Spatial distribution of physical contaminants in a topsoil after mixed waste organic output (MWOO) application

Final Report, September 2017

A. Prof. Stephen Cattle

School of Life and Environmental Sciences

The University of Sydney

Summary

This project, with a field component based at Menangle, NSW, is an assessment of the spatial distribution of physical contaminants in topsoil previously treated with a mixed waste organic output (MWOO) and with a garden waste compost (GWC). The assessment of the amounts and spatial distribution of physical contaminants in treated topsoil was achieved by sampling soil at 2 cm depth increments for particle size and contaminant fractionation, and sampling 'undisturbed' 15 × 10 × 7.5 cm blocks of soil for thin section production. A nearby natural soil profile, which has never received an application of MWOO or GWC, was used as a Control treatment.

Both the MWOO and GWC treatments increased the gravel and coarse sand fractions of the soil; physical contaminants including glass, rigid plastic and film plastic contributed much of this increase in the MWOO-treated soil, while soil mineral material and recalcitrant organic material contributed much of this increase in the GWC-treated soil. In the MWOO-treated soils, the depth of physical contamination extended only to the depth of incorporation and rigid plastics were the most common contaminant class on a mass basis. In thin section, the rigid plastics and synthetic fibres were observed inside pores, blocking pores and encapsulated by soil mineral material. This suggests that soil hydraulic conductivity may be compromised if enough physical contaminants are present to block the majority of large pores.

THE UNIVERSITY OF SYDNEY

This project has been assisted by the New South Wales Government through its Environmental Trust

Aims of the work

(i) to assess the spatial distribution, including depth in the soil, of physical contaminants in topsoil previously treated with different application rates of a mixed waste organic output (MWOO), and for comparison topsoil treated with different application rates of a garden waste compost (GWC)
(ii) to assess any change in particle size distribution of soil solids following the application of different rates of MWOO and GWC

Materials and Methods

The assessment of the spatial distribution of physical contaminants in topsoil was achieved by sampling soil from small plots (2 × 4 m) of land at Menangle, NSW, which had previously received applications of a mixed waste organic output (MWOO) or a Garden Waste Compost (GWC). Both the MWOO and the GWC were applied to different plots in April 2014 at rates of 20 t/ha, 60 t/ha, 100 t/ha and 200 t/ha dry weight. By way of comparison, existing permissible application rates for MWOO (NSW EPA, 2014) are 10 t/ha dry weight for broadacre agricultural use, 50 t/ha dry weight for forestry use and for non-contact agricultural use, and 140 t/ha dry weight for mine sites. Prior to MWOO/GWC application, all plots had been rotor tilled to a depth of approximately 15 cm, and this tillage operation was repeated on each plot immediately after MWOO/GWC application. Subsequently, all plots were lightly harrowed twice before wheat was planted (direct drilled) in early May, 2014. No further tillage took place until the soil was sampled for this project in mid-2015.

All treatments (MWOO and GWC, each at 4 rates) were applied in a randomly allocated design to two separate parts of the same field, giving a total of sixteen plots for sampling. The two areas of plots were separated by a distance of 300 m and were located on similar, but not identical, soil types. Although both soil types were texture-contrast Chromosols, the western-most soil type has a yellowish-red subsoil, while the eastern soil type has a yellowish-brown subsoil (Appendix 2). Both soils have a clay loam topsoil overlying a light clay (western site) or silty clay (eastern site) subsoil. A natural soil profile located 10 m west of the western experimental sites, was used as a Control site (see Appendix 1); this soil has never received an application of MWOO or GWC, or been cultivated. On all sixteen plots where MWOO or GWC had been applied, a wheat crop was grown between April and November 2014. Soil samples were taken from these plots, for this research, in April and May 2015, some 12–13 months after the application of the MWOO and GWC.

Two sets of soil samples were collected from each of the MWOO- and GWC-treated plots; a set of depth-increment samples to estimate particle size distributions and amounts of physical contaminants in the soil, and a set of 'undisturbed' samples for micromorphological study.

Soil particle size distributions

From each of the MWOO- and GWC-treated plots, approximately 50–150 g of soil was sampled from each 2 cm-depth increment between the soil surface and a depth of 24 cm. That is, samples were taken from depths of 0–2, 2–4, 4–6, 6–8, 8–10, 10–12, 12–14, 14–16, 16–18, 18–20, 20–22 and 22–24 cm. All samples

were disaggregated through end-over-end shaking in a solution of deionised water and sodium hexametaphosphate, and then size-sorted into gravel (>2 mm diameter), coarse sand (200 μm to 2 mm diameter), fine sand (20 to 200 μm), silt (2 to 20 μm) and clay (<2 μm) fractions, using a combination of gravimetric measurement and sieving (Gee and Or, 2002). The organic components of the gravel, coarse sand and fine sand fractions were removed by treating the particles with hydrogen peroxide. Depth functions (0–24 cm) were then constructed for the proportions of each particle size fraction in each plot. For the gravel fraction of each sample, fragments of rigid plastics, film plastics and glass were separated by hand and weighed. For the coarse and fine sand fractions of each sample, photographs were taken of these materials under a light microscope to assess their morphological features.

Samples for micromorphological analysis

From each of the MWOO- and GWC-treated plots, three 15 × 10 × 7.5 cm blocks of 'undisturbed' soil were sampled with the ultimate goal of producing soil thin sections. As indicated in Appendix 2, the undisturbed soil samples were excavated in Kubiëna Tins to preserve the soil structure in current field condition. The sampled tins of soil were then impregnated in resin, allowed to set hard, cut, affixed to glass slides and then lapped to a soil thickness of approximately 30 μm (further details of the methodology given in Jongerius & Heintzberger, 1975). The thin sections produced were photographed under a light microscope to record typical soil structural units, pedological features and the spatial organisation of physical contaminant fragments. Thin sections were produced at three depth increments (0–5 cm, 5–15 cm, 15–25 cm) in each of sixteen plots previously treated with MWOO or GWC. A nearby natural soil profile, which had never received an application of MWOO or GWC, was used as a Control treatment and had thin sections produced for the 0–5, 5–15 and 15–25 cm depth increments. At each sampling site, the 15–25 cm depth increment sample was taken across the boundary of the clay loamy topsoil and the more clayey subsoil.

