.5YR 5/2 when dry and a darker 7.5YR 3/2 when wet (Figure 4-5).

When the rescue dummy was placed on the Rose Garden path in the field and photographed in situ, image processing software recorded a dominant colour of 7.5YR 2.5/2 when soil transferred was dry; with minor peaks at 2.5YR 6/1, 7.5YR 5/2, and a cluster at 10YR 4/2, 5/3, 6/3 and 7/2. When wet, the same dominant and minor Munsell colour peaks are identified, but with higher peaks due to the greater abundance of soil transferred during wet soil runs (Figure 4-5).

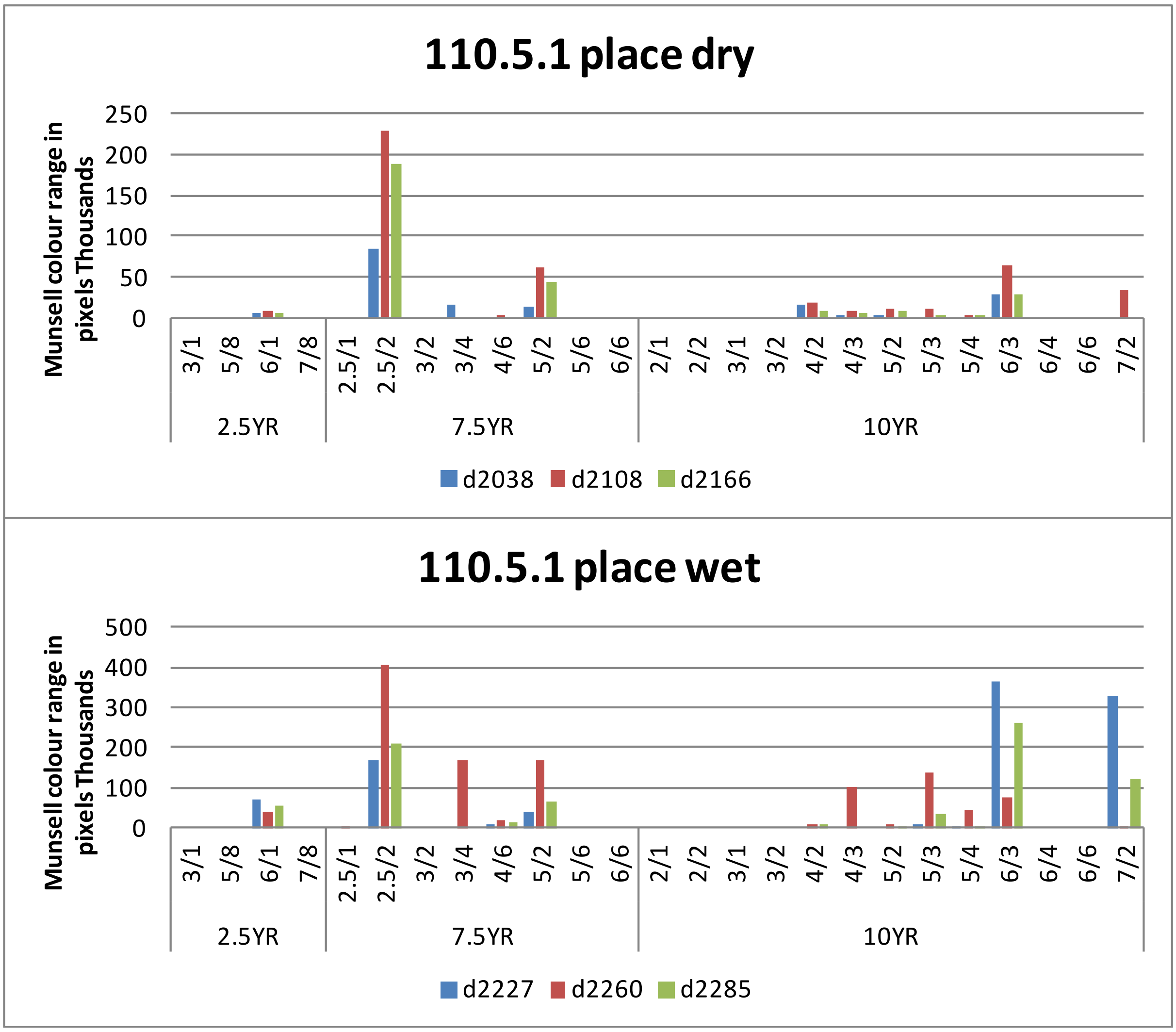

Figure 4-5 Munsell soil colour range recognised by image processing software of soil from the Rose garden path (110.5.1) transferred onto fabric during placement STEs when soil was either dry or wet.

When the rescue dummy was dragged across the Rose Garden path soil surface (Figure 4-6), the dominant Munsell colours transferred to bra fabric were analysed as

10YR 7/2 and 2.5YR 6/1 when dry; with minor peaks at 7.5YR 2.5/2 at 10YR 6/3. When wet, dominant Munsell soil colours of 10YR 7/2 and 6/3 were identified, with minor peaks at 2.5YR 6/1, 7.5YR 2.5/2 and 10YR 5/3.

