Countryside Survey 2007 (Soils)
Preparatory Phase II

Soil Bulk Density Sampling

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Task 1.2 (2) Bulk Density Scoping Study
(to determine accuracy of CS2000 sampling cores for determining bulk density, through comparison of CS2000 data and limited field sampling)

Task 2.2 Sampling of organic and sandy soils
(to assess and improve, if required, sampling of highly organic and sandy soils)

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Aim of Investigation

It is desirable to measure soil bulk density as a variable in CS2007/MASQ2. The most preferable method for measuring bulk density is usually the 'thumb crusher' corer, with the double walled cylinders (Allen, 1989). However, in the Countryside Survey, this is not possible, due to the survey logistics and health and safety issues. The most efficient method would be to use either one of the two pipes already in use for the chemistry and biology samples. The aim of this investigation is to determine their accuracy in determining bulk density, and to assess whether another method would be more suitable. Field and laboratory notes made during the investigation will also be used to make recommendations to update the soil sampling protocols in the Countryside Survey Field Handbook (Barr, 1998).

1. Introduction

Bulk density refers to the weight (mass) of soil per unit volume. The soil bulk density is normally expressed in g cm^{-3} (weight divided by volume) (University of Plymouth, 2006). It is an index of porosity and compaction, which affects root development potential and solute/gaseous movement (Costantini, 1995).

Bulk density calculation:

$$\text{Bulk density (g cm-3)} = \frac{\text{(Dry weight soil (g) - stone weight (g))}}{\text{(Core volume (cm-3) - stone volume (cm-3)}}$$

Whilst mass can easily be determined by drying the soil to a constant weight, volume is less easy to determine accurately (Allen, 1989).
Several methods have been proposed for bulk density measurement (see table 1).

1. Soil Coring

For sites where cores can be obtained with minimal disturbance, the use of a cylindrical core enables a known volume of soil to be extracted. The cylinder walls should be a thin as possible to minimise compaction (Allen, 1989). Double walled cylinders are particularly effective. The inner cylinder may be withdrawn and excess soil trimmed at either end. If used, single cylinders should, if possible, be driven slightly below the soil surface to allow trimming (Allen, 1989).

2. Extraction method

Where rocks and gravel prevent sampling using a core method, the extraction method can be used. This involves digging a hole, approximately 10cm deep and 15cm wide. Using a 2mm sieve, soil from the hole is sieved to remove rocks and gravel. The soil is then placed in a plastic bag. The hole is then lined with plastic/cling film. The sieved rocks are replaced in the hole. Using a syringe, the hole is filled with water. Alternatively, a funnel and sand may be used. The amount of water/ sand used represents the volume of soil removed from the hole (British Standards Institution, 1999).

3. Other methods

Other methods of measuring bulk density have been proposed, including the involvement of wax (Allen, 1989; Frasier & Keiser, 1993) and balloons (British Standards Institution, 1999). It has also been proposed that bulk density can be calculated using Loss on Ignition values (Harrison & Bocock, 1981; Jeffrey, 1970).

Table 1. Methods of measuring bulk density

Two differently sized plastic pipe cores were utilized in the 2000 field survey to collect soil samples for biology and chemistry analysis. This survey aims to investigate the accuracy for assessing bulk density from soil samples taken using these cores in relation to other types of cores and in relation to the pit extraction method, particularly in 'difficult soils' such as peat or sand. The other methods in no. 3, table 1, are not being considered in this study for reasons of practicality.

2. Methodology

Two methods of measuring bulk density were assessed; the coring method and the pit extraction method. For both methods, a maximum depth of 15cm was considered. Soil from any different horizons occurring was bulked together.
Samples collected were dried at 105^o for 24 hours, and weighed. Bulk density was calculated using the formula on page 3.

3.1 Coring Method

In addition to the 2 cores used in the last survey (black core - 15cm, white core - 8cm long), 3 further core types were tested (see table 2 for all cores). The 5 cores differ in various aspects, including length, width, volume, material and shape. A set of pliers was found to be invaluable for removing cores from the ground easily.

Five different cores were tested:

1. Black plastic core – 10cm long (volume 324ml *B*, 322ml *R*)
2. Black plastic core* – 15cm– trowel vs. tile method (peat/sand only) (volume 258ml *B*, 281ml *R*)
3. Small square metal core – 10cm long (volume 250ml *B*, 245ml *R*)
4. Larger square metal core – 10cm long (volume 622ml *B*, 632ml *R*)
5. White plastic core* - 8cm long (volume 95ml R)

**Core used in previous survey (CS2000)*
B = volume ascertained by bead method, R = volume ascertained by ruler method

Table 2. Core types tested in study.

As light sandy/organic soils are difficult to extract using the coring method, the method of removing the core after digging a pit and driving a plate horizontally to seal of the cylinder base (Allen, 1989) was tested in these two soil types. *See appendix Ia and figure 11 for detailed protocol.*

The volume of the plastic/metal core was determined by two different methods:

1. Plastic beads were used to fill the core, then the beads were measured in a measuring cylinder.
2. The core was measured by a ruler and the cylinder volume calculated from the measurements.

It is important to note the different results obtained by these two different methods of measuring the actual core/pipe volume, namely measurement of volume by beads, and measurement by ruler. The ruler method is likely to be more accurate, as beads can settle unevenly inside the core. However, the bead method was essential to ensure volume measurements were comparable across all methods, including the pit, for which it was not possible to measure accurately using a ruler.