Results

Particle size distribution and micromorphological features of the Control soil

The unamended and uncultivated Control soil, located approximately 10 m from the western edge of the first set of MWOO- and GWC-treated plots, is characterised by a brown, clay loam topsoil (A horizon) overlying a yellowish-red, light clay upper subsoil (upper B horizon) (Appendix 1). This soil is known as a Chromosol because it shows a field texture contrast and is not strongly acidic in the subsoil. The sharp A horizon-B horizon boundary occurs at a depth of 26 cm in this profile, and at a shallower depth in the nearby cultivated soil, presumably due to previous erosion or the packing down of the cultivated topsoil after rainfall. Similarly, the A/B boundary of the second set of plots, located 300 m from the Control soil, was at a depth of around 14-16 cm, as evidenced by the images in Appendix 2. The proportions of the particle size fractions in the Controls topsoil and upper subsoil are given below in Table 1; these data indicate a distinct increase in clay and fine sand content across the A/B boundary. There is only a small amount of gravel-sized material (>2 mm diameter) occurring in the A and upper B horizons of the Control soil.

Table 1. Proportions of gravel, coarse sand, fine sand, silt and clay in the Control soil

	Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
A horizon	<1	7	38	34	21
upper B horizon	<1	5	44	21	28

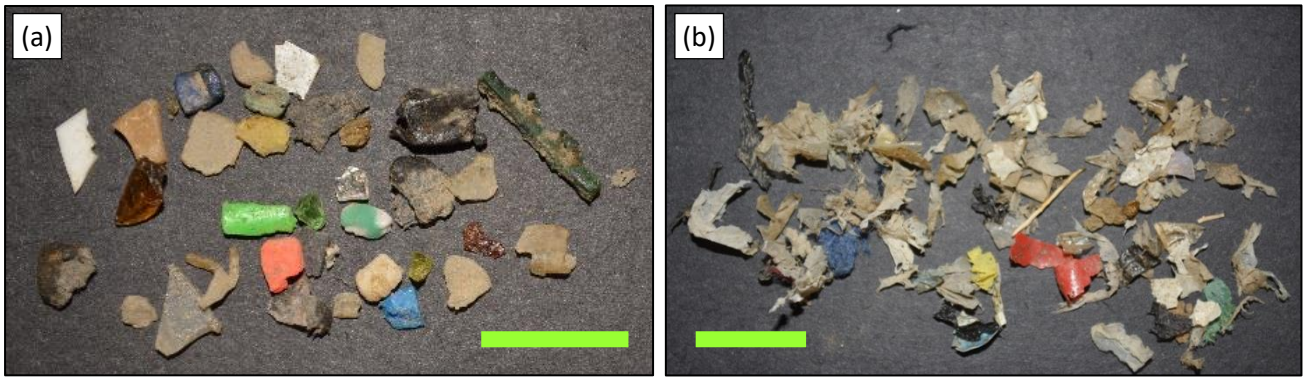
Photographs of the coarse and fine sand fractions of the Control soil A and B horizons (Appendix 3), show a prevalence of clear quartz grains and iron oxide-stained or coated quartz grains. These reddish-brown and yellowish-brown iron oxide stains and coats are particularly evident in the image of the coarse sand fraction of the upper subsoil (Appendix 3b). Morphologically, the coarse sand grains are overwhelmingly sub-rounded to sub-angular in shape, although a few grains are more angular with a tabular or platy habit (e.g. left-side of Appendix 3a). The fine sand grains of both the topsoil and upper subsoil tend to be more mixed in terms of shape, with substantial populations of angular, sub-angular and sub-rounded particles. The proportion of clear, angular and somewhat jagged quartz grains in the fine sand fraction appears to be substantially greater than is found in the coarse sand fraction.

The thin section images of the Control soil are characterised by a broad range of fine and coarse sand-sized particles embedded in a clayey and silty matrix (Appendix 4). There is a sporadic occurrence of black Mn and reddish Fe oxide nodules in the fine and coarse sand fractions (Appendix 4a, e, g), the occurrence of various (largely empty) pore shapes and types, and somewhat stronger aggregation of the upper subsoil. The surface soil is further characterised by frequent small (50–100 μm) black particles (Appendix 4b, c), which are likely to be organic matter and/or charcoal. Appendix 4a shows a coarse sand-sized, reddish ferruginous nodule, and beneath this feature, running from left-to-right in a broad U-shape, is a largely in-filled pore; the generally fine material in this pore suggests that it is an earthworm cast.

Physical contaminants present in the gravel fraction of MWOO- and GWC-treated soil

Although accounting for only a very small proportion of the total mass, physical contaminants were nevertheless visually prominent in many of the soil samples taken from MWOO-treated plots. As an example, Figure 1 shows both; (a) the glass + rigid plastic component and (b) the film plastic component of the gravel fraction taken from the 8–10 cm depth soil sample of one of the MWOO 200 t/ha plots. Although only accounting for about 1.3% of the soil mass in this sample, such physical contaminants were conspicuous inclusions in those topsoils treated with the larger rates (100, 200 t/ha) of MWOO. For those plots treated with GWC or lower rates of MWOO, the numbers of physical contaminant particles present in the 2 cm depth interval soil samples were distinctly less; in many of the samples from GWC-treated plots, there were three or less pieces of physical contaminant in the entire sample.

Figure 1. Glass and rigid plastic fragments (a), and film plastic fragments (b), extracted from the gravel fraction of the 8–10 cm depth increment soil sample taken from a MWOO 200 t/ha plot. The scale bar represents 1 cm in both cases.



