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# Research Review No. 95

## Analysis of top and subsoil data from the High Speed 2 (HS2) rail project

## Work package 1

## East Midlands to South Yorkshire (Section A): Soils on Carboniferous Sandstone, Siltstone and Mudstone

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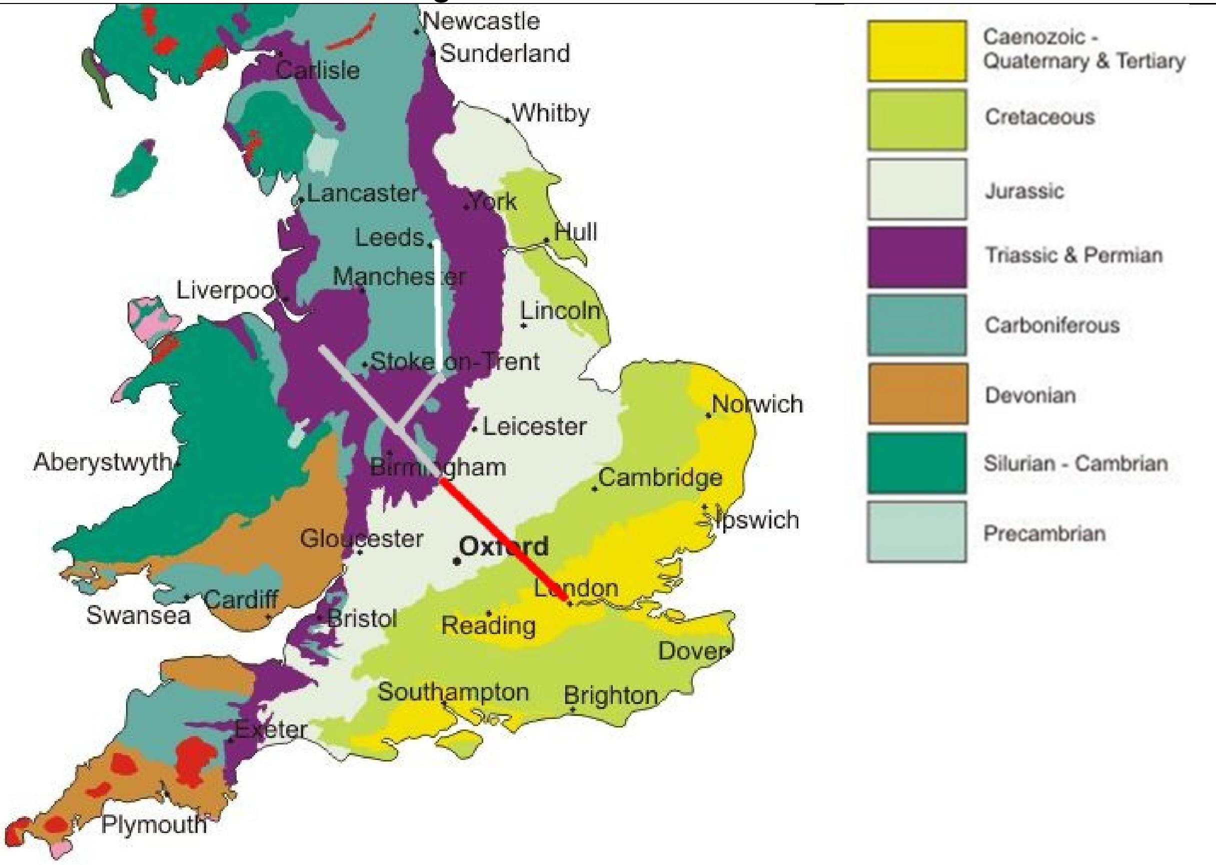


# 1. Executive Summary

This data set comprises 221 sampling points, 76% arable and 22% grassland. All had soil profiles described and samples of topsoil and upper subsoil sent for analysis to NRM laboratory.

The land is on Carboniferous rocks with minimal superficial Drift. 22% of profiles were formed on Sandstone (soft or hard), 19% on Siltstone and 35% on Mudstone plus an estimated 15% of disturbed profiles (coal workings) reinstated over Siltstone or Mudstone.

In 37% of the profiles the upper subsoil 30-50cm was more clayey than the topsoil and on 17% the subsoil was lighter (sandier) than the topsoil. Neither geological or soil association maps could be used reliably to predict the soil texture.

Median depth of identifiable topsoil was 29cm for arable and 28cm for grassland. On arable land topsoil depth varied from 22 to 40cm; on only 10% was it 25cm or less. 10% of profiles had topsoil-like horizons to at least 35cm - evidence of historical deep cultivation.

Composite samples were taken either by corer (0-20/22cm and from 25-30 to 50cm) or by representative samples from Dutch auger. The differences due to method were evaluated and did not significantly affect the correlations found.

