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# A multi sensor data fusion approach for creating variable depth tillage zones

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## Abstract

In this research a multi-sensor and data fusion approach was developed to create variable depth tillage zones. Data collected with an electromagnetic sensor was fused with measurements taken with a hydraulic penetrometer and conventionally acquired soil bulk density (BD) and moisture content (MC) measurements. Packing density values were then calculated for eight soil layers to determine the need to cultivate or not. From the results 62% of the site required the deepest tillage at 38 cm, 16% required tillage at 33 cm and 22% required no tillage at all. The resultant maps of packing density were shown to be a useful approach to map layered soil compaction and guide VDT operations.

***Keywords.*** Variable depth tillage, data fusion, bulk density, packing density.

## Introduction

Traditional tillage practices use a whole field approach in which the tillage effect is applied uniformly across the whole field. Management decisions on which tillage machinery to use and how deep to operate it at are usually decided on historical management or occasionally based on information derived from a soil profile inspection. This universal approach is attractive to growers because it requires little specialist knowledge of the soil, therefore often relying on cultivator design to achieve a satisfactory result.

There are several disadvantages to this approach. Firstly from an economic perspective, disturbing the soil unnecessarily in areas where the soil structure and condition is not required is wasteful of time and fuel (Keskin et al., 2011). Secondly, incorrect tillage depth can cause damage to the soil structure by smearing wet plastic soil (Gill and Vandenberg 1965). This problem can lead to the formation of an impervious layer, restricting the development of plants roots, negatively impacting on yield. Finally inappropriate tillage may lead the soil to be susceptible to erosion where nutrients are not retained in the soil but are lost to the environment through leaching and runoff (Halcro 2013). An alternative approach to traditional tillage is variable depth tillage (VDT) (Fulton et al., 1996).

VDT requires the state of the soil to be measured through the profile, in advance of tillage or on-the-go, to determine the optimum tillage depth spatially (Adamchuk et al., 2004). Utilising VDT has both physical benefits to the soil, in terms of preventing tillage damage to the soil profile (Gill and Vandenberg 1965) and economic benefits to the grower by optimising fuel consumption (Keskin et al., 2011). The objective of this research was to develop a new soil compaction measurement system which utilised a multisensory data fusion approach to determine the extent of VDT treatment zones spatially and with depth.

## Materials and Methods

A 2.43 ha agricultural field, situated in Lincolnshire, UK was selected as the research site. The organic clay site is part of a cereal and root crop rotation, which is typical of the area. At the time of the study the field was fallow and had not been cultivated. To conduct the experiment an area 90 x 270 m area was divided into 243, 10 x 10 m grid squares. At the centre of each grid square a hydraulic penetrometer was used to measure the soil resistance, every 20 mm, down to 450 mm. Two depth $EC_a$ data was collected using both HCP & PRP arrays from a DUALEM 1S instrument (Dualem, Inc., Milton, ON, Canada) along 10 m transects which intersected each penetrometer point.

It was not economically feasible to take soil samples from each of the 243 penetrometer sample points. Therefore the number of samples and their location was determined from homogeneous zones derived from the $EC_a$. Using a GPS device (NOMAD, Trimble, USA), pre-loaded with the interpolated $EC_a$ plan, four sample sites were identified to collect bulk density (BD) and soil moisture (MC). A further three sites were selected to collect samples for particle size distribution analysis, thereby determining clay content (CC) of each homogeneous zone.

Bulk density and soil moisture samples by depth were collected using the Kopecky ring method. At each sample location a 5 cm deep ring was hammered into the ground collecting 100 cc of soil per sample. In total 8 undisturbed soil samples were taken sequentially every 5 cm down the profile. For the clay content three soil pits (50 cm x 50 cm x 50 cm) were manually excavated. From the side of each of pits, 4 x 10 cm samples of soil were carefully removed. Soil moisture content of the soil was determined by drying the soil samples in an oven at 105℃ for a minimum of 24 hours (BS 7755, 1994). The moisture content measurement was deduced by calculating the difference between the mass of the wet samples and the samples after drying. Bulk density was determined by subtracting the dry weight values from the moisture content analysis and dividing them by the volume (100 cm3) of the soil core. Percentage clay content was determined using a sieve and sedimentation method according to BS 7755 section 5.4 (BSI, 1998).

