

# **Trials to Identify Soil Cultivation Practices to Minimise the Impact on Archaeological Sites**

(Defra project number BD1705)

## **Effects of Arable Cultivation on Archaeology**

(EH Project number 3874)

**Known collectively as: 'Trials'**



## **Appendix 5: Conclusions and Recommendations**



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# **Appendix 5**

## **Conclusions and Recommendations**

**By**

**Spandl, K, Hann, M and Godwin, D, Dian-Owens, A**

**Edited by**

**Booth, P and Spandl. K**

## **Appendix 5**

### **Conclusions and Recommendations**

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## Appendix 5

### Conclusions and Recommendations

#### 1 CONCLUSIONS

1.1.1 Based on the results of this study the following conclusions can be drawn:

#### 1.2 Pressures at depth

- 1.2.1 The subsoil pressure applied to buried archaeological deposits and objects is a function of the magnitude of the applied surface contact pressure, load, depth of burial and soil strength. The surface contact pressure influences the magnitude of the subsoil pressure and the load influences the depth to which it occurs. For a given applied pressure and load the subsoil pressure decreases significantly with depth (typically by a factor of 3 between the depths of 0.25 and 0.50 m). There is evidence that the transmitted pressure is greater as soil strength decreases with increasing moisture content.
- 1.2.2 The greatest subsoil pressure will therefore be at the shallowest burial depth. For the purposes of this study this was taken as 0.25 m, as most artefacts buried shallower than this are likely to have been sustained physical damage over time as a result of agricultural practices.
- 1.2.3 The pressures transmitted to buried objects by wheeled and track loads are two orders of magnitude greater than those of a practical range of tillage implements. For example a truck tyre loaded to 5 t and inflated to 7 bar is the most damaging of all the loads applied, resulting in a subsoil pressure at 0.25 m of 6.7 bar. Less than half this subsoil pressure is transmitted by a combine harvester tyre loaded to 10 t and inflated to 2 bar; a reduction in tyre pressure to 1 bar reduces the subsoil pressure to 2 bar. In comparison the greatest subsoil pressures from tillage implements are 0.38 and 0.3 bar deriving from furrow presses and heavy rollers respectively. All other tillage implements produce pressures of less than 0.1 bar and are similar to or less than that caused by a man walking (*c* 0.03 bar).
- 1.2.4 The above and other data comparing the effects of the same load at higher and lower tyre pressures illustrate the importance of reducing tyre pressure to the lowest safe working pressure as specified by the equipment and tyre manufactures for the operating load and conditions. The use of dual tyres and rubber tracks significantly reduces subsoil pressure.
- 1.2.5 The pressure transmission to buried objects from wheel and track loads is marginally less in clay soil than in sandy soils at depths greater than 400 mm. This is ascribed to a potentially greater strength of the undisturbed clay soil.

#### 1.3 Buried artefact breakage laboratory trials

- 1.3.1 Of the replica ceramic pots buried in a horizontal orientation at 0.25 m below ground surface the lowest breakage point of 1.3 bar was recorded for the shell-tempered pot (representative of some later historic period wheel thrown vessels). The rims of all pots failed at slightly lower pressures than their bodies. This provides a reference point to pot breakage indicating the 'worst case scenario' for the most fragile pots. The other pots broke at higher subsurface pressures, ranging from 1.6 bar to 3.6 bar.

- 1.3.2 Analysis of the fragments of the replica ceramic vessels suggested that fabric composition is probably less significant than factors such as the degree (ie hardness) of firing in determining the ability of the vessel to withstand pressure. Better-fired pots will generally be more resistant to pressure in the first instance, and once broken their component fragments will still have been more robust than low-fired ones. However, very highly-fired sherds (eg the modern terracotta pots discussed in Appendix 2.1, which broke at 1.1 bar as opposed to 1.3 bar) can be brittle and may continue to fragment under pressure, whereas some vessels in softer fabrics may be distorted after initial cracking rather than broken further under continued pressure. This appears to be the explanation for the survival of a number of some of the handmade 'prehistoric' vessels (both Beaker and later prehistoric) in cracked but not shattered form, although in the present instance this survival is probably also related in part to the shape of the vessel.
- 1.3.3 The breakage dynamics of the aged non-collagenous, medieval, human radius bones showed that the perpendicularly-orientated bones broke primarily in tension. The orientation of the bones was a very significant factor in whether or not the bone would break. No parallel-orientated bones broke in this study, while most of the perpendicularly-orientated bones broke. The lowest recorded pressure resulting in the breakage of bones was 2.8 bar.
- 1.3.4 Experiments with modern terracotta pots buried at 0.25 m at different orientations showed that the lowest breaking peak subsurface pressures were:
- 1.1 bar for the horizontally-orientated pots
  - 1.9 bar for the 45-degree-orientated pots
  - 2.2 bar for the vertically-orientated pots
- 1.3.5 Regarding the breakage dynamics of the modern pots themselves, it was observed that similarly-orientated pots always broke in a similar manner. With pots in the horizontal orientation, the rim always seemed to break first. The crack would then extend through the body of the pot. The influence of the bottom of the pot on the ability of the terracotta material to resist breakage seemed to have an effect 1/2 to 2/3 of the way down the pot. The crack then split into an upside-down Y-shape, ending at the bottom of the pot. The 45-degree orientated pot broke in a different fashion; four main cracks would appear in the rim, all almost parallel to each other. One crack would always occur at the uppermost part of the vessel, one at the bottom, and the other two on either side of the pot. The vertically-orientated pot was the most resistant to pressure. In every case the bottom of the pot popped out leaving the remainder of the vessel unbroken.