'Subsoil' in this summary henceforth refers to upper subsoil to 50cm depth.

Note: agricultural soils are routinely sampled to 15cm (arable) and 7.5cm (permanent grass) which might generate indicate higher nutrient values than found in this survey.

**Phosphorus**

On arable land half the topsoils were below target index (2) of which 18% were index 0. In grassland more than half were Index 0. These are much worse than reported in national (PAAG, 2019) laboratory survey: 22% arable and 34% grassland were below target.

In this region only 6% exceeded the lower half of index 3, so excess P application was rare.

On arable land, two thirds of upper **subsoils** were P index 0 with only 15% at Index 2 or higher. Two thirds of grassland subsoils were in the *lower part* of Index 0.

Subsoil P is strongly related to Topsoil P. Increasing clay content has a small negative effect on the subsoil P; OM has some positive effect. pH seems irrelevant. Correlation equations are given.

Typically a topsoil of 20 mg/l Olsen P (mid index 2) overlay subsoil P of 12 mg/l on sands, 11 mg/l on sandy loams (index 1), 10 mg/l on medium loams, 9 mg/l on heavier loams (index 0) and 8 mg/l on clays (Arable or Grassland). Up to 30 mg/l in topsoil (lower index 3) the subsoil is likely to remain within P index 1 though not in every case ($r^2$ = 0.62).

Subsoil P was related to topsoil P with some influence of subsoil OM – the best fit prediction increased subsoil P by ~0.9 mg/l for each 1% subsoil OM up to 6%.

High P was only found on light loam topsoils and these exhibited a 'change point' effect: above 35 mg/l in topsoil subsoil P rose steeply (1:1) with increasing topsoil P. This might be related to (recent) deep cultivation or the P adsorption capacity of the topsoil being exceeded.

Irrespective of P index, it is likely that earthworms carry down Organic Matter and 'available P' into lighter subsoils more readily than into heavier subsoils.

The very low levels of available P in most clay subsoils suggest that risk of transmission into under drains is minimal. Soil survey manuals distinguish Carboniferous clay soils as non-swelling (Dale series) and less prone to deep cracking in summer than the swelling clays which characterise most younger geological formations (Denchworth series).

**Potassium**

Half the arable samples were below target index (2-), worse than reported in PAAG, 2019 survey (21%). 9% of samples were Index 0 and median was 124 mg K / l (low end of 2-). Only 19% exceeded target and very few were index 3 or 4, indicating that excessive potassium applications are rare in this region.

75% grass topsoils were below index 2- of which 34% were index 0. This may be indicative of lack of testing or neglect of potassium fertiliser application to replace offtakes in hay or silage. PAAG (2019) found a lower proportion (44%) of grassland below target.

Topsoil K level is weakly related to texture, stone content and pH, but not annual rainfall.

Topsoil K correlates with topsoil P indicating that management is an important influence.

Of the arable **subsoils** 80% had low K of which 32% were index 0. 74% of grassland subsoils (74%) were in the range index 0 upper to 1 lower.

When averaged over all soil types, K level in the subsoil was 65% of topsoil K. However light loams behaved differently to medium or heavy topsoils. At index mid 2- (150 mg/l) the subsoil K was typically 95 and 83 mg/l respectively. At mid index 3 (320 mg/l) subsoil K was188 for light loams and 154 mg/l for medium/heavy soils. Topsoil K plus texture explained only 50% of the variance in subsoil K, so other variables are in play especially on arable land.

Subsoil organic matter was associated with improved subsoil K especially on lighter soils, either due to deep ploughing or earthworm activity or (in heavier subsoils) more "easily exchanged" K sites on the organic matter.

a) for **light loams** (SL/SZL) some leaching of (applied) potassium may occur as topsoil is raised above 150 mg/l. This may be advantageous: a topsoil index of 2+ (>180 mg/l) guarantees index 2- in the upper subsoil which could be useful if the topsoil temporarily dries out rendering plants dependant on the subsoil for their K supply.

However where topsoil was <120 mg/l, land subsoil was usually index 0, and the aim should be to raise topsoil to at least 150 mg/l if possible (mid index 2-)

b) for **medium** arable soils at topsoil index 2- or low index (<120 mg/l) subsoil could vary from 0 to 2-). Variation in subsoil K could not be linked to subsoil texture. Sampling too close to manure or fertiliser application could have been a factor in a few cases. By common observation 90 mg/l (mid index 1) is the point below which obvious K deficiency is observed in the field.  Maintaining topsoil above 150 mg/l (in upper part of index 2-) would usually ensure subsoil K >90 mg/l.

c) on **heavier** topsoils where topsoil was <120 mg/l the subsoil was less than mid index 1 (90 mg/l) and in some cases <45 mg/l K was found on clay-textured subsoils.  Carboniferous clay tends to be more kaolinitic than other English clays and is cited in RB209 as an example of a "non-releasing clay."