3.2 Pit Extraction method

In addition to the cores, the extraction method was utilised. This involved digging a pit, then filling the resulting hole with a plastic bag and using water to measure the volume. *See protocol in appendix Ib for more details.*

3.3 Sites visited

Five field sites were visited, to allow the comparison of 5 different soil types. Soils tested were: clayey soil, sandy soil, peaty soil, stony soil and a woodland loam. Sites visited are in table 3.
Three replicates per extraction method (both coring and pit extraction), per soil type, were taken (excepting sand and clayey sand, as it was decided that the soils were uniform enough for just one sample to be taken).

Peaty soil: Moor House NNR, Cumbria. **Sandy soil:** Merlewood Garden/Lysimeter trench, Grange-over-Sands, Cumbria **Stony:** Merlewood Wood, Grange-over-Sands, Cumbria **Woodland loam:** Meathop Wood, Grange-over-Sands, Cumbria **Clayey sand (silt):** Holme Island Shore, Grange-over-Sands, Cumbria

Table 3. Sites visited.

3. Results and Discussion

3.1 Overall Results

Results are presented in two ways: firstly where the volumes of the different plastic/metal core types has been ascertained with the use of plastic beads; the other by measurement using a ruler, and subsequent calculation. The two methods have yielded slightly different results.

Bead Method

With core volume calculated by bead method	*Sandy clay*	*Stony loam*	*Sand*	*Peat*	*Woodland loam*
Pit	0.93	0.39	0.74	0.06	1.01
Black core 15cm (Tile method)	-	-	1.51	0.08	-
Black core 15cm (Trowel method)	1.02	0.47	-	0.06	1.08
Black core 10cm	0.83	0.30	1.08	0.07	0.89
Square large	0.85	0.35	1.22	0.08	0.92
Square small	0.72	0.41	1.20	0.08	0.84
White	-	-	-	-	-
Typical values (Harrison & Bocock, 1981):	0.43-1.14	0.11-0.99	0.43-1.14	0.03-1.8	0.11-0.99

Table 4. Mean bulk density values (in g cm-3), measuring core volume by plastic bead method.

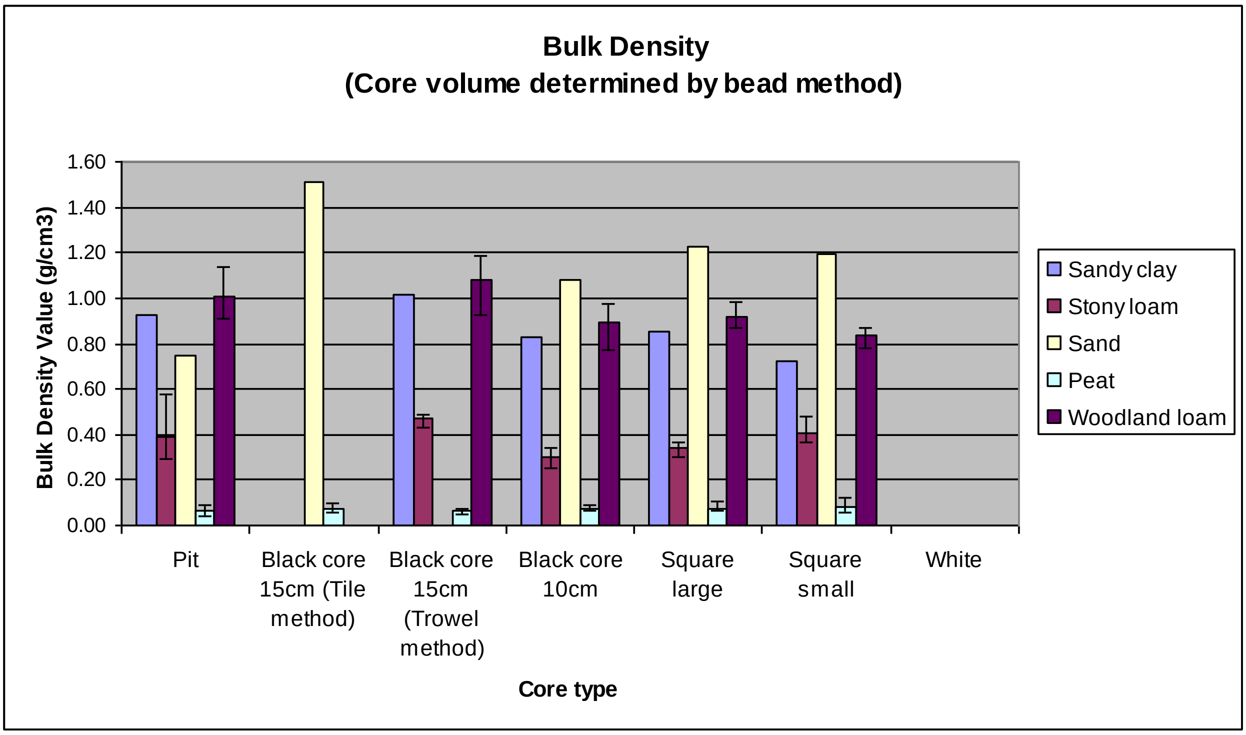

Figure 1. Graph of mean bulk density values, measuring core volume by plastic bead method.