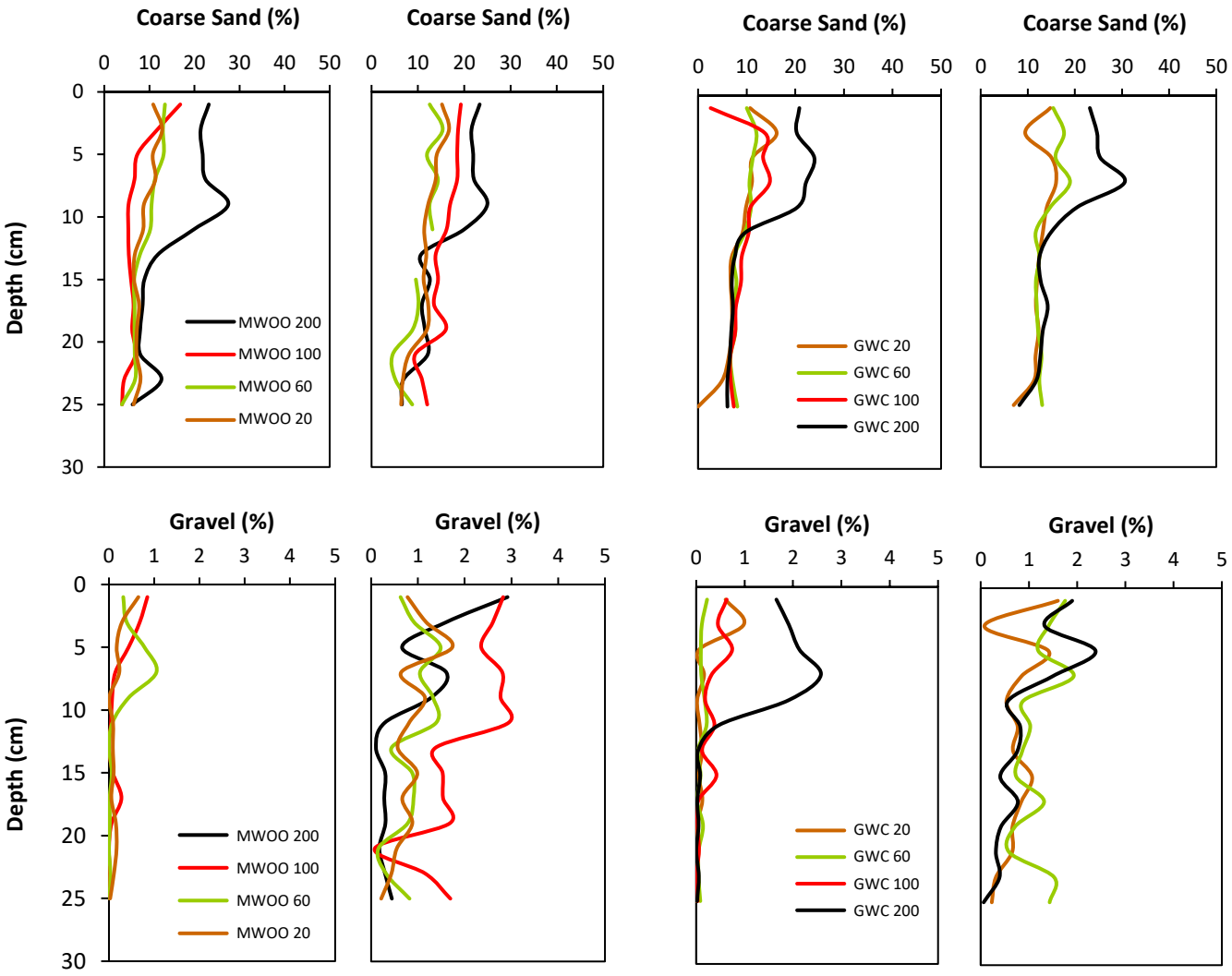
As indicated in Appendix 7, measurable amounts of gravel-sized physical contaminants were observed to depths of 16–18 cm, but tended to be concentrated between depths of 0 and 14 cm. This broadly corresponds to the depth of incorporation of the MWOO and GWC, and subsequent cultivation for the wheat crop that was grown in this soil during the winter and spring of 2014. The MWOO-treated soils contained far greater amounts of physical contaminants than the GWC-treated soils, and across all three categories of physical contaminant (glass, rigid plastic, film plastic). Although there is some variability in physical contaminant content at different topsoil depths, presumably reflecting the heterogeneity of the added MWOO and soil mixing during MWOO incorporation, these amounts generally reflect the MWOO application rate, *viz.* contaminants in MWOO 200-treated topsoil > contaminants in MWOO 100-treated topsoil > contaminants in MWOO 60-treated topsoil > contaminants in MWOO 20-treated topsoil (Appendix 4). On a mass basis, rigid plastics are the most prevalent physical contaminant type in the gravel fraction.

Particle size distributions of soil amended with MSW and GW

Particle size depth functions for the MWOO- and GWC-treated soils show that the greatest increases in size fractions with increasing application rates were afforded to the gravel and coarse sand fractions. The clay and fine sand fraction depth functions of MWOO- and GWC-treated soils were all similar, irrespective of the rate of application (data not shown), while the silt depth functions showed no consistent trends (data not shown).

In Figure 2, the coarse sand fractions of the MWOO 200- and GWC 200-treated soils are consistently greater than those of the other treated soils to a depth of approximately 13 cm. Although there is some variability, the gravel fraction of the MWOO 200- and GWC 200-treated soils are also generally greater than those other treated soils down to a depth of approximately 10–12 cm. The coarse sand and gravel fractions of the MWOO 20- and MWOO 60-treated soils, and of the GWC 20- and GWC 60-treated soils, are generally similar to each other and similar to the coarse sand and gravel fractions of the Control soil.

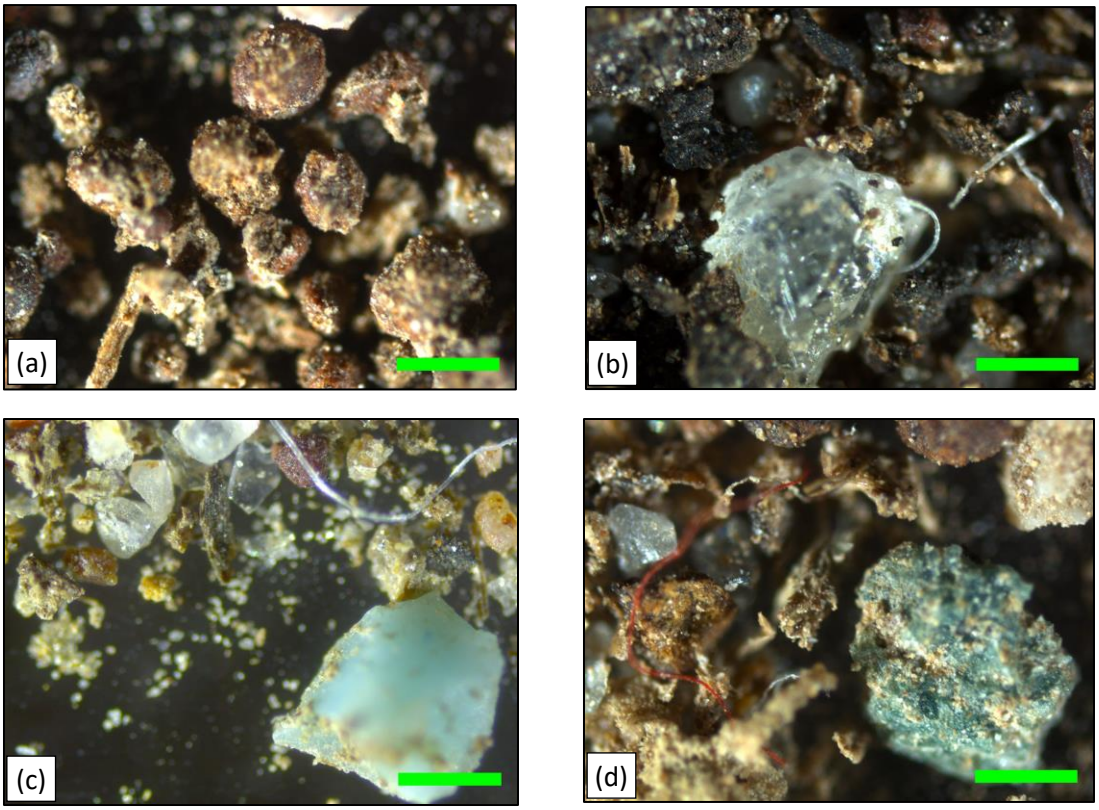
Figure 2. Depth functions for coarse sand and gravel contents of soil previously treated with different rates of MWOO or GWC. The two pairs of depth functions on the left refer to the two sets of plots treated with MWOO, and the two pairs on the right refer to the two sets of plots treated with GWC.