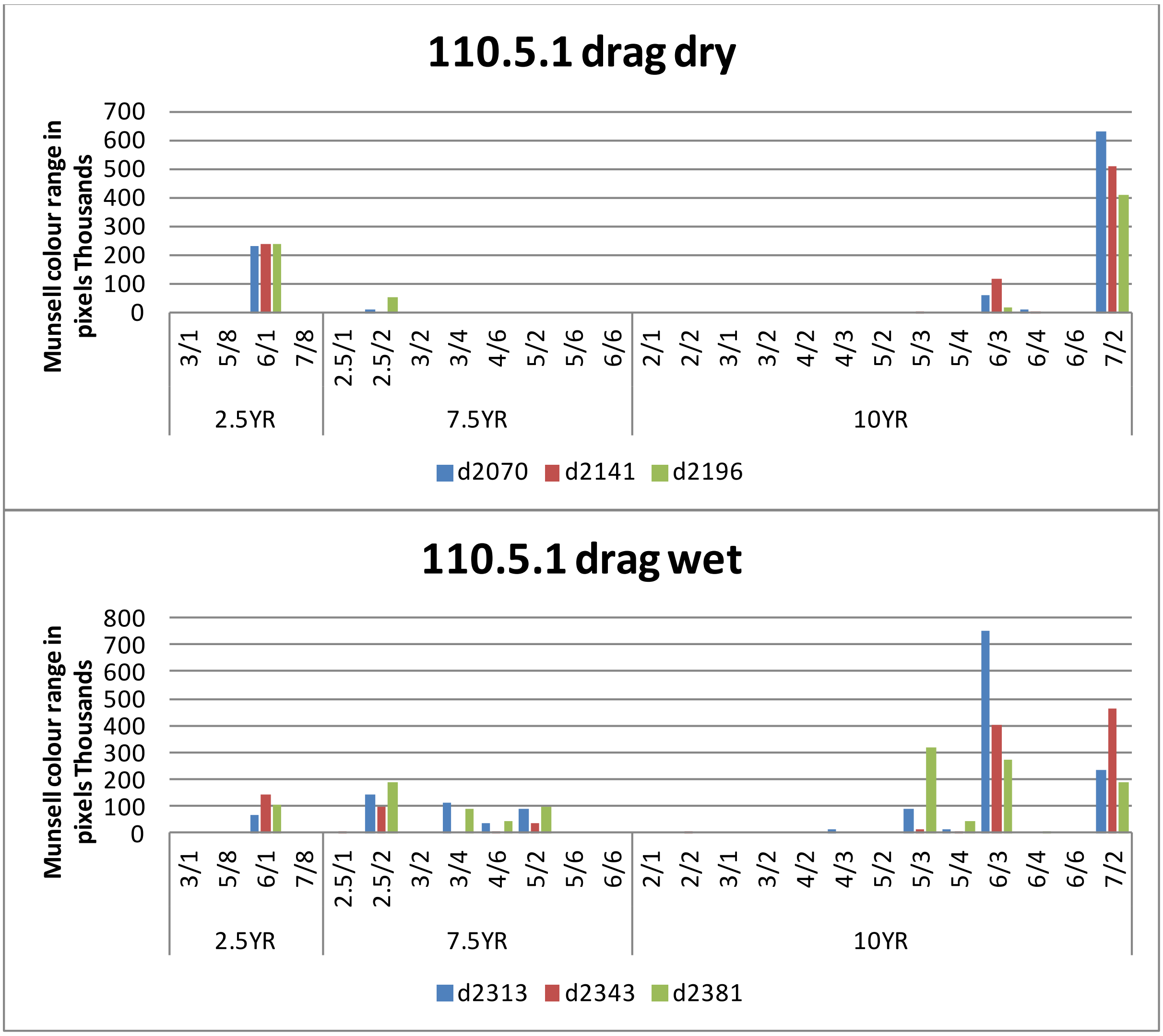

Figure 4-6 Munsell soil colour range recognised by image processing software of soil from the Rose garden path (110.5.1) transferred onto fabric during dragging STEs when soil was either dry or wet.

Original Munsell colour analysis of a fine (<2mm) sample of the organic-rich soil underlying the leaf matter (110.9.2) under natural daylight, showed a fine fraction Munsell colour of 7.5YR 2.5/2 when dry and a darker 10YR 2/2 when wet (Figure 4-7). The natural soil sample composed of undecomposed leaves (110.9.1) was not analysed by naked eye for a Munsell soil colour.

When the body was placed on this natural soil surface in the field, image processing software recorded the colour of soil transferred to fabric as having dominant peaks when dry at 10YR 6/3 and 7/2; with minor peaks at 2.5YR 6/1, 7.5YR 2.5/2 and 10YR

5/3. When wet, dominant peaks at 7.5YR 2.5/2 and 10YR 6/3 and 7/2 were identified; with a minor peak at 2.5YR 6/1 (Figure 4-7).