## 1.4 Pressure at depth in the field

- 1.4.1 The data for subsoil pressures applied to buried archaeological features in the field trials show that for primary tillage with secondary tillage operations, deep inversion produces the greatest values (ie greatest transfer of pressure at depth), followed by shallow inversion, then non inversion and finally zero/no-till. However in terms of the overall effect of field operations on archaeological remains the significance of these differences is minimal; other factors result in much more significant impacts. As subsoil pressure reduces significantly with depth, at a depth of 0.35 m and below only the truck tyre inflated to 7 bar with a 5 t load might cause fracture of the weakest pots.
- 1.4.2 Higher moisture content could account for up to a 0.25 bar increase in pressure transfer. This suggests that the moisture content at the time of field loading and pressure transfer needs to be considered when making management decisions. Higher

soil moisture content weakens the soil, allowing greater wheel sinkage and hence greater pressure transmission.

- 1.4.3 When tillage implements (eg rollers and harrows) were pulled by lighter tractors equipped with LGP tyres the resulting pressure transmitted was much less than when they were drawn by heavier tractors on conventional tyres. Using a harvester with tracks rather than wheels also reduces pressure transmission.
- 1.4.4 The lowest breakage threshold value recorded in the soil bin trials using the replica historic pots, 1.3 bar for the shell-tempered late Saxon St Neots type cooking pots, would have been exceeded by the pressure achieved below the ploughsoil (at a depth of 0.25 m) by the drill, 'Simba Solo', sprayer, combine harvester, tractor and trailer and both ploughs. The modern terracotta pots buried horizontally (broken at 1.1 bar) would also have been broken by these operations.
- 1.4.5 Only the pressures generated by shallow ploughing and conventional ploughing at a depth of 0.25 m would have affected the pots breaking at 1.6 bar, and none of the secondary tillage operations would have broken the stronger pots breaking at 3.1 bar and 3.6 bar, nor would they have broken the bones.
- 1.4.6 The field results suggest that secondary operations, including zerotill, harrowing, rolling and drilling present little or no risk to the buried artefacts considered.

## **1.5 Effects of cultivation on the flat sites**

- 1.5.1 The depths of truncation of the replica archaeological sites over time were recorded at:
  - accelerated mouldboard plough plots 0.10 m over 30 years - 0.003 m a year
  - accelerated shallow plough plots 0.07 m over 30 years - 0.002 m a year
  - real time mouldboard plots 0.03 m over 3 years - 0.01 m a year (this faster rate may indicate an initial settling).
- 1.5.2 These rates are similar to those seen on real archaeological sites where this information has been recorded.
- 1.5.3 Mouldboard plough and shallow ploughing tend to damage archaeological sites over time – as seen in both the accelerated and real time trials. This is likely to be caused by a combination of a) long term erosion because of the difficulties in maintaining an exact plough depth (especially a shallow depth), b) soil movement created by the forward movement of the plough and c) more dramatic erosion as a consequence of undertaking cultivation when soil moisture levels are high (above 20% in the case of the sandy loam soil, which is at or just above the field capacity condition).
- 1.5.4 The ploughed plots showed significantly greater soil depth disturbance when primary cultivation occurred at times of higher moisture content. This is probably caused through a combination of some sinkage of the tractor wheels (although this was minimised by using large tyres inflated at low pressure) and the decreased capacity of the soil to maintain the weight of the plough, causing it to bite deeper.
- 1.5.5 The study shows no development of compaction pans away from the wheelings in any of the plots, including the direct drill and non-inversion tillage plots, even after 30 years of primary and secondary tillage.
- 1.5.6 Conventional ploughing and shallow inversion are likely to reduce the natural soil strength and make soils more vulnerable to compaction. The shallow non-inversion tillage and direct drilling operations carried out here were found to result in better retention of natural soil strength and make the soil less prone to compaction.