Ruler Method

With core volume calculated by ruler method	*Sandy clay*	*Stony loam*	*Sand*	*Peat*	*Woodland loam*
Pit	-	-	-	-	-
Black core 15cm (Tile method)	-	-	1.39	0.07	-
Black core 15cm (Trowel method)	0.94	0.42	-	0.06	1.00
Black core 10cm	0.83	0.30	1.09	0.07	0.90
Square large	0.84	0.34	1.20	0.08	0.90
Square small	0.74	0.42	1.22	0.08	0.86
White	0.81	0.33	1.25	0.07	0.85
Typical values (Harrison & Bocock, 1981):	0.43-1.14	0.11-0.99	0.43-1.14	0.03-1.8	0.11-0.99

Table 5. Mean bulk density values (in g cm-3), measuring core volume by ruler method.

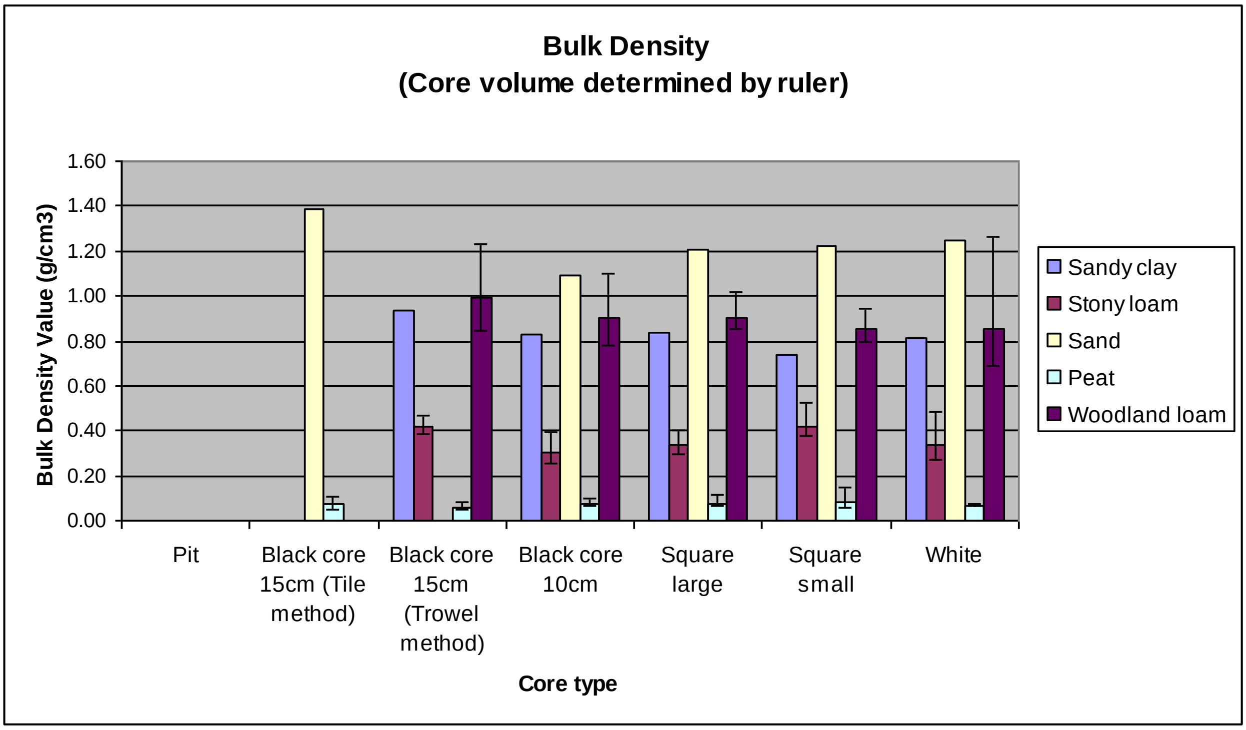

Figure 2. Graph of mean bulk density values, measuring core volume by ruler method.

From figures 1 and 2, it can be seen that measurements for bulk densities within soil types are fairly uniform. As could be expected, sand has the highest bulk density values, being very dense and compact, whilst conversely, peat has the lowest values.
In the sandy clay, the small metal square gave the lowest value (0.72/0.74 g cm-3), whilst the 15cm black core, excavated with a trowel gave the highest (0.94/1.02 g cm-3). In the stony soil, the 10cm black core gave the lowest value (0.3 g cm-3), whilst the 15cm black core gave the highest (0.47/0.42 g cm-3).
In the sand, the pit gave the lowest value (0.74 g cm-3), and the 15cm black core the highest (1.51/1.39 g cm-3). In the peat, the results were relatively consistent, with a range of 0.02 g cm-3 between the lowest (0.06 g cm-3) and highest values (0.08 g cm-3). The woodland soil had the small metal square as the lowest value (0.84/0.86 g cm-3) and the 15cm black core as the highest (1.08/1 g cm-3).

Beads

	Sandy clay	Stony loam	Sand	Peat	Woodland loam
Range:	0.29	0.17	0.77	0.02	0.24

Table 6. Range between lowest and highest values across soil types. In g cm-3. (bead method)

Ruler

	Sandy clay	Stony loam	Sand	Peat	Woodland loam
Range:	0.20	0.12	0.30	0.02	0.14

Table 7. Range between lowest and highest values across soil types. In g cm-3. (ruler method)

Sand has the highest range between sampling techniques, with the lowest value being measured using the pit method (0.74g cm-3) and the maximum value being 1.51 g cm-3 for the 15cm black core, with the tile. Peat has the smallest range with a difference of 0.02 g cm-3 between the lowest and highest values (figures 1,2,3 and 4; tables 6 and 7).