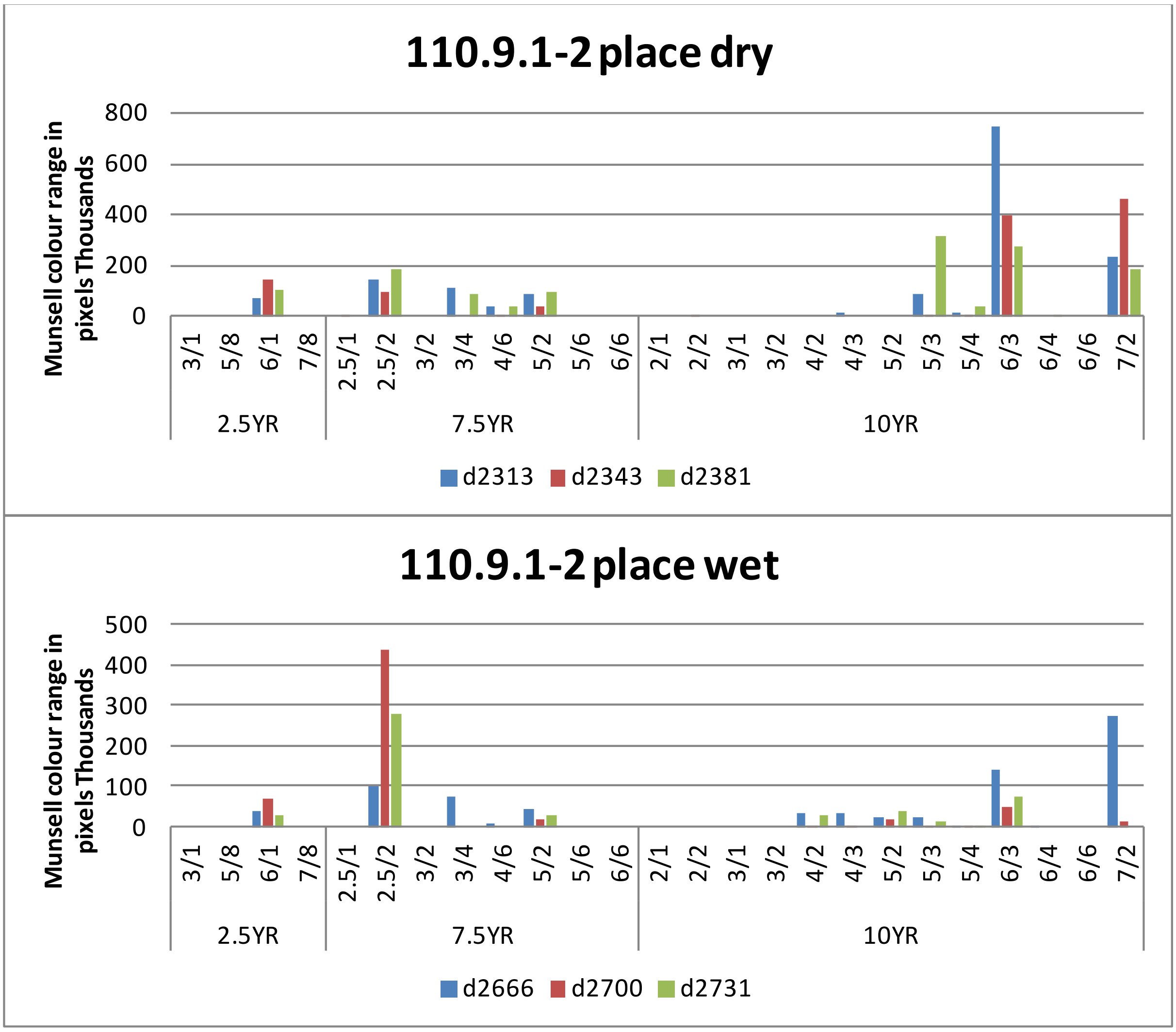

Figure 4-7 Munsell soil colour range recognised by image processing software of soil of undecomposed leaf litter covering natural soil on the southeast boundary of RTBG (110.9.1-2) transferred onto fabric when soil was dry and wet.

When the rescue dummy was dragged across this natural soil surface when dry, a dominant Munsell colour was analysed as 7.5YR 2.5/2, with minor peaks at 2.5YR 6/1 and 10YR 7/2 (Figure 4-8). When wet, soil transferred showed a cluster of dominant Munsell colours at 7.5YR 2.5/2, 3/2, 3/4 and 10YR 7/2. Minor peaks occurred at 2.5YR 6/1 and 10YR 6/3.