Morphological features of sand-sized grains from soil treated with MWOO and GWC

Due to the relatively small numbers of physical contaminant particulates found in the GWC-treated soil, the morphological features of these particles are difficult to summarise. In Figure 3a, a typical collection of coarse sand-sized grains from a GWC-treated soil are shown; these are generally sub-rounded, stained with a veneer of iron and manganese oxides and with various smaller particulates adhering to the surface. These mineral grains are very typical natural soil materials. A few recalcitrant organic fragments are also present in this particle size fraction. Nevertheless, in most of the 2 cm depth increment soil samples down to a depth of approximately 14 cm, a few physical contaminant particulates were evident, mainly glass fragments, rigid plastic fragments and synthetic (?) fibres. In Figure 3b, an example of a glass fragment and several synthetic fibres are shown; the glass fragment is clearly identifiable from the surrounding sand grains by its clear colour, angularity and its reflectivity under white light.

Figure 3. Sand-sized grains extracted from soil sampled from; (a) GWC 200, 14–16 cm, (b) GWC 200, 6–8 cm, (c) MWOO 100, 0–2 cm, and (d) MWOO 20, 0–2 cm. In each case the scale bar represents 500 μm.

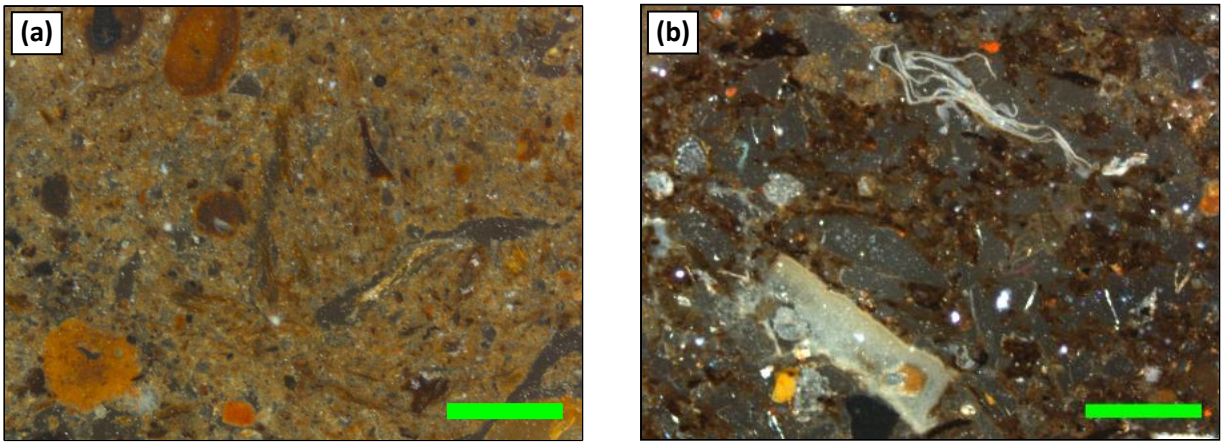


For the MWOO-treated soils, physical contaminant particles were much more prevalent in the coarse sand fraction, as indicated in the depth functions of Figure 2. In Figure 3c, a tabular and somewhat jagged piece of blue rigid plastic is prominent, along with a synthetic fibre and a small, clear glass fragment (upper centre of image). In Figure 3d, a prominent red synthetic fibre can be seen, along with a bluish-green physical contaminant that may be a piece of rubber. Other examples of coloured glass fragments, angular shards of clear glass in the fine sand fraction, and coloured film plastic, all present in the sand fraction MWOO-treated soil, are shown in Appendix 6.

Spatial distribution of physical contaminants in soil treated with MWOO and GWC

In keeping with the identification of physical contaminants in the gravel and sand-sized fractions of the 2 cm depth-increment soil samples, physical contaminants were most readily identified in thin sections of the MWOO-treated topsoil and were generally difficult to locate in the MWOO-treated subsoil and in the GWC-treated soil. In Figure 4, a typical part of a GWC-treated topsoil and a MWOO-treated topsoil are shown for comparison; the GWC-treated topsoil (Figure 4a) is characterised by an abundance of organic materials (fresh roots, streaky brown organic matter, charcoal fragments), while the MWOO-treated topsoil (Figure 4b) contains a mixture of soil mineral grains, organic matter, synthetic fibres, rigid plastic particles and glass shards. The somewhat linear orientation of the streaky brown organic matter in Figure 4a suggests that this material was added and mixed into the soil from the GWC source; similarly, the darker brown-stained aggregation in Appendix 7a, which contains a conspicuous particle of rigid plastic, appears to be a separate inclusion of the GWC material. Notwithstanding the effects of soil mixing, the majority of the GWC-treated soil thin sections from 5–15 cm depth and 15–25 cm depth are similar in appearance (well aggregated, some organic matter, some Fe- and Mn-oxide particles) to the Control subsoil thin sections.

Figure 4. Images of thin sections sampled from (a) GWC 200, 0–5 cm, and (b) MWOO 200, 0–5 cm. The scale bar represents 500 µm.



As shown in Figure 4b and Appendix 7b-h, rigid plastics, synthetic fibres, and to a lesser extent glass shards, are very conspicuous in the MWOO-treated soil thin sections. Generally speaking, the physical contaminant particles are surrounded to some extent by dark brown-stained material; the paler brown material is the pre-existing soil, while the darker brown material is clearly derived from the organically enriched MWOO. The physical contaminants occupy a range of positions in the soil – in some cases these particles sit in pores (Appendix 7c), completely block pores (Appendix 7b, f), act as a nucleus for soil mineral particles (Appendix 7g), coat existing ped surfaces (Appendix 7h), or are completely encase in soil mineral particles (Appendix 7d, h). Fibrous particulates appear to occupy several positions at once due to their flexibility and length (Appendix 7e). Although the rate of MWOO application has an obvious effect on the amount of physical contaminant evident in the thin sections, the physical contaminants that are present occupy the same range of positions in the soil regardless of application rate.