### *Data Fusion*

Each measured soil property was interpolated using inverse distance weighting (IDW) and then transformed into a common 10 m raster using Manifold GIS (Manifold Software Ltd, Wanchai, HK). The raster squares of the soil property layer were then converted into a grid of common points by spatially joining the mid-point of each raster square. The output from this process was a 10m grid of point values. To determine the spatial extent of VDT zones within the field, two depth ECa, penetration resistance, bulk density and soil moisture measurements of each 5 cm depth layer were clustered into three groups using the k-means algorithm within STATISTICA 12 (Statsoft. Inc. OK, USA).

### *Packing Density*

Bulk density measurements are sensitive to changes in soil texture making it unsuitable as a measure of compaction for VDT where soil texture is expected to change significantly in a short distance across the field and through the soil profile. Overcoming this limitation is therefore important and can be achieved by adopting the packing density of the soil instead of the bulk density. By extrapolating the appropriate clay content (CC) values, according to $EC_a$, across all 243 grid nodes then transforming the bulk density value into a clay independent indicator by adding a correction term given as the product of clay content with the slope of the regression lines, the packing density was derived for each 5 cm depth layer (Kaufmann 2008) using the following equation.

Packing density = BD + (0.009 x CC)

where - PD is packing density, bulk density is bulk density ($g/cm^3$) and 0.009 CC is the correction term given as a product of clay content clay content with the slope of the regression lines (Renger 1970).

Determining the need for tillage and more specifically the depth of tillage was decided based on the effect of packing density values on crop growth. As can be observed in the table 1 below, the need for tillage can start from any packing density values in the upper optimum range (1.55-1.70 $t/m^3$), but will be definitely needed for any packing density value larger than 1.70 $t/m^3$. This was the guideline adopted in this work to calculate the need for variable depth tillage.

**Table 1 Packing density classifications for crop growth (Kaufmann 2008)**

| PD value ($t/m^3$) | Crop growth condition |
|---|---|
| < 1.40 | Below optimum range |
| 1.40-1.55 | Lower optimum range |
| 1.55-1.70 | Upper optimum range |
| 1.70-1.82 | Lower limiting range |
| > 1.82 | Upper limiting range |

*VDT plan.*

A three zone VDT plan was developed by filtering each cluster with the packing density classifications (Figure 1), where values of packing density ≤ 1.7 $t/m^2$ were ignored (no tillage required) and those values ≥ 1.7 $t/m^2$ (tillage required) were recorded by layer. This was repeated for each 5 cm layer until a 3D VDT was realised (Figure 1).