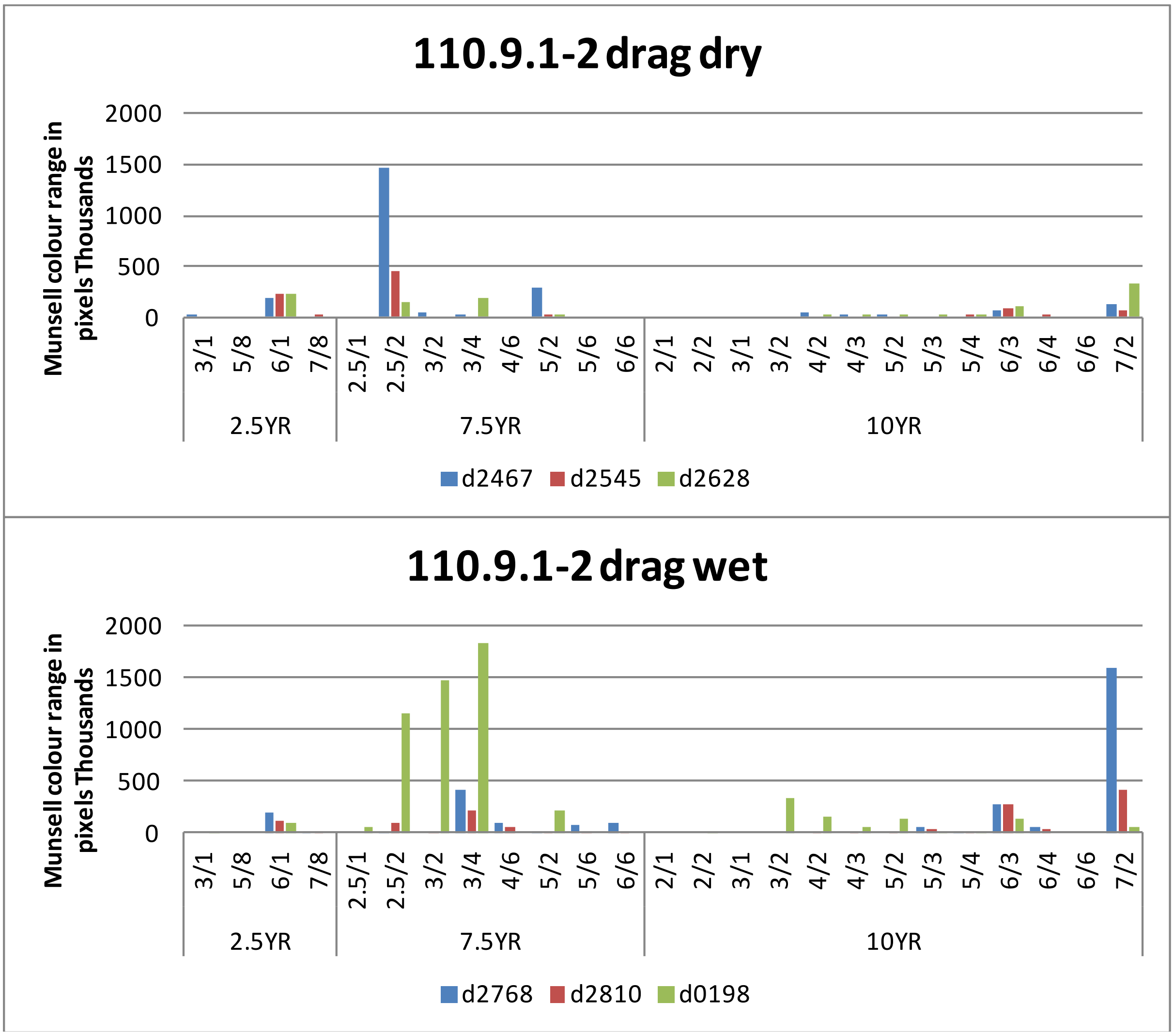

Figure 4-8 Munsell soil colour range recognised by image processing software of soil of undecomposed leaf litter covering natural soil on the southeast boundary of RTBG (110.9.1-2) transferred onto fabric when soil was dry and wet.

4.4 Directionality

Using directional statistics provided by image processing software, Rose diagrams illustrated the directionality of wet and dry soil particles transferred onto fabric (Figure 4-9).

Rose diagrams mapped the directionality of thousands of soil particles >100 microns. This method consistently created a simple yet definitive pictorial record of the soil transferred onto fabric during dragging experiments. Each Rose diagram only took minutes to create, relying upon image processing directional statistics.

A strong uni-modal directionality was displayed when the rescue dummy was dragged in one direction across the soil surface (from right to left). Dry soil particles had a greater tendency than wet soil to gather against the bra's middle seams; producing more of a bi-modal directionality. The cross-pattern was created on dragging rose diagrams when directional data from both left and right bra-cups was combined from one site. Dry soil building up on opposing perpendicular seams created this cross-like pattern.

When the body was only placed on the soil, a lesser number of particles were transferred to the fabric. There were no recognisable signs of directionality in the soil objects transferred; as was seen when the rescue dummy was dragged across a soil surface. This lack of obvious directionality in placing STE results, coupled with the reduced amount of data available for image processing analysis, caused the subsequent rose diagrams to show no distinct directionality of soil objects transferred. Individual soil objects tended to appear scattered indiscriminately in all directions on the fabric.