Extended Conclusions

1. The incorporation of a MWOO and of a GWC at various rates to Chromosol topsoils in the Sydney Basin had the effect of increasing the relative proportions of the coarse sand and gravel fractions of the soil. These increases were seen to a depth of around 14 cm, which coincides with the depth of incorporation and subsequent tillage. The fine sand, silt and clay contents of this soil were not affected by MWOO or GWC application.
2. Manual sorting of the gravel fractions of MWOO-treated and GWC-treated topsoils showed that physical contaminants were the main cause of the gravel increase in MWOO-treated soil, whereas soil mineral material and recalcitrant organic matter were the main sources of the gravel increase in the GWC-treated soil. Although, by mass, the amounts of physical contaminants present in the gravel fraction of MWOO-treated topsoils were not great, these were nevertheless visually striking and included glass fragments, rigid plastics and film plastics. Rigid plastics contribute approximately twice the mass of both glass and film plastic to the gravel fraction.
3. Although not quantified due to the difficulties of separating glass shards from quartzose sand grains, physical contaminants were also very prominent in the coarse sand fraction of soils previously treated with MWOO. Morphological attributes such as colour, angularity, jaggedness and lack of impurities/coatings made rigid plastics and glass fragments easy to distinguish from soil mineral grains. Synthetic fibres were also a common physical contaminant in the coarse sand fraction of topsoils treated with MWOO. In the topsoil samples from GWC-treated plots, some plastic and glass particles were evident, but far fewer than in the soil with equivalent rates of MWOO previously applied.
4. Even in the soil with the greatest rates of MWOO application, only very minor amounts of physical contaminants were found beneath the depth of incorporation/tillage, suggesting that percolating water has had little effect on the distribution of these contaminants. This is presumably due to the relatively coarse size of most of the physical contaminant particles; ‘illuviation’, or washing of soil solids down the profile, usually only affects clay particles and very fine silt particles.
5. In thin section, rigid plastics and synthetic fibres are very evident in the topsoil of MWOO-treated plots. These physical contaminants are usually associated with organically-stained aggregations or clumps of material, indicating the MWOO provenance of those contaminants. The physical contaminant particles occupy a variety of positions in the soil, including within pores, completely blocking pores, and completely encapsulated by soil mineral material. The GWC-treated soils tend to exhibit relatively few physical contaminants in thin section, and instead show clear effects of mixing of organic materials with the pre-existing soil mineral material.
6. While not explicitly measured in this work, the effect of the presence of physical contaminants on soil hydraulic conductivity is worth some consideration given the observations of pore blockage by plastics and fibres in particular. The act of incorporation/tillage will initially ‘open up’ the porosity of the soil, but subsequent rainfall events and consolidation/packing of the soil solid particles will reduce this connected porosity, and physical contaminants may play a role in plugging some of this porosity.

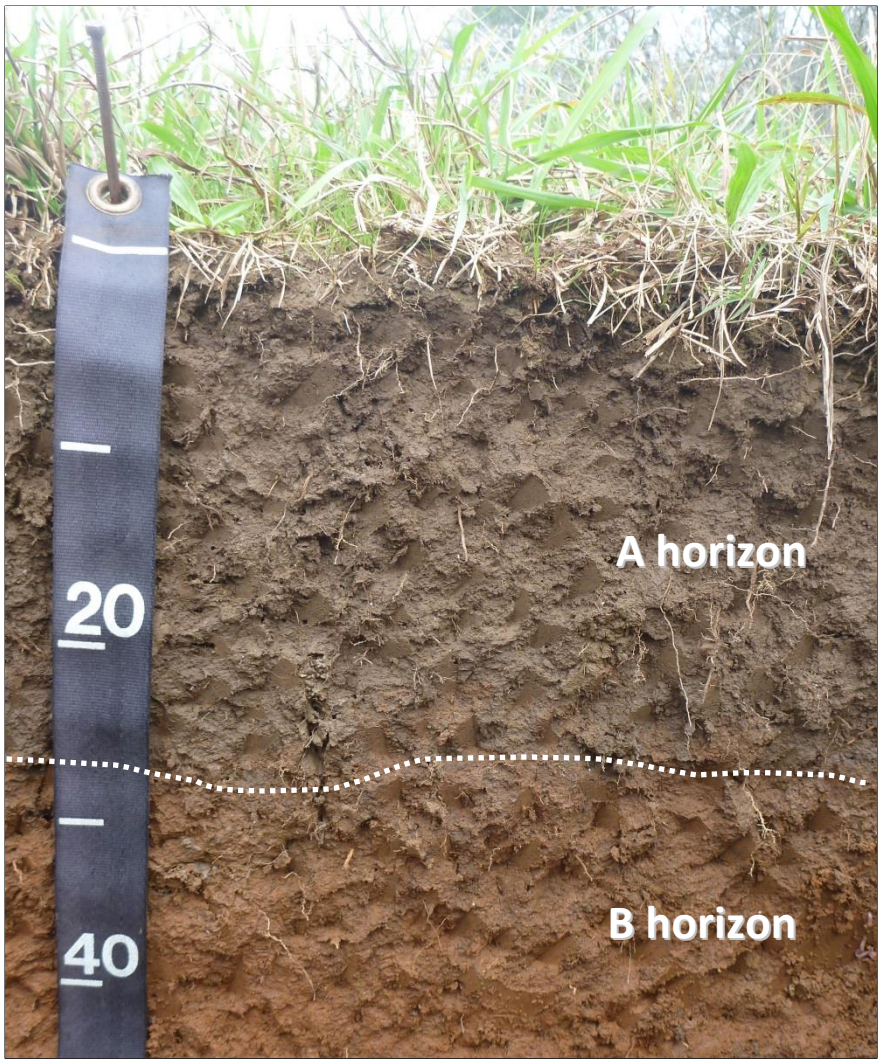
References

Gee, G.W. & Or, D. (2002) *Particle-size analysis.* In: Methods of Soil Analysis: Part 4 – Physical Methods. (Eds J.H. Dane, G.C. Topp) No. 5, Soil Science Society of America Book Series. Madison, Wisconsin, USA. Pp. 255-293.