This data shows that o*n this type of clay, arable or grassland farmers must* <u>*not*</u> *assume they can settle for a lower (topsoil) target K index (1) on the grounds they have a heavy subsoil*. In fact K in heavy subsoils may be more deficient in K than lighter subsoils.

Soil K levels may be lower during the main growing season March to July, though most of the data set was sampled outside of this period.

For any given topsoil K, the subsoil K can vary significantly. Therefore for potassium response trials, it is imperative to *measure* both topsoil and subsoil K, texture and OM%, preferably by a coring technique.

It may be instructive for farmers to check some of their medium and heavy land for subsoil K.

**Magnesium**

98% of arable samples were above target (index 2) and 90% of grassland.  Medians were 182 and 207 mg Mg / l (Index 4).  30% of arable samples were Index 5 (very high) and 12% Index 6 (excessive*), more than national average PAAG (2019) of 6% and 6% respectively. Index 6 is typical for soils on Dolostone, but also found on some Carboniferous profiles.

In the subsoils very few arable and no grassland samples were index 0 or 1. For arable land the median was similar to topsoil but was higher under grassland (median 262 mg/l index 5).

Up to index 4 the ratio of subsoil : topsoil Mg depended on subsoil texture: if sandy (S/LS) the subsoil Mg was ~80% of the topsoil Mg, for light loam and medium subsoils was parity, and for heavier loam and clay subsoils was 20–40% higher. Magnesium is much more prone to leaching than potassium.

At index 5 and above, the subsoil Mg could be higher or lower than topsoil Mg.

Three factors determine soil Mg: a) parent material Mg release/retention by clay minerals and/or dolomitised limestone in parent material, b) pH correction if done by high Mg limes (a ridge of Dolostone rock occurs east of the area surveyed), c) animal returns on grazed grass.

Notwithstanding the possibility that high Mg on the cation exchange sites destabilises clay-OM complexes leading to 'harder soil', there is clearly a *strong likelihood of Mg-induced K deficiency for crops in this region*.

Agronomists often report K deficiency on high Mg soils; no specific threshold has been established but K:Mg < 0.5 (mg/l:mg/l) is cited as a warning trigger.  This applies to a large number of topsoils in this data (median ratio 0.55) and the majority of subsoils (0.33).

Up to Mg index 4 the importance needs emphasising of maintaining topsoil K at least 150 mg/l (mid index 2-). At Mg index 5 and 6, K index 2+ (>180 mg/l) might be a better target, especially since the underlying *subsoil* K is more difficult to raise on heavier land.

Where lime is used, sources lower in Mg (from quarries further to the west or east) or calcium-rich sugar beet waste lime should be used if the Mg index is above 3.

**pH**

pH 6.5-6.9, the optimum for arable land, comprised 31% of the topsoils;.20% were pH 6–6.4 and only 6% below pH 6.0 which is less than PAAG (2019),19% . 43% were (slightly) alkaline. 21% of grass topsoils were below target pH 6.0 and 13% < pH 5.5 (fewer than PAAG, 2019, 19%). However, if only the surface 7.5cm had been sampled more samples may have registered as acid.

Only 18% of arable upper subsoils were below pH 6.5 and 8% of grass subsoils below 6.0.

Because soils are subject to downward leaching of calcium, magnesium and bicarbonate, the expectation is that the pH of the subsoil will be higher than the topsoil, which the data confirms. For grass and arable data with topsoil pH below 7.1:

Subsoil pH = topsoil pH x 0.72 + 2.17 $r^2 = 0.39$

Subsoil pH is about 0.5 higher than topsoil pH although with considerable uncertainty *.

Above pH 7 there was no relationship. Despite few profiles registering as calcareous according to the field method (10% HCl), a quarter of the subsoils had pH > 7.5. Dolomitised limestone fizzes slowly and may explain lack of detection. Exchangeable Mg correlated (weakly) with pH in the topsoil but not with pH in the subsoil, indicating that clay content and mineralogy were the main determinant of Mg levels not dolomitic lime.

* although $r^2$ of 0.39 is poor, most importantly in only 20 cases was subsoil pH *less* than the topsoil pH and less than 6.5.

Where subsoil pH was more acidic than topsoil by 0.5 or more, most instances had heavy subsoils and/or coal fragments present. Low pH might be linked to oxidation of pyrites.

Testing of topsoil for pH is usually sufficient although sample is best taken to 20cm depth. Upper subsoil pH (25-50cm) is worth pH testing also on remade land and naturally coal-rich profiles.

Where the topsoil pH is below 5.5 the upper subsoil to 50cm is likely to be below 6 and additional lime should be recommended based on pH 0.5 higher than topsoil. The additional lime can be ploughed under before main liming or applied the following autumn.