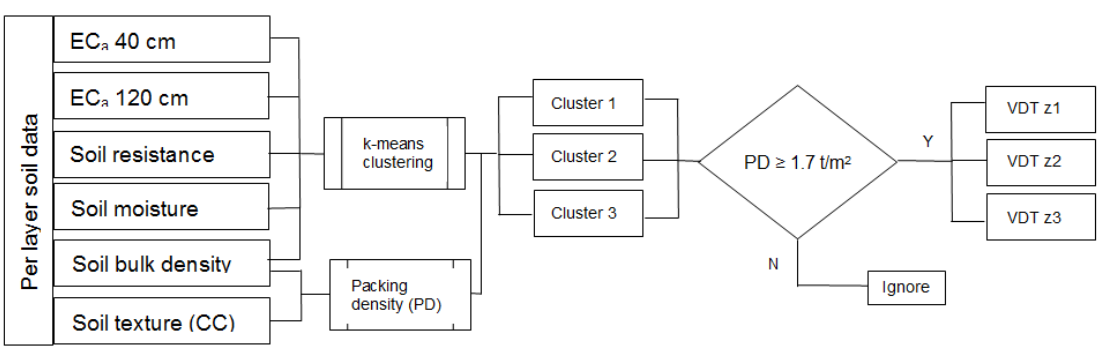


**Figure 1 Scheme illustrating VDT plan layer logic**

## Results

*Analysis of site parameters.*

Analysis of the soil texture and organic matter (OM) were taken at three locations across the site and revealed a predominately clay texture to the west of the site with an increasing sand fraction to the east (Table 2). As is typical for the area, there was a high OM range of 10.9 % to 14.2% in the top 35 cm of the soil profile. A noticeable reduction of OM was observed at 40 cm where the subsoil layer began.

**Table 2 Particle size distribution analysis results by sample location and depth interval**

| Sample location | Sample depth (cm) | Sand % | Silt % | Clay % | Organic Matter (LOI) % |
|---|---|---|---|---|---|
| **West** | 10 | 20 | 38 | 42 | 13.5 |
| | 20 | 20 | 44 | 36 | 11.7 |
| | 30 | 19 | 42 | 39 | 11.4 |
| | 40 | 19 | 43 | 38 | 8.5 |
| **Central** | 10 | 22 | 38 | 40 | 14.2 |
| | 20 | 21 | 40 | 39 | 14 |
| | 30 | 22 | 37 | 41 | 13.9 |
| | 40 | 20 | 46 | 34 | 8.1 |
| **East** | 10 | 28 | 36 | 36 | 12.2 |
| | 20 | 29 | 36 | 35 | 11.7 |
| | 30 | 31 | 32 | 37 | 10.9 |
| | 40 | 39 | 37 | 24 | 3.6 |

*Apparent $EC_a$*

The measures $EC_a$ values corresponded with the soil texture analysis with the higher EC values being observed in the west of the site and the lowest values in the east here the sand content increased between 10 - 20% (Figure 2, 3).

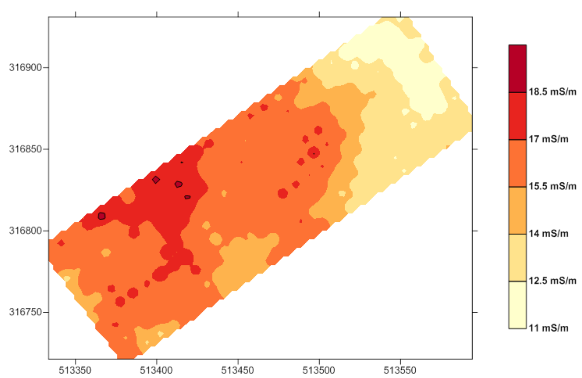


**Figure 2 Spatial variation of $EC_a$ at 0 – 40 cm**

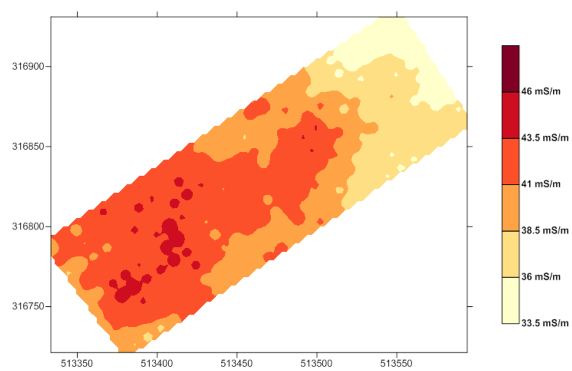


**Figure 3 Spatial variation of $EC_a$ at 0 – 120 cm**

*Multivariate k-means clustering*
Multivariate k-means clustering was used for the creation of per layer management zones for the eight soil layers (Table 4-5). The selected variables were ECa at 40 cm (ECa 40) and 120 cm, (ECa 120), penetration resistance (PR), bulk density (BD) and moisture content (MC) with depth. Analysis parameters were set to maximise the initial Euclidean distance of the cluster separation whilst the cluster number was limited to three in order to minimise the amount of management zones created.