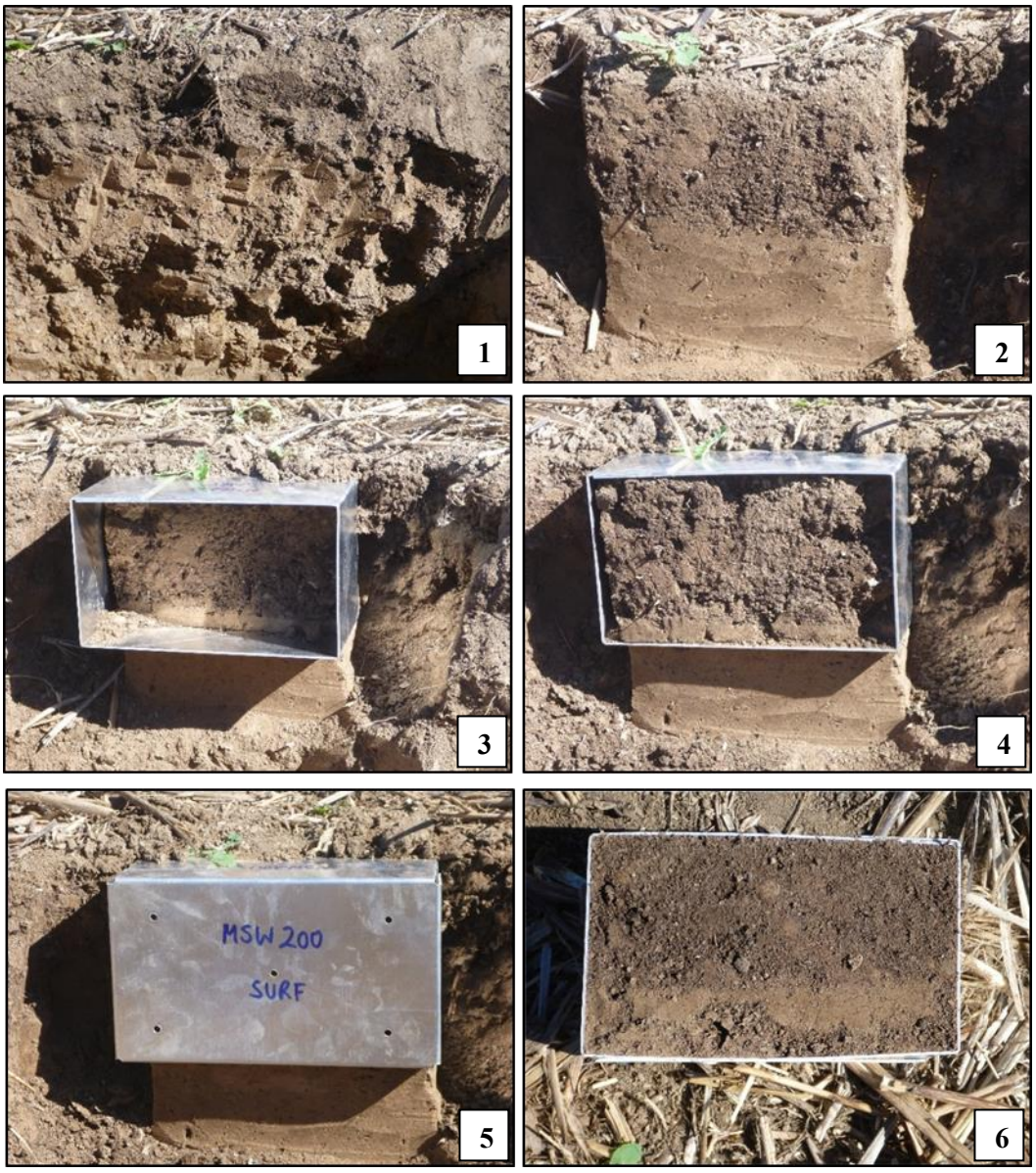
Jongerius, A. & Heintzberger, G. (1975) *Methods in soil micromorphology. A technique for the preparation of large thin sections.* Soil Survey Papers, No. 10. Netherlands Soil Survey Institute, Wageningen, The Netherlands.

NSW EPA (2014) *The organic outputs derived from mixed waste exemption 2014*. Resource Recovery Exemption under Part 9, Clauses 91 and 92 of the Protection of the Environment Operations (Waste) Regulation 2014.

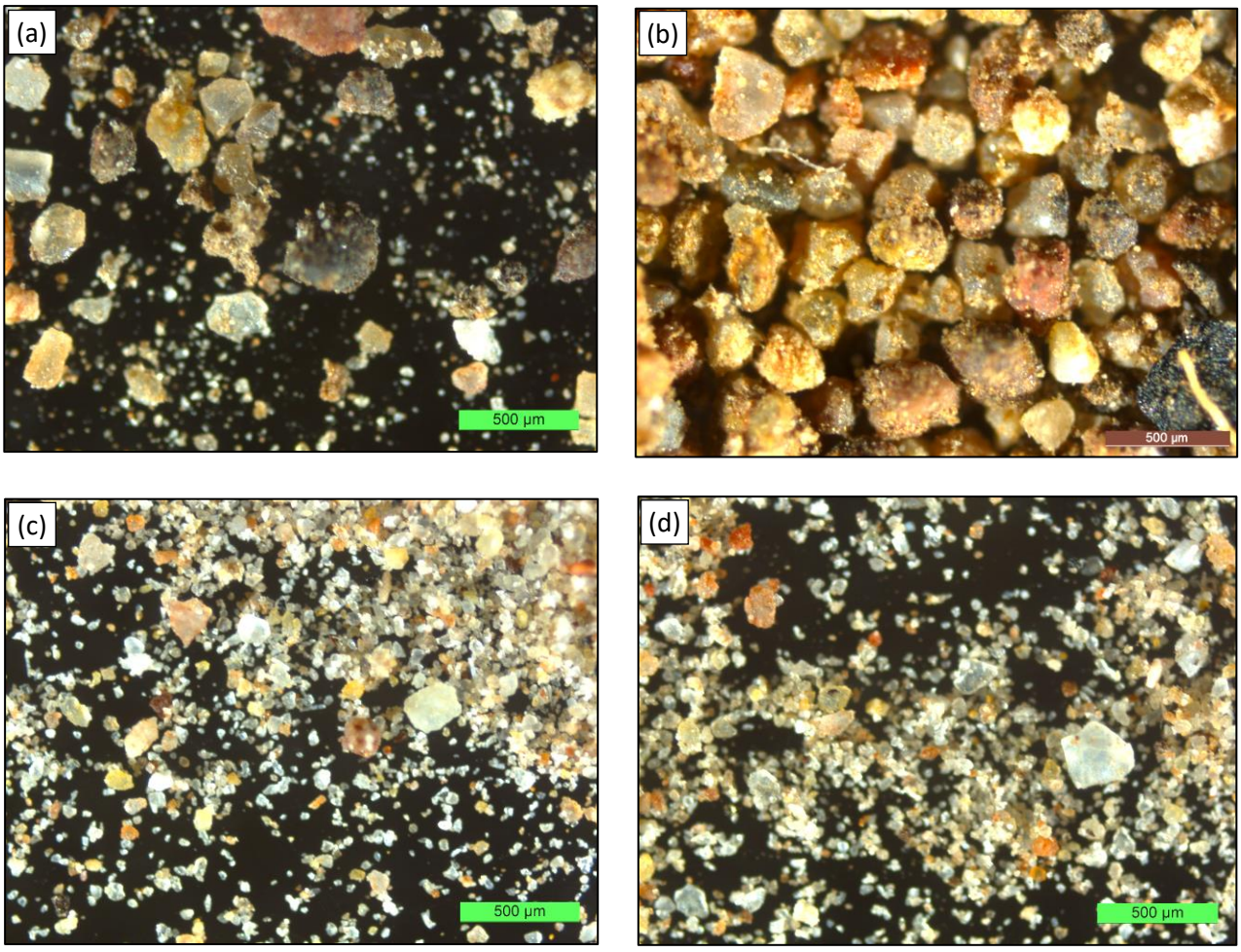
Appendix 1. The natural soil profile (Brown Chromosol) located adjacent to the MWOO- and GWC-treated plots.