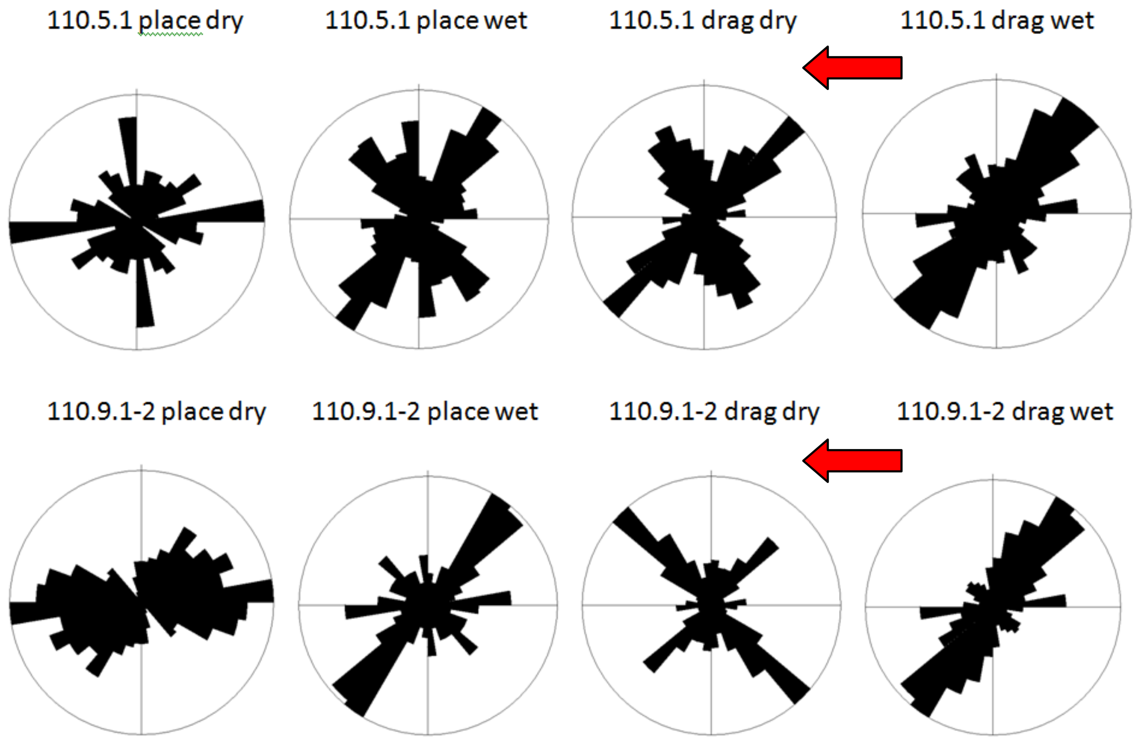

Figure 4-9 Rose diagrams display the directionality of dry and wet soil transferred onto fabric during STEs. Dry soil particles had a greater tendency than wet soil to gather against the middle seam, creating more of a bi-modal directionality.

5. CONCLUSIONS

Soil transfer experiments tested the transfer methods of placing and dragging a human rescue dummy dressed in a padded nylon/elastane sports bra across both wet and dry soil surfaces in the field at the Royal Tasmanian Botanical Gardens.

XRD results indicated the mineral composition, which comprised twelve (12) minerals of the bulk soil samples as being typical loamy to clayey Tasmanian soils. NDIR identified carbon levels as 0.70% on the gravel-rich Rose Garden path soil and 22.8% in natural soil. No Sulfur-bearing species were identified.

Image processing software proved valuable in providing in-depth quantifiable statistics on: (i) abundance of soil transferred, (ii) percentage of individual soil objects and aggregates transferred and (iii) direction patterns.

The most forensically valuable statistics involved a specific, reproducible Munsell soil colour range for trace soil evidence on fabric that shared the same location; as well as the directionality of soil transferred plotted as Rose diagrams.

6. ACKNOWLEDGEMENTS

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- Garth Oliver, Project Officer, Tasmanian Institute of Agriculture, School of Agricultural Science, University of Tasmania, for his technical support in the lab.

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8. Appendix 1 – Soil Transference patterns identified in STEs using the transfer methods of placing and dragging

SOIL TRANSFERS:		Bra-strap &/or cup						
CAFSS no.	Run	Sediment trails strap/cup	Elongate fragments aligned	Raised or folded seam sed build-up	Fabric speckled with sed	Damaged or frayed fabric	Fold & crease marks	Wet: Water stains
PLACEMENT	Dry 1	X	X	X	√	X	X	N/A
CAFSS_	Dry 2	X	X	X	√	X	X	N/A
110.5.1	Dry 3	X	X	√	√	X	X	N/A
Rose Garden	Wet 1	X	X	√	√	X	X	√
Path	Wet 2	X	X	√	√	X	X	√
	Wet 3	X	X	√	√	X	X	√
% occurrence	Dry	0%	0%	33.3%	100%	0%	0%	N/A
CAFSS_110.5.1	Wet	0%	0%	100%	100%	0%	0%	100%
PLACEMENT	Dry 1	X	X	X	√	X	√	N/A
CAFSS	Dry 2	X	X	X	√	X	X	N/A
110.9.1	Dry 3	X	X	X	√	X	X	N/A
Natural	Wet 1	X	X	√	√	X	X	√
Soil	Wet 2	X	X	√	√	X	X	√
	Wet 3	X	X	√	√	X	X	X
% occurrence	Dry	0%	0%	0%	100%	0%	33.3%	N/A
CAFSS_110.9.1	Wet	0%	0%	100%	100%	0%	0%	66.6%
DRAG	Dry 1	√	X	√	X	√	√	N/A
CAFSS_	Dry 2	√	√	√	X	√	√	N/A
110.5.1	Dry 3	√	√	√	√	√	√	N/A
Rose Garden	Wet 1	√	X	√	√	√	√	√
Path	Wet 2	√	X	√	X	√	√	√
	Wet 3	√	X	√	√	√	√	√
% occurrence	Dry	100%	66.6%	100%	33.3%	100%	100%	N/A
CAFSS_110.5.1	Wet	100%	0%	100%	66.6%	100%	100%	100%
DRAG	Dry 1	√	√	√	X	X	√	N/A
CAFSS_	Dry 2	√	√	√	X	X	X	N/A
110.9.1	Dry 3	√	√	√	√	X	√	N/A
Natural	Wet 1	√	X	√	X	X	√	√
Soil	Wet 2	√	√	√	X	X	X	X
	Wet 3	√	X	√	X	X	√	X
% occurrence	Dry	100%	100%	100%	33.3%	0%	66.6%	N/A
CAFSS_110.9.1	Wet	100%	33.3%	100%	100%	0%	66.6%	33.3%