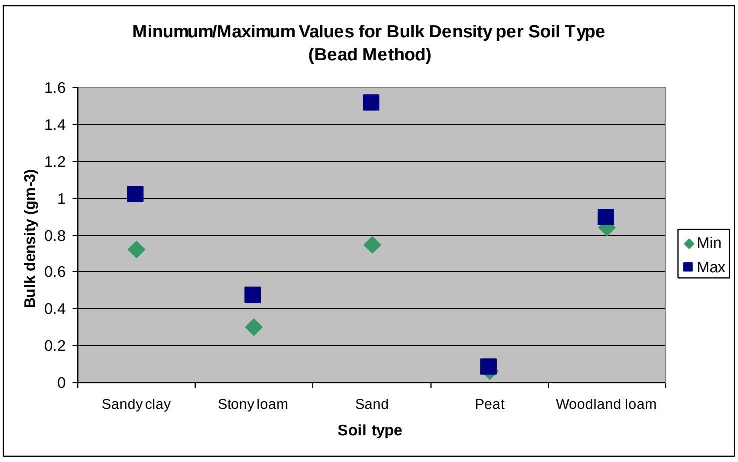

Figure 3. Graph to show minimum and maximum bulk density values across soil types (bead method).

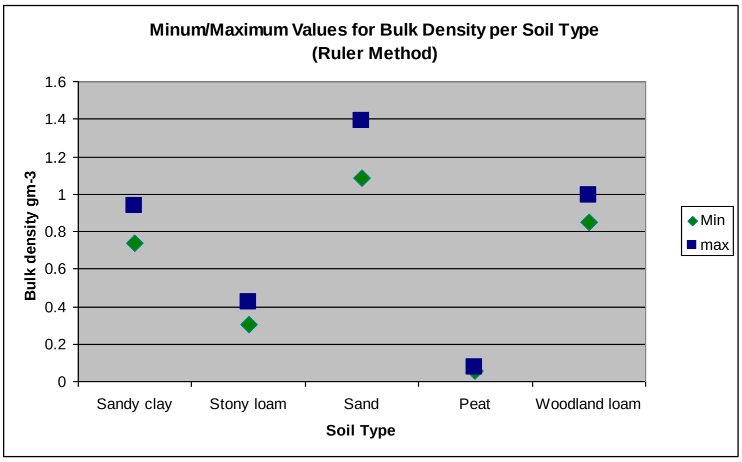

Figure 4. Graph to show minimum and maximum bulk density values across soil types (ruler method).

4.2 Results by Core Depth

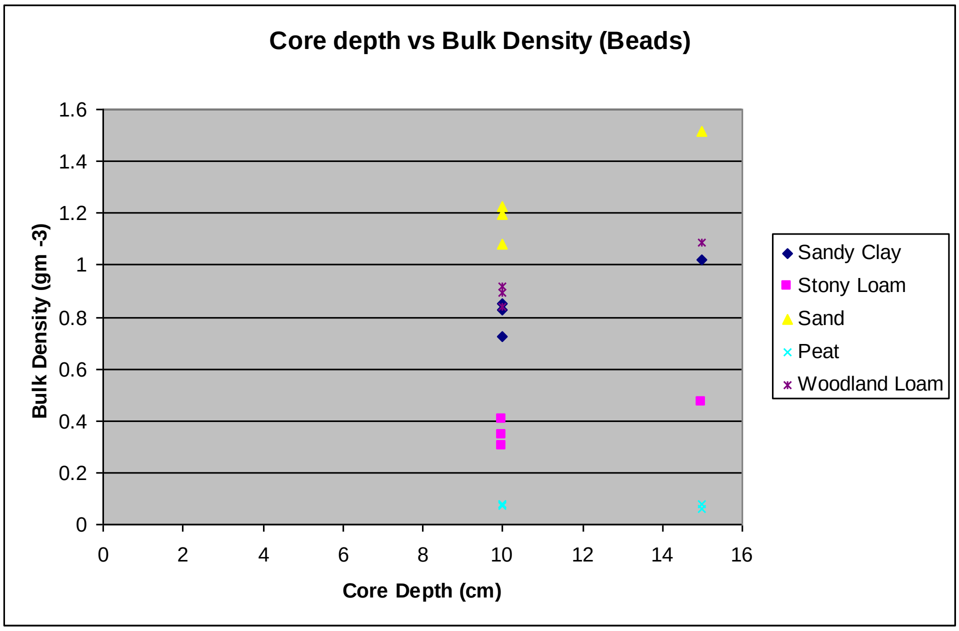

Figure 5. Scatter graph to show relationship between core depth and bulk density value (bead method)