- 1.5.7 More carbon is retained in the plots where cultivation works the soil the least. All types of cultivation affect the density of the soils over a 30 year period, but direct drilling and shallow ploughing tended to have the least effect overall.
- 1.5.8 Direct drilling and shallow non-inversion tillage will offer long term protection over archaeological sites if they are sustainable without the need for subsoiling below the primary cultivation depth.
- 1.5.9 There is evidence to suggest that shallow subsoiling/deep tillage/loosening to a depth of 0.25-0.30 m will remove the effects of shallow soil damage caused by surface wheelings. It is probably only the single grain structured sandy loams and similar soils that will need this aftercare, as many clay soils in England will naturally crack and restructure during drying periods. It is better, however, to prevent the formation of ruts and pans in the first place by following the recommendations laid out below and in the Defra guide to good soil management (Defra 2009)
- 1.5.10 Subsoiling will cause significant damage both to buried artefacts when the implement tines come into direct contact with these and to archaeological features from dragging and mixing of deposits.
- 1.5.11 Moisture is a key factor in affecting damage. High moisture levels in the soil can lead to higher pressure transference, rutting and compaction in the wheelings, and the reduced soil strength can lead to the plough penetrating deeper into the ploughsoil and the underlying deposits.

## 1.6 Cultivation of earthworks

- 1.6.1 The average height loss of the minimum tilled earthworks was *c* 0.01-0.03 m per year, the variation correlating significantly with earthwork type. The average height loss of the ploughed earthworks was *c* 0.01 m per year.
- 1.6.2 Minimal tillage of earthworks does not offer significant protection to earthworks compared to conventional ploughing. Non-tillage (direct drilling) was found to offer the only long-term sustainable protection for most earthworks if they remain in cultivation. Managed pasture forms the only other sustainable protection for earthworks, although increased bioturbation may be an issue.
- 1.6.3 Erosion of the earthwork, especially leading to the redistribution of the soil over a wider area in the direction of cultivation may lead to the miscalculation of the location of the original centre point of the feature and (for example) of the location of associated features such as burials. Over a long period erosion may lead to misconceptions as to the original position of the earthwork feature.
- 1.6.4 Buried soils and features below earthworks are likely to be affected at the edges of the earthwork first. Conversely even severely plough-damaged earthworks can preserve buried soils, artefacts, burials and other features beneath.
- 1.6.5 Earthworks located on a slope or on lighter sandy or sandy loam soils may be prone to greater rates of erosion because of their natural erodibility. Some earthworks, which tend to follow natural contours, such as ridge and furrow, could act as soil conservation terraces and help to reduce the gradual downslope drift.

## 2 RECOMMENDATIONS FOR LAND MANAGEMENT

### **Where farmers and land managers are aware of the presence of buried archaeological features, deposits and artefacts in cultivated fields, they should:**