**Soil Organic Matter**

This data is based on total carbon measured by Dumas method (after removal of carbonates) not Loss on Ignition which can include significant amounts of structural water in heavier soils.

As per convention, Organic matter (OM) results are reported as Organic C x 1.72. This study retains the same interpretation ranges as in Soil Survey of England and Wales manuals (they used Walkley Black method). <1.5% OM very low, 1.5-2.9% low, 3-4.4% is moderate, 4.5-6.0 % ('high' here termed good), 6-9% very high (here termed high) and 10-20% "organic" (as in RB209).

In this data the median in arable topsoils (3.8%) was 'moderate', 26% of samples were 'good' (4.4-6.0%) but only 12% are above this level. None were very low.

In Grassland the median value for the top 20cm was 6.5% (high) though a large number had only moderate OM levels (possibly shorter term leys).

Arable *subsoils* were distributed around the median of 1.9% (low) with 26% of samples very low. The tail of higher values probably due to coal fragments in subsoil.

Grassland subsoil median, 2.7%, was 0.8% higher than for arable. Only 11% of grass subsoils were very low (<1.5%) with a tail of higher samples due to coal or wet subsoil.

For statistical analysis, samples with topsoil OM greater than 10% were excluded as were subsoils suspected of significant coal fragments in the <2mm sample.

Topsoil and subsoil OM% correlated for arable land ($r^2 = 0.53$), but only weakly for grassland ($r^2 = 0.24$) although it seems that under grass the ratio of subsoil OM : topsoil OM is lower.

Topsoil and subsoil OM trend was in sequence: sands < light loams < medium & heavy soils.

For arable land at topsoil OM 3.0%, upper subsoil OM was typically half (1.5%) irrespective of texture but as the topsoil rose from 4.5 to 10% there was steep (0.7-0.8:1) climb in subsoil OM, except where there is clay subsoil where OM rise is difficult to predict and generally lower (0.5-0.6:1), probably because of barriers to earthworms and to lateral rooting.

For grassland, at topsoil OM of 4.5% subsoil OM was 2.5% but as topsoil OM% increased there is large degree of uncertainty in the subsoil OM, which might be expected in view of variation in the time under grass since cultivated and the depth of cultivation.

Measurement rather than estimation of subsoil OM is advocated where a) clay subsoil, b) reinstated profile, c) topsoil OM% >6% or being increased by regular manuring, d) experimental trials, especially those testing organic amendments.

A suitable OM level to aim for.in subsoil to 50cm in these soils is 3.0% (Dumas method). This will improve potash retention and soil structure. Above 4.5% might be of dubious benefit and could raise issues of enhanced phosphate transfer to drains.

Carbon stocks in soil are not simply proportional to OM% because they also depend on horizon depths, stones and bulk density. A rigorous evaluation of this data here awaits a further report after verification of the calculation, however preliminary estimates of mean Carbon to 50cm depth are 125 t/ha on arable land and 170 t/ha in grassland.

## 2. Land Use and Soils

**Region A: East Midlands to South Yorkshire**

The analysis corridor stretches northward from Nottinghamshire (M1 junction 27), past the M18 junction (east of Sheffield) continuing northward to east of Leeds.

The data is representative of this area which is predominantly arable land growing cereals, oilseed rape and occasional root crops. 22% of the samples were from grassland, ranging from good quality leys to 'rough grass'.

**Table 1. Region A: Land Use**

| Land Use | Sample/survey points | Proportion |
|---|---|---|
| | | |
| Arable [1] | 171 | 76 % |
| Game cover | 2 | 1 % |
| Horse paddock | 8 | 4 % |
| Grass ley | 20 | 9 % |
| Other grassland | 21 | 9 % |
| Amenity grass | 1 | 0.5 % |
| Woodland | 2 | 1 % |
| Total | 225 | |

[1] including one market garden site

This region is unusual in that the British Geological Society (BGS) maps [1] indicate *only Carboniferous* Rocks, usually with no superficial Drift. These deposits (Upper, Middle or Lower Pennine Coal measures, interspersed with various named Sandstones) comprise bands of Sandstone, Siltstone and Mudstone, with all three sometimes in the same field. .

Similar Carboniferous rocks also occur in north-east England, parts of South West England as well as South Wales and Scotland.

The Sandstones vary in fineness and softness. BGS designations for each profile are logged in the data base. For simplicity parent material is shown by profile observation in Table 2a.

**Table 2a Region A: Soil Parent Material**

| Material in (lower) subsoil | Proportion |
|---|---|
| | |
| Sandstone medium-grain | 13 % |
| Sandstone fine-grain | 9 % |
| Siltstone * | 19 % |
| Mudstone * | 35 % |
| * disturbed soils (on above) | 15 % |
| Dolorite ("Magnesian") | 1 % |
| Drift / Till / Colluvium