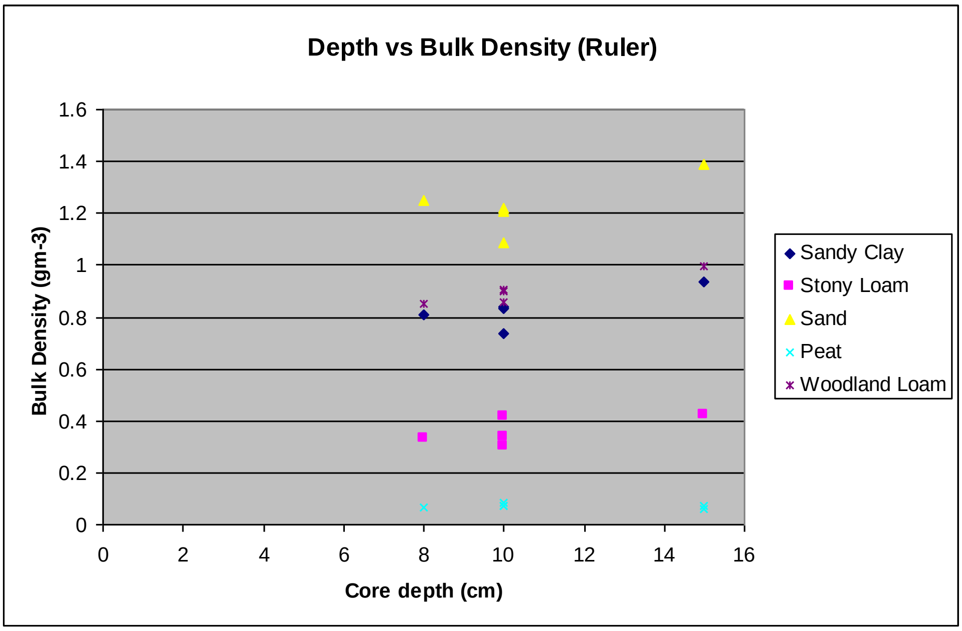

Figure 6. Scatter graph to show relationship between core depth and bulk density value (ruler method)

Where the black 15cm core was used, particularly with the trowel extraction method, the bulk density tended to be higher than cores taken by other shorter core types, notably within the loams and sandy clay. This is likely to be because soils have a higher bulk density with depth, due to a higher level of compaction lower down the profile, and more organic matter in top layers, with more mineral layers further down. When taking bulk density measurements, this must be borne in mind, as the value obtained is not directly comparable with that at higher depths. The ideal situation would be to take separate samples at different depths. However this will not be practical for the Countryside Survey due to the additional time incurred.

4.3 Material and Shape of Cores

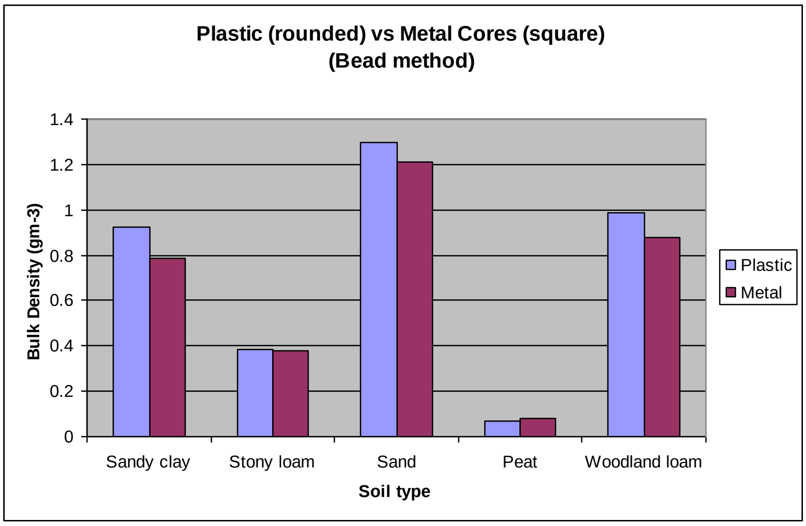

Figure 7. Graph to show a comparison between plastic (rounded) and metal (square) cores (bead method).

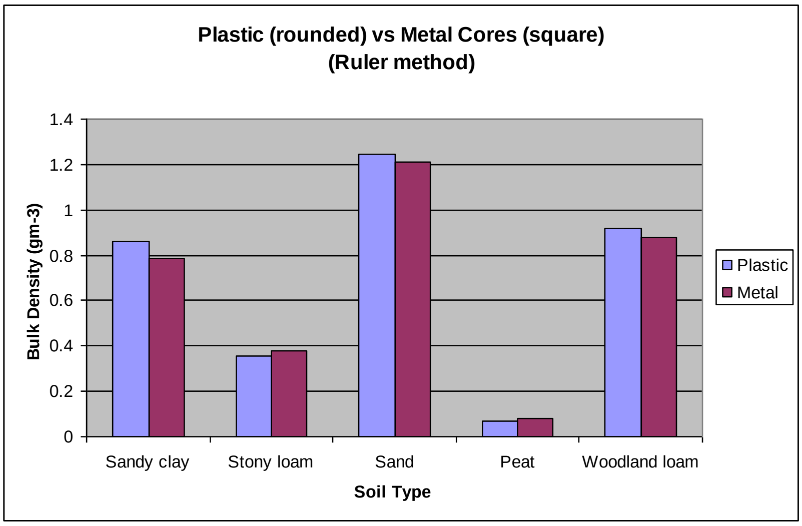

Figure 8. Graph to show a comparison between plastic (rounded) and metal (square) cores (ruler method).