KEY:

√ = pattern occurs on bra-strap and/or cup

X = pattern does not occur on bra-strap or cup

N/A = Not applicable

Appendix 1 continued...

SOIL TRANSFERS:		Bra-strap only				
CAFSS no.	Run	Strap edge sediment build-up	Buckle sed build-up	Fluffy seam sed build-up	Dry: Dusting sed evenly over buckle	Wet: buckle clean &/or mud clumps
PLACEMENT	Dry 1	X	X	X	X Clean	N/A
CAFSS_	Dry 2	X	X	√	X Clean	N/A
110.5.1	Dry 3	X	X	X	X Clean	N/A
Rose Garden	Wet 1	√	X	√	N/A	√
Path	Wet 2	√	√	√	N/A	√
	Wet 3	√	X	√	N/A	√
% occurrence	Dry	0%	0%	66.6%	0%	N/A
CAFSS_110.5.1	Wet	100%	33%	100%	N/A	100%
PLACEMENT	Dry 1	X	√	X	√	N/A
CAFSS	Dry 2	√	X	√	√	N/A
110.9.1	Dry 3	X	√	√	√	N/A
Natural	Wet 1	X	X	X	N/A	√
Soil	Wet 2	X	√	X	N/A	√
	Wet 3	X	X	X	N/A	√
% occurrence	Dry	66.6%	100%	66.6%	33.3%	N/A
CAFSS_110.9.1	Wet	33.3%	33.3%	0%	N/A	100%
DRAG	Dry 1	√	√	√	X	√
CAFSS_	Dry 2	√	√	√	X	√
110.5.1	Dry 3	√	√	√	X	√
Rose Garden	Wet 1	√	√	√	N/A	√
Path	Wet 2	√	√	√	N/A	√
	Wet 3	√	√	√	N/A	√
% occurrence	Dry	100%	100%	100%	0%	100%
CAFSS_110.5.1	Wet	100%	100%	100%	N/A	100%
DRAG	Dry 1	√	√	X	√	N/A
CAFSS_	Dry 2	√	√	√	√	N/A
110.9.1	Dry 3	√	√	√	√	N/A
Natural	Wet 1	√	√	√	N/A	√
Soil	Wet 2	√	√	√	N/A	√
	Wet 3	√	√	√	N/A	√
% occurrence	Dry	1005	100%	66.6%	100%	N/A
CAFSS_110.9.1	Wet	100%	100%	100%	N/A	100%
KEY:						
√ = pattern occurs on bra-strap and/or cup						
X = pattern does not occur on bra-strap or cup						
N/A = Not applicable						

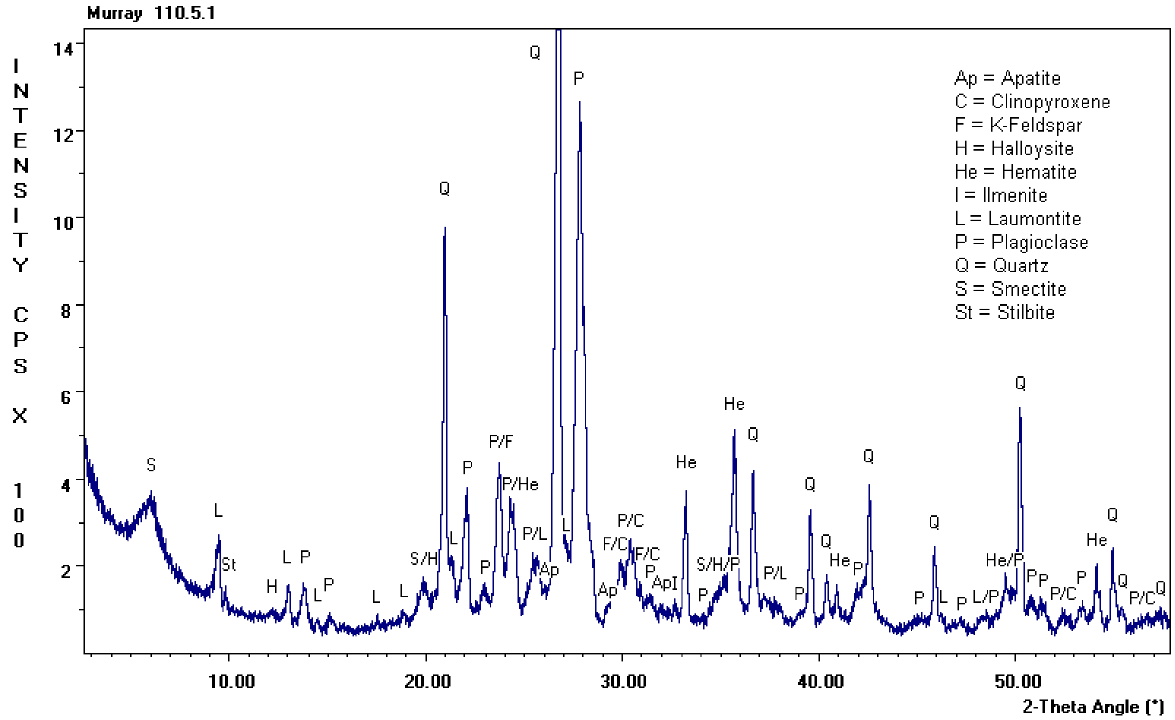
9. Appendix 2 – Image processing statistics showing Munsell colour range of soil samples shown as area in pixels