- 2.1.1 Avoid mouldboard ploughing - i.e tillage operations which invert the soil
- 2.1.2 Use shallow tillage and direct drilling (no/zero tillage) operations with tractors equipped with wide section tyres, low ground pressure or dual tyres or rubber tracks.
- 2.1.3 Where possible use harvesters, tractors and trailers equipped with rubber belted tracks or the largest possible tyre diameters and section widths and or dual tyres or tandem/triple axles to reduce the load per tyre.
  - a. Operate all field going equipment with the safest low inflation pressure for the required load and field/road speed duty cycle.
  - b. Consider using central tyre inflation pressure systems where there are conflicts between field and road going speeds, as can be the case with pea harvesters and tractors and trailers undertaking both field and road transport of produce.
- 2.1.4 Where practicable concentrate as many wheelings as possible in one place and apply the principles of controlled traffic farming.
- 2.1.5 Prevent road going trucks with high inflation pressures from traversing the fields, permit them to park on the headland by the gateway.
- 2.1.6 Discharge crop harvesters to trucks and trailers located on the headlands or alternatively reduce the load in harvesting trailers and “chaser wagons”.
- 2.1.7 Where possible avoid field operations in high moisture content conditions with weak soils at or above field capacity.
- 2.1.8 Only undertake subsoiling operations to depths no greater than 0.30 m (12”) or within the current depth of ploughsoil - whichever is least - as they will damage buried archaeological deposits and objects by direct impact.
- 2.1.9 Non-inversion tillage of earthworks using combination tillage tool (discs and tines, eg Simba Solo) does not offer significant protection to earthworks compared to conventional mouldboard ploughing. When farmers and land managers are attempting to preserve earthworks direct drilling (no/zero tillage) and managed pasture are the only feasible options
- 2.1.10 For slopes neither mould board plough nor shallow ploughing should be undertaken for the same reasons as for flat sites.
- 2.1.11 Whilst non-inversion tillage is damaging to earthworks due to its capacity to move and level irregularities, it can be used on slopes with the following caveats:
  - Non-inversion tillage or indeed any tillage should not be undertaken on the upper and middle slopes where the slope is more than 5/6 degrees (direct drilling may be possible but should be assessed on a case by case basis). This is especially relevant on predominately fine sand and silty soils where the risk of soil erosion is greatest. Soils with higher clay content may be cultivated but they would need to be assessed on a case by case basis depending on the history of erosion and soil depth etc.
  - Non-inversion tillage must be undertaken either along the contours of the slope or approximately perpendicular to the main field slope, and not up/down slope.

- Good slope tillage management should be adhered to i.e. tillage should be practised in one direction one year and the other direction the year after. This will compensate for any small movements of the soil
- 2.1.12 All of the above recommendations support the principles of good soil management which help to sustain good agricultural practices by minimizing compaction and promoting crop growth whilst attempting to preserve buried archaeology.
- 2.1.13 The above recommendations apply to all soil types albeit the quoted “erosion losses” may be higher on the sandy soil used in this study than on soils with higher clay contents. Similarly, the deeper subsoil pressures in the clay field were less than those in the sandy loam soil in the laboratory.
- 2.1.14 Follow Defra’s *Protecting our Water, Soil and Air: A code of good practice for farmers, growers and land managers* (2009)
- 2.1.15 The glass and sand indicator stations and transponders in general worked well in indicating damage to the archaeological sites, with glass being best in terms of visibility. It may be that the two techniques would be best used in combination. Glass would be used to show the farmer that he was getting close to the archaeological deposits so that he could self regulate. In terms of methodology, monitoring the sand stations would have to be carried out directly after primary cultivation, as the sand will not remain visible for long on the soil surface. The timetable for glass would have more flexibility, although operations subsequent to primary cultivation would tend to disperse the glass and make any concentrations less distinct. Evidence for both the sand and glass on the surface of the plough soil could also be removed by a farmer. The transponders (32mm glass cylinders in point configurations) could then be used as a way of cross-checking compliance. Monitoring of the transponders could be done at any time after primary cultivation without fear that the evidence would disappear or be tampered with.





#### **OA East**

15 Trafalgar Way  
Bar Hill  
Cambridgeshire  
CB23 8SQ

t: +44 (0) 1223 850500  
f: +44 (0) 1223 850599  
e: oaeast@thehumanjourney.net  
w: <http://thehumanjourney.net>

#### **OA North**

Mill 3  
Moor Lane Mills  
Moor Lane  
Lancaster LA1 1GF

t: +44 (0) 1524 541 000  
f: +44 (0) 1524 848 606  
e: oanorth@thehumanjourney.net  
w: <http://thehumanjourney.net>

#### **OA South**

Janus House  
Osney Mead  
Oxford OX2 0ES

t: +44 (0) 1865 263 800  
f: +44 (0) 1865 793 496  
e: info@oxfordarch.co.uk  
w: <http://thehumanjourney.net>

#### **OA Grand Ouest**

7 Rue des Monderaines  
ZI - Ouest  
14650 Carpiquet  
France

t: +33 (0) 249 88 01 01  
f: +33 (0) 249 88 01 02  
e: info@oago.fr  
w: <http://oago.fr>

#### **OA Méditerranée**

115 Rue Merlot  
ZAC La Louvade  
34 130 Maugeio  
France

t: +33 (0) 4.67.57.86.92  
f: +33 (0) 4.67.42.65.93  
e: oamed@thehumanjourney.net  
w: <http://oamed.fr/>

**Director:** David Jennings, BA MIFA FSA



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Head Office: Janus House, Osney Mead, Oxford, OX2 0ES, t: +44 (0) 1865 263 800*