Appendix 2. The procedure for sampling Kubiena tins of soil for thin section production.

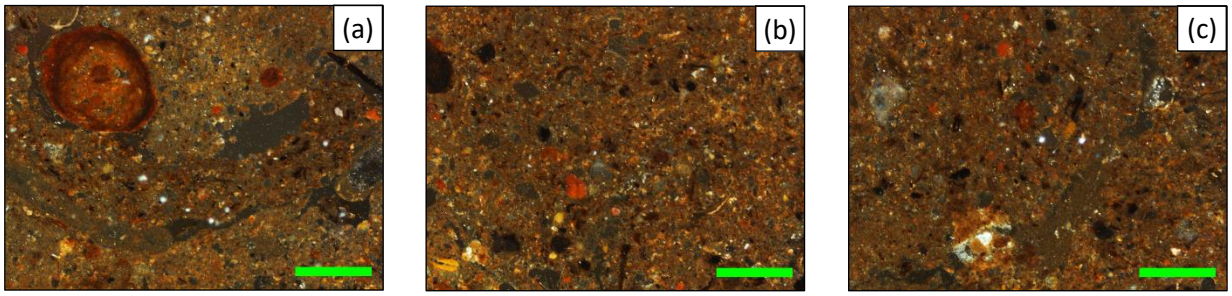


Appendix 3. Coarse-grained sand and fine-grained sand in the topsoil (a), (c) and upper subsoil (b), (d) of the Control soil.

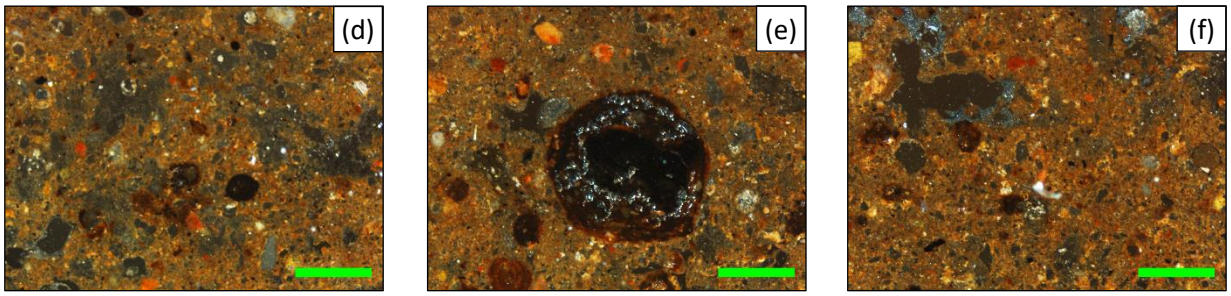


Appendix 4. Thin section images of the Control soil. Scale bar = 500 µm.