Soil Sample no.	Soil Transfer Method	Soil Moisture content	Digital Photo no.	Munsell colour range (Area of each colour in pixels)											
				2.5YR				7.5YR							
				3/1	5/8	6/1	7/8	2.5/1	2.5/2	3/2	3/4	4/6	5/2	5/6	6/6
110.5.1	place	dry	d2038	0	0	5732	0	0	83899	0	15775	0	13684	0	0
110.5.1	place	dry	d2108	0	0	8750	0	0	228112	0	0	2440	60962	0	0
110.5.1	place	dry	d2166	0	0	6789	0	0	188156	0	0	0	44289	0	0
110.5.1	drag	dry	d2070	0	0	235008	0	0	13218	0	0	0	0	0	0
110.5.1	drag	dry	d2141	0	0	242406	0	0	0	0	0	0	0	0	0
110.5.1	drag	dry	d2196	0	0	240977	0	0	53634	0	0	0	0	0	0
110.5.1	place	wet	d2227	0	0	69038	0	0	166264	0	0	6464	41733	0	0
110.5.1	place	wet	d2260	0	0	40436	0	1591	402730	0	167384	16476	169387	0	0
110.5.1	place	wet	d2285	0	0	55983	0	0	207037	0	0	11085	62463	0	0
110.5.1	drag	wet	d2313	0	0	69331	0	0	142976	0	114182	39441	89902	0	0
110.5.1	drag	wet	d2343	0	0	142858	0	1057	94635	0	0	3496	40390	0	0
110.5.1	drag	wet	d2381	0	0	104399	0	0	188498	0	88965	43500	96584	0	0
110.9.1-2	place	dry	d2420	0	0	3631	0	0	172301	72430	265140	0	24288	0	0
110.9.1-2	place	dry	d2513	0	0	15928	0	0	49526	0	21460	0	3225	0	0
110.9.1-2	place	dry	d2590	0	0	41417	0	3416	282676	45342	402354	11257	76057	0	0
110.9.1-2	drag	dry	d2467	55	0	185060	0	0	1460805	43857	33458	0	283498	0	0
110.9.1-2	drag	dry	d2545	0	0	223183	62	0	444300	0	0	0	15672	0	0
110.9.1-2	drag	dry	d2628	0	0	234362	0	0	141061	0	180923	0	37738	0	0
110.9.1-2	place	wet	d2666	0	0	37458	0	0	99017	0	74889	8913	41274	0	0
110.9.1-2	place	wet	d2700	0	0	71434	0	0	436962	0	0	0	18452	0	0
110.9.1-2	place	wet	d2731	0	0	28179	0	0	277622	0	0	0	30155	0	0
110.9.1-2	drag	wet	d2768	0	0	190728	2064	0	24497	0	420365	96342	20843	71103	101978
110.9.1-2	drag	wet	d2810	0	0	114326	630	0	104191	23502	228457	51897	27410	17897	11976
110.9.1-2	drag	wet	d0198	4	0	92606	0	68216	1152272	1482014	1837810	0	210599	0	0