*Management Zone (MZ) maps by cluster analysis*
The newly delineated clusters were plotted for the 8 individual soil layers using a Nearest Neighbour interpolation (Figure 3, a-h). The clustering process affords an a priori selection of cluster number which was set to three for this experiment. Using only three clusters, the pattern of variation is very distinct. Underlying trends of soil type are evident. Cluster 1 on the eastern side of the site, has an increased sand fraction when compared to the higher clay content soil on the western side which visually compares very well with the $EC_a$ results (Figure 1, 2). Cluster 3 demonstrated the most spatial variation across all depths.

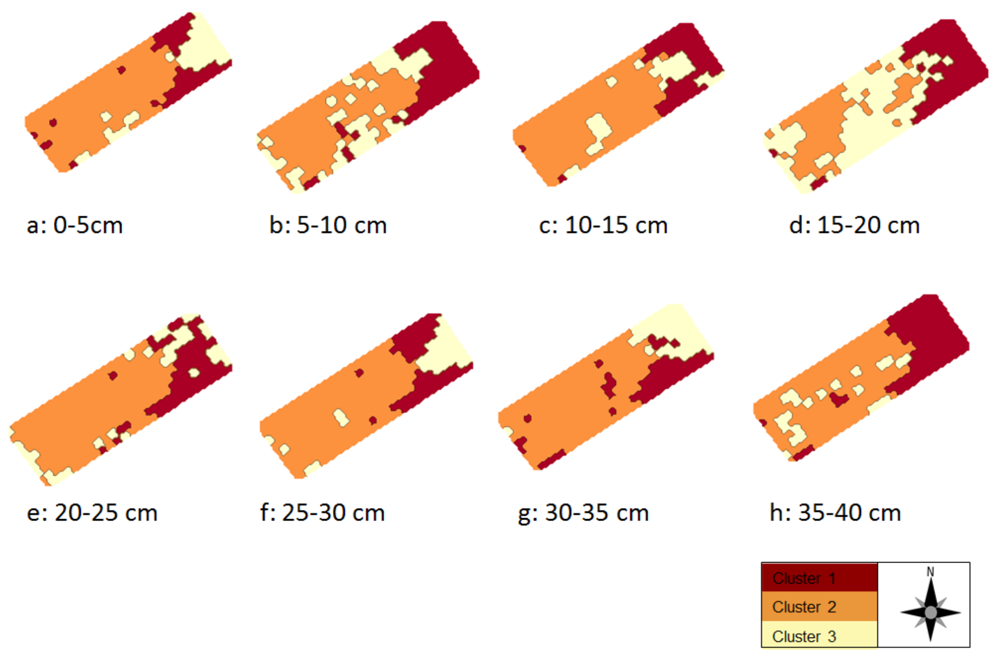


**Figure 4 Visualisations of the spatial extent of each tillage zone cluster created using nearest neighbour interpolation.**

In the 0-5 cm and 5-10 cm there was a distinct change in cluster location from the small triangular area at the eastern extent 0-5 cm manifesting itself in a more general way at 5-10 cm. This was caused by the reducing bulk density values between a shallow layer of surface compaction and the looser soil just below. Cluster 3 has the most significant change in spatial extent occurring at 20 cm which was a result of the close alignment of normalised means of penetration resistance, bulk density and moisture content variables. Initially the map looked like a layer of compaction but this was discounted by the low bulk density means. A possible reason behind the spatial extent is the wide range of bulk density and penetration resistance values indicated a transient layer between the regularly cultivated surface and the less frequently cultivated subsoil. Below the 20 cm layer the clusters are spatially more stable, adding further evidence that 20 cm is a transient layer.