In the field, the metal cores tended to be more easily inserted into the peat and sands, whereas they easily became distorted in the woodland soils, where the plastic cores became more practical. Distortion leads to a change in volume which affects the bulk density calculation. In the sandy and loamy soils, part of the sample could easily become lodged in the corners of the core. This was less of a problem in the cylindrical cores.

In terms of results, the material from which the core was made appeared to not affect the results greatly. In all cases besides peat, the round plastic cores gave a slightly higher bulk density value than the square metal cores. The differences between the two metal cores were in many cases greater than between metal and plastic or round and square (figures 1 and 2).

4.4 Volume of core

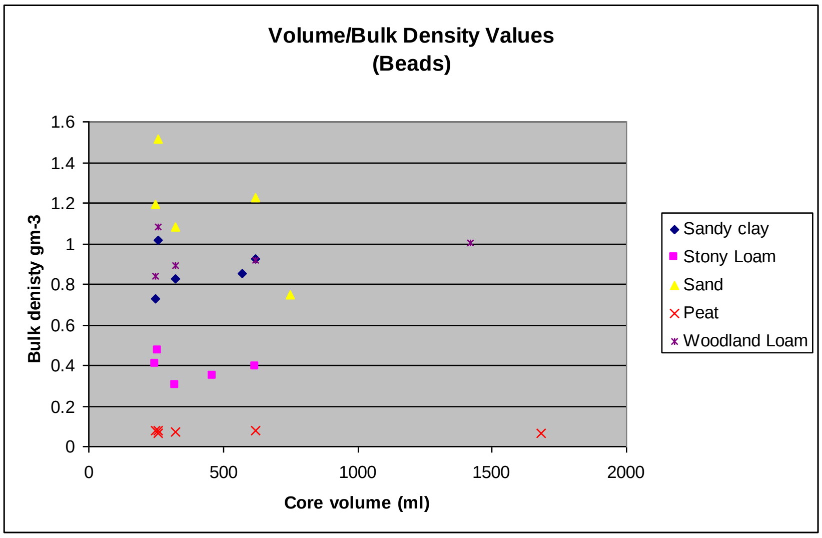

Figure 9. Graph to show the relationship between core volume and bulk density values (bead method).

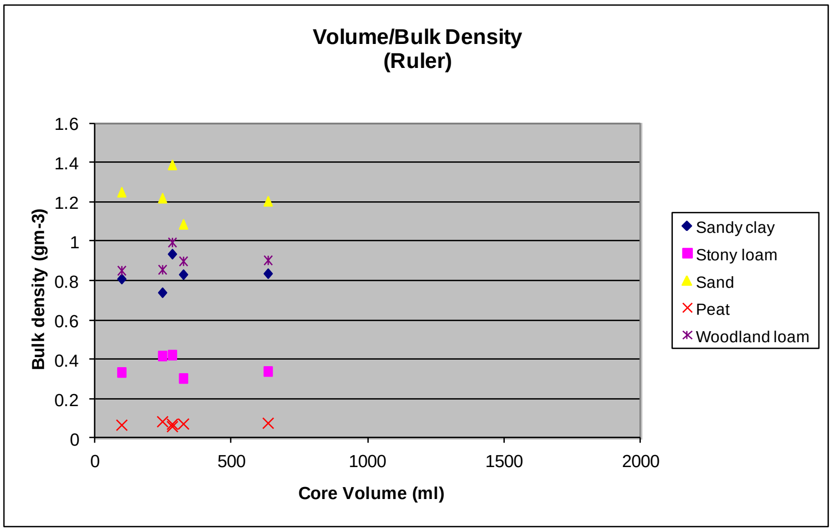

Figure 10. Graph to show the relationship between core volume and bulk density values (ruler method).

The graphs in figures 9 and 10 show that the larger volume corers are no more likely to give a higher or lower bulk density value than the smaller volume corers.

The overall volume of the coring device does not appear to make an important contribution to the final bulk density value, therefore a wider core is no more useful than a narrower corer. Differences are more likely to be affected by the depth of core (figures 5 and 6) and also possibly the care in which the core was taken.

4.5 Method of extraction

In the sand, the tile method was the only possible method of removing the core, as digging the core out with a trowel resulted in a large loss and disruption of the sample. In the peat, both methods were tested. The tile method used with the 15cm core gave the highest bulk density value, while using the trowel gave one of the lowest values. This either signifies that the tile method compacts the soil, or the trowel method doesn't allow a full core to be taken. The difference between the two was 0.02 g cm-3.

In terms of the pit excavation method, in the woodland soils and sandy clay, the pit excavation method gave the second highest value for bulk density. However, for the sand and peat, the pit gave the lowest value for bulk density. In the peat, the difference between the pit method, and the next closest method was not great (0.01 g cm-3). In the sand, the difference was 0.34 g cm-3. The difference could be due to sand caving into the hole at the crucial volume measurement stage, meaning the hole from which the sand was extracted became a smaller volume when the volume was actually measured with the water.

4.6 Comparisons with typical values

Results compared well with the range of typical values in tables 4 and 5 (Harrison & Bocock, 1981). Although the ranges are fairly wide, results fell within the range, apart from the 15cm core, which was 0.01 g cm-3 above the typical values for woodland loam, and the white core, the squares and the 15cm core; which are above the range for sand. However, the typical values are for close approximations to the soil types tested, and may not necessarily be a good indication of the correct value for the exact soil types in this study.