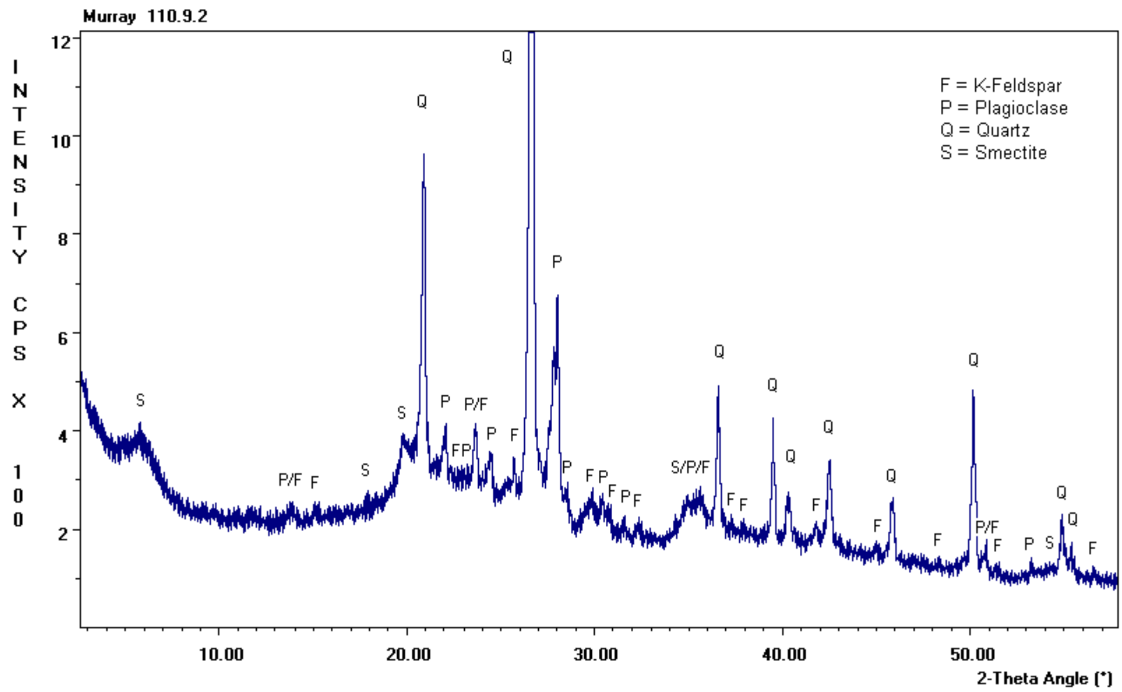
Soil Sample no.	Soil Transfer Method	Soil Moisture content	Digital Photo no.	Munsell colour range (Area of each colour in pixels)												
				10YR												
				2/1	2/2	3/1	3/2	4/2	4/3	5/2	5/3	5/4	6/3	6/4	6/6	7/2
110.5.1	place	dry	d2038	0	0	0	0	15574	1334	3868	0	0	28670	0	0	0
110.5.1	place	dry	d2108	0	0	0	0	18041	7102	10253	10720	1463	63404	0	0	32952
110.5.1	place	dry	d2166	0	0	0	0	8634	5406	8788	4113	3249	28533	0	0	0
110.5.1	drag	dry	d2070	0	0	0	0	0	0	0	0	0	62254	13111	0	631896
110.5.1	drag	dry	d2141	0	0	0	0	0	0	0	6055	0	123608	3146	0	515379
110.5.1	drag	dry	d2196	0	0	0	0	0	0	0	0	0	20891	0	0	412316
110.5.1	place	wet	d2227	0	0	0	0	0	0	0	10109	1569	362136	0	0	327536
110.5.1	place	wet	d2260	0	0	0	0	6194	100830	6531	134622	42885	77327	0	0	4955
110.5.1	place	wet	d2285	0	0	0	0	6727	0	3028	32353	2792	258699	0	0	122264
110.5.1	drag	wet	d2313	0	0	0	0	0	18036	0	91763	15327	749209	0	0	231683
110.5.1	drag	wet	d2343	0	6746	0	0	0	0	0	11090	2413	401583	0	0	464077
110.5.1	drag	wet	d2381	0	0	0	0	0	0	0	317899	43202	273559	866	0	189901
110.9.1-2	place	dry	d2420	0	0	0	24825	16701	24855	10487	9224	1976	37211	0	0	5207
110.9.1-2	place	dry	d2513	0	0	0	0	5970	2849	0	0	0	3889	0	0	0
110.9.1-2	place	dry	d2590	0	0	0	0	21033	46124	57157	56809	3077	120419	0	0	118887
110.9.1-2	drag	dry	d2467	0	0	0	0	45330	2429	33006	0	0	63011	0	0	135907
110.9.1-2	drag	dry	d2545	0	0	0	0	0	0	0	0	657	94412	3366	0	63130
110.9.1-2	drag	dry	d2628	0	0	0	0	17492	18659	35887	3087	619	101958	0	0	332690
110.9.1-2	place	wet	d2666	0	0	0	0	32192	31459	24060	22473	640	142197	1933	0	275698
110.9.1-2	place	wet	d2700	0	0	0	0	3148	3078	19671	4680	1011	49496	0	0	11157
110.9.1-2	place	wet	d2731	0	0	0	0	30440	0	37620	11860	352	72080	0	0	0
110.9.1-2	drag	wet	d2768	0	0	0	0	0	0	0	55057	18817	278664	61249	0	1598092
110.9.1-2	drag	wet	d2810	0	0	0	0	6440	3311	11068	31090	3698	284043	39724	0	409954
110.9.1-2	drag	wet	d0198	0	19351	0	335709	153801	61194	137721	20375	1164	130562	0	0	51022

10. APPENDIX 3 – XRD patterns

Soil no. 110.5.1	*Site 5 RTBG, Rose Garden path*	Queens Domain, Hobart	Dark brown Soil
Soil no. 110.9.2	*Site 9 RTBG, Natural soil*	Queens Domain, Hobart	Very dark brown Soil



Sample no. 110.5.1: Site 5 Rose Garden path, RTBG, Queens Domain, Hobart Dark brown Soil



Sample no. 110.9.2: Site 9 Natural soil SE boundary, RTBG, Queens Domain, Hobart Very dark brown soil

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