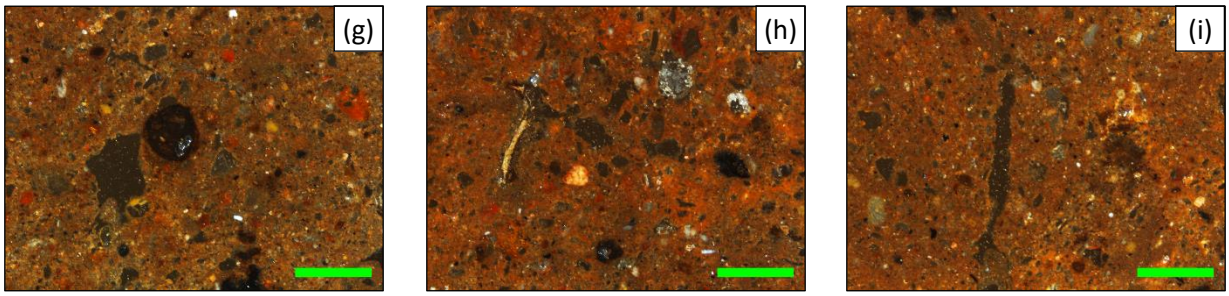
0–5 cm depth



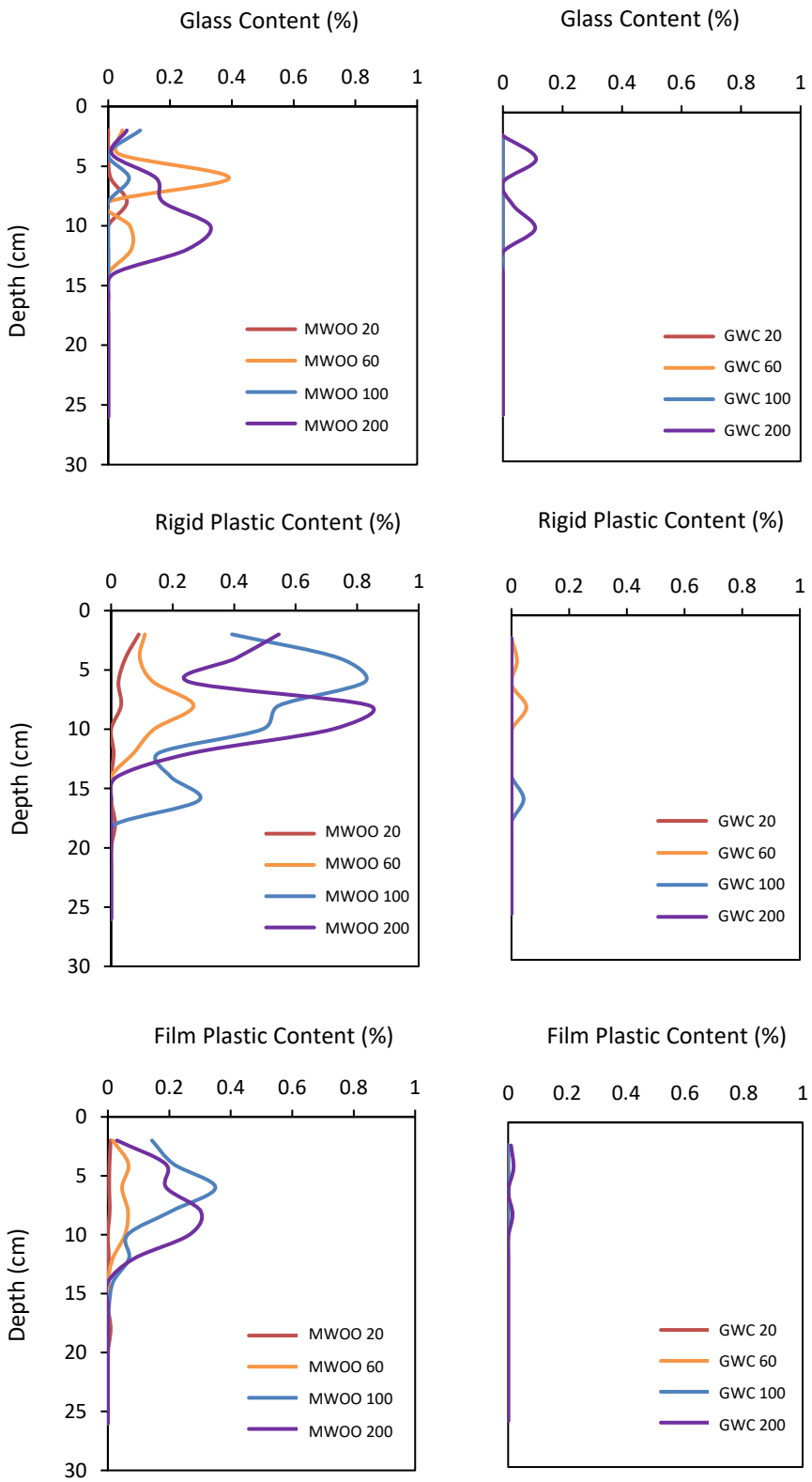
5–15 cm depth



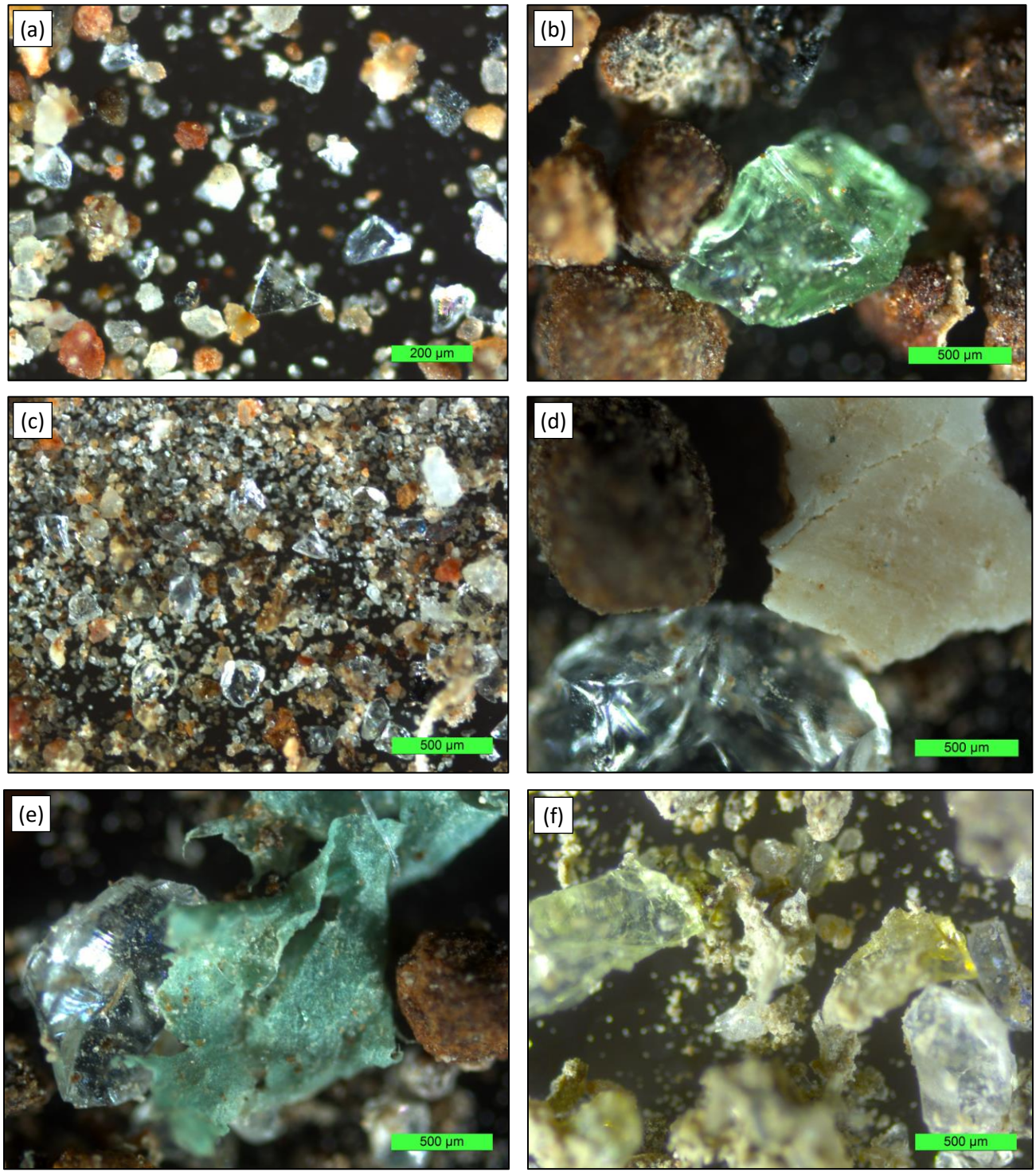
15–25 cm



Appendix 5. Proportions of physical contaminant types, by mass, in soil amended with MWOO (left column) and with GWC (right column).



Appendix 6. Glass and/or plastic fragments found in the sand fraction of MWOO 200-treated soil from depths of; (a) 4–6 cm, (b) 16–18 cm, (c) 10–12 cm, (d) 2–4 cm, (e) 8–10 cm, and (f) 0–2 cm.



Appendix 7. Physical contaminant particles in soil of; (a) GWC 200, 0–5 cm, (b) MWOO 200, 0–5 cm, (c) MWOO 200, 5–15 cm, (d) MWOO 200, 5–15 cm, (e) MWOO 100, 0–5 cm, (f) MWOO 100, 0–5 cm, (g) MWOO 20, 0–5 cm, and (h) MWOO 20, 0–5 cm. The scale bar represents 500 µm.