4.7 Comparisons with previous data (CS2000)

In the last survey, bulk density values were calculated for certain soils. For one survey square with typical sand clay soil, such as that at Meathop, the bulk density in 2000 was 0.95 g cm-3. The closest to this value was the value obtained by the 15cm core (used in CS2000), when measuring the core using a ruler. This gave a value of 0.94 g cm-3, only 0.01 g cm-3 difference from the value in the last survey, as you would expect. The pit method (0.93 g cm-3) was the next closest. The small square, with a value of 0.72 g cm-3 was the furthest from the previous value, probably because it sampled a shallower depth.

4. Conclusion

Overall, the different core types tested gave fairly consistent bulk density values across soil types, with variation between soil types being higher than variation in the bulk density sampling method used. The low bulk density value measured in the sand pit can be explained by sand caving into the pit whilst volume measurement is being undertaken. For this reason, the pit method is not suitable for very sandy soils. The black 15cm core tended to yield higher bulk densities, but the deeper cores can't be directly compared to the shorter cores, as soil tends to have higher bulk densities further down the profile due to increased compaction, and higher levels of organic matter in the top of the profile. No one core type gave consistently higher/lower bulk density values. For these reasons, it is concluded that the 15cm black pipe already in use in Countryside Survey is adequate for measuring soil bulk density.

The key point to note is that surveyors must remove whichever core they are using very carefully from the ground, and ensure the core is filled fully to obtain best results.

The study has been useful for identifying issues in the field which will can be added to the Countryside Survey field handbook (Barr, 1998). Recommendations to be considered for CS2007 are outlined in the next section.

Recommendations for 2007 Survey

Recommendations – *Core Type*

Any methods used for sampling in the Countryside Survey must take into account the time available in the field, the capacity of the field team to carry equipment, and the logistics of the survey.

- The pit extraction method is not feasible due to the amount of heavy equipment needed and the complexity of the task.
- Although the metal square cores tended to hammer in more easily, they tended to distort easily in difficult soils, making their use limited. In ‘sticky’ soils, some of the sample was left in the corners of the core. They are also heavier to transport by post.
- Taking the above into account, the pipe coring method is the only method which can be realistically carried out in a consistent manner on such a large scale.
- The black 15cm cores used in the last survey are acceptable to use for measuring bulk density in the majority of soils, on the condition that surveyors/lab. personnel follow careful instructions.
- Results vary a small amount depending on the method used to measure the actual core of the pipe/core used (i.e. beads or ruler measurement).
- Chamfered edges on core pipes are desirable

Recommendations - *Field Sampling*

- The tile to hammer on top of the core must be toughened plastic, not wood or metal, as these break and distort.
- A good pair of pliers is required to pull cores from ground.
- Brightly coloured tape should be affixed to all tools, including knives, pliers, trowel and hammer to increase visibility in the field.

Recommendations – *Lab. Preparation*

- For clayey soils, ensure core is spread well over tray before drying, otherwise soil core sets in a solid cylinder shape.
- If core is longer than the pipe (e.g. peat) carefully trim the extra sample so the core is flush with the ends. Discard the extra.

Changes to field handbook/protocol

- Take care not to compact or distort the soil when taking the sample.
- Make sure soil is level with ends of plastic core – i.e. core is full of soil.
  If necessary, 'top up' pipe using a trowel.
- As a last resort, in very dry sandy soils, it may be necessary to dig a pit, then insert a tile horizontally into the profile at the depth of the pipe before taking the core to prevent loss of sample (figure 11). This should only be used if it is not possible to 'top up' the core for some reason with the trowel, to cause minimum disturbance to the plot.
- In very stony soils it may not be possible to take the sample. *Detailed instructions for relocation are already in the handbook.*
- It is possible to extract peat using a trowel, placed underneath the core. The core should ideally be hammered slightly lower than the ground surface, to ensure a full core. **It is better to have the sample overhanging the ends of the core than to have a half empty core.**

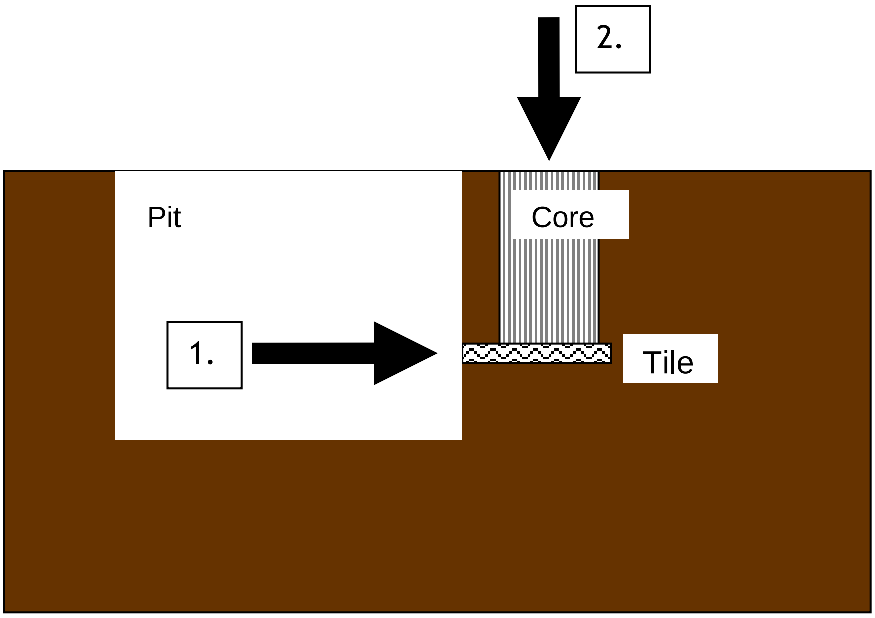

Figure 11. Diagram to show method to be used in very dry, sandy soils.