*Derivation of packing density*

According to the packing density classes in Table 1, values of packing density ≥ 1.7 t/m$^3$ were deemed to be yield and root growth limiting and tillage should be carried out. Results shown in table 3 illustrate the overall packing density range across the soil profile extends from 1.20 to 2.02. However, this range can be further sub-divided between values above 25 cm, mean packing density of 1.45 - 1.53 t/m$^3$ , and below 30 cm, mean packing density range of 1.49 – 1.69 t/m$^3$. The reason for this stepped increase in packing density between the these two observed layers can be attributed to historical tillage practices where ploughing for root crops would often extend down to 25 cm, regularly disturbing the upper soil and potentially compacting the deeper sub soil with large vertical and shear forces. Typically if a grower had identified a compacted layer like this he would look to remediate it with homogeneous deep tillage, which is an expensive and time consuming operation (Mouazen and Neményi, 1999). However with this approach of packing density cluster analysis it is possible to identify areas below 30 cm that do not require deep tillage offering the potential to reduce tillage depth saving money and resources. Examining the maximum packing density calculated per cluster in Table 3 reveals that values exceeding 1.6 t/m$^3$ already appear on the top layer of 5-10 cm deep, indicating the presence of surface compaction, and suggesting a gentle surface tillage to be considered down to 10 cm in the entire field. After this layer another layer but with critical values on crop growth can be observed at 15-20 cm layer in cluster 1 & 3, suggesting tillage of these two clusters only, whereas no tillage is needed for cluster 2. Going further down in the profile, one can observe the presence of hard pan at cluster 1 and 2 at 30 cm layer, and that expand into cluster 2 at 35 cm layer, where the highest packing density of 2.02 t/m$^3$ is observed. This may suggest the need for subsoiling down to 35 cm in cluster 2 in particular. At depth of 40 cm another compacted layer can be observed in the entire field with the three clusters.

**Table 3 Descriptive statistics of packing density by cluster and by depth.**

| Depth | Cluster | PD Mean | PD Min | PD Max | PD Std D |
|---|---|---|---|---|---|
| **5 cm** | 1 | 1.43 | 1.35 | 1.53 | 0.05 |
| | 2 | 1.39 | 1.24 | 1.49 | 0.05 |
| | 3 | 1.31 | 1.20 | 1.39 | 0.04 |
| **10 cm** | 1 | 1.47 | 1.37 | 1.63 | 0.05 |
| | 2 | 1.46 | 1.46 | 1.60 | 0.03 |
| | 3 | 1.45 | 1.36 | 1.66 | 0.05 |
| **15 cm** | 1 | 1.44 | 1.39 | 1.60 | 0.05 |
| | 2 | 1.43 | 1.32 | 1.52 | 0.03 |
| | 3 | 1.40 | 1.34 | 1.47 | 0.03 |
| **20 cm** | 1 | 1.42 | 1.23 | 1.71 | 0.07 |
| | 2 | 1.43 | 1.30 | 1.63 | 0.06 |
| | 3 | 1.36 | 1.25 | 1.81 | 0.08 |
| **25 cm** | 1 | 1.53 | 1.44 | 1.66 | 0.05 |
| | 2 | 1.50 | 1.29 | 1.62 | 0.06 |
| | 3 | 1.45 | 1.31 | 1.54 | 0.05 |
| **30 cm** | 1 | 1.69 | 1.56 | 1.79 | 0.06 |
| | 2 | 1.61 | 1.43 | 1.81 | 0.07 |
| | 3 | 1.49 | 1.35 | 1.58 | 0.05 |
| **35 cm** | 1 | 1.49 | 1.42 | 1.64 | 0.03 |
| | 2 | 1.64 | 1.41 | 2.02 | 0.11 |
| | 3 | 1.42 | 1.25 | 1.65 | 0.10 |
| **40 cm** | 1 | 1.57 | 1.47 | 1.73 | 0.07 |
| | 2 | 1.58 | 1.32 | 1.89 | 0.08 |
| | 3 | 1.61 | 1.43 | 1.97 | 0.11 |

Green values indicates packing density values ≥ 1.6 (tillage may be required).
Red values indicate packing density ≥ 1.7, where tillage required.
Figures highlighted yellow indicate the final depths of tillage used for the VDT plan.