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Appendix Ia – Field Protocols

Equipment Required (per site)

For coring method:

- White core
- Black cores
- Metal cores
- Plastic square/wooden block/aluminium tile
- Mallet
- Knife

For extraction method:

- Cling film
- Measuring jug/graduated syringe/graduated cylinder
- Funnel
- Water (5l)
- Trowel
- 2mm sieve

Other useful items:

- Plastic bags
- Marker pen
- Spade
- Pliers

Coring Method

**Take care not to compact or distort the soil core when taking the sample*

1. Remove surface vegetation and litter.
2. Drive white core into soil using plastic plate (placed on top of core) and mallet, until plate is level with surface. Make sure the whole core is filled with soil.
3. Cut around the core using the knife. With the trowel underneath core, carefully lift the core out to prevent loss of soil. Use pliers if necessary.
4. Place core in bag. Do not trim any excess soil off either end.
5. Repeat using black cores and metal cores.

Extraction Method

1. Choose a level spot of ground.
2. Dig a hole, approximately 10cm deep and 15cm wide.
3. Using a 2mm sieve, sieve the soil from the hole remove rocks and gravel, if necessary.
4. Place soil in a plastic sample bag.
5. Line the hole with plastic/cling film.
6. Place the sieved rocks in the hole.
7. Using a syringe or graduated measuring cylinder, fill the hole with water.
8. Note down the amount of water required to fill the hole

Appendix Ib – Laboratory Protocol

Equipment Required

- *Foil trays*
- *Oven*
- *Balance to 2 d.p.*
- *Pen/notebook*

Laboratory Work

1. Weigh foil tray labelled with sample ID.
2. Lay out core in tray, and weigh. Continue for all samples.
3. Place samples in oven at 105^o for 24 hours.
4. Weigh samples again.
5. Record tray weight, wet weight and dry weight in Excel. Subtract weight of tray from final dry weight.
6. Perform bulk density formula with data.

Appendix II - Field observations

Peat (Moor House)

Core Type	Advantages	Disadvantages
Small square core – trowel	Chamfered edge allows easy insertion of core. Full core was easily removed.	May cause soil compaction?
Large square core – trowel	" "	" "
Narrow 15cm black core – tile/trowel	May mean less compaction, as tile is inserted at depth of core.	Difficult to remove full core, bottom portion of core often missing. Corrected by inserting metal tile at correct depth, but, necessary to dig pit in order to insert tile horizontally into soil. Causes disturbance of plot. Difficult to insert core into soil easily, as relatively thick edges. (Higher risk of hammering hand!) Core less likely to enter soil vertically than metal core.
Wide black core- trowel	" "	" "
Pit	Little compaction of soil.	Difficult to judge exact surface of soil in order to fill water to be level. Spade and water very heavy to carry. Cling film doesn't work, plastic bag used.
White Core- trowel		Difficult to hammer in. Likely compaction.

Woodland Loam (Meathop Wood)

Core Type	Advantages	Disadvantages
Pit		Difficult to judge when water is level with ground
Black core 15cm- trowel	Plastic more easy to insert than metal.	
Black core 10cm- trowel	Wider core slightly easier to hammer in than the narrower, 15cm core.	
Square large- trowel		Distorts easily when hits a rock.
Square small- trowel		Distorts easily when hits a rock.
White- trowel		

Clayey sand (Holme Island shore)

Core Type	**Advantages**	**Disadvantages**
Pit		Difficult to judge when water is level with ground.
Black core 15cm - trowel	Inserted easily	
Black core 10cm- trowel	Inserted easily	
Square large- trowel	Inserted easily	More likely to leave part of core still in corners of square than in circular core.
Square small- trowel	Inserted easily	" "
White- trowel	Inserted easily	

Sand (Merlewood Garden Lysimeter trench)

Core Type	**Advantages**	**Disadvantages**
Pit		Difficult to judge when water is level with ground. Sand caved into hole.
Black core 15cm - ***trowel***		Not really possible to use trowel, as core is disturbed easily.
Black core 15cm - **tile**		Tile method was possible, but difficult, as sand tended to fill hole. May be only method possible however.
Black core 10cm- **tile**	Inserted easily	""
Square large- **tile**	Inserted easily	""
Square small- **tile**	Inserted easily	""
White- **tile**	Inserted easily	""

Stony Soil (Merlewood Wood)

Core Type	**Advantages**	**Disadvantages**
Pit	Easier to dig hole with spade than hammer core in.	
Black core 15cm - trowel		Necessary to 'top up' core underneath to ensure full core.
Black core 10cm- trowel		""
Square large- trowel		"" Distorted easily on rocks.
Square small- trowel		"" ""
White- trowel		""
		All cores fairly difficult to insert. Had to keep trying several times in different places (within $2m^2$) until possible.