*Variable depth tillage (VDT) plan*

A VDT plan scaled in cm depth was developed using the data found in Table 3. Tillage depth was calculated as the depth of the largest maximum packing density value per cluster of each grid node + 3 cm. (The additional 3 cm was to ensure that the cultivator tine was sufficiently deep as to fully remove the compacted layer). The 40 cm depth layer was excluded from the tillage plan because of the distinctly different nature of the soil at that depth. Using the new the new depth attributes the data was interpolated using a nearest neighbour method to create a VDT plan (Figure 4).

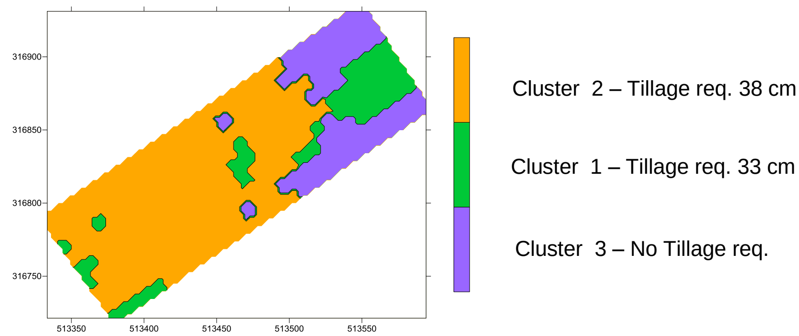


**Figure 5 Variable depth tillage plan illustrating the spatial variation of tillage depth based on the mean packing density values**

A visual assessment cluster 1 indicates that deep tillage is required to 33 cm where as cluster 2 requires deep tillage to 38 cm and cluster 3 requires no deep tillage at all. This is because at 23 cm the soil would be cultivated when the field is ploughed as part of the farms normal cultivation practice.

## Conclusion

From the results of this research the following conclusions were made:

1.The multi-sensor data-fusion approach can be used successfully to provide key information sufficient to derive a soils state of compactness as an indicator of whether to cultivate or not to a certain depth.

2.As a preliminary assessment of data fusion for the creation of VDT plans it was found that K-means multivariate clustering enabled the factors affecting physical soil compaction to be fused together to delineate management zones suitable for variable depth tillage.

3.Because packing density is dependent on soil texture (e.g. percent clay), it is a more suitable indicator of soil compaction than bulk density in fields with varied soil textures and therefore is ideally suited as a variable depth tillage solution.

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## References

Chamen,T (2006-2011). Minimising the area of soil compacted by traffic in cropping system. PhD thesis. Cranfield University, UK.

Domsch, H., Ehlert, D., Giebel, A., Witzke, K. and Boess, J. (2006), "Evaluation of the soil penetration resistance along a transect to determine the loosening depth", Precision Agriculture, vol. 7, no. 5, pp. 309-326.

Halcro, G., 2013 Site specific land management of cereal crops based on proximal soil sensing. PhD thesis. Cranfield University, UK.

Kaufmann, M., 2008 Multi criteria evaluation of land restoration for agricultural use (PhD Thesis). Swiss Federal institute of Technology, Zurich.

Keskin, S. G., Khalilian, A., Han, Y. J. and Dodd, R. B. (2011), "Variable-depth tillage based on georeferenced soil compaction data in Coastal Plain Soils", International Journal of Applied Science and Technology, vol. 1, pp. 22-33.

Mouazen, A.M.; Nemenyi, M. 1999. Tillage Tool Design by the Finite Element Method: Part 1. Finite Element Modelling of Soil Plastic Behaviour. Journal of Agricultural Engineering Research, Volume 72, Issue 1, January 1999, Pages 37–51

Renger, M., 1970. Uber den Einflus der Dränung auf das Gefüge und die Wasserdurchlässigkeit bindiger Böden. Mitteilungen Deutschen Bodenkundlich Gesellschaft 11, 23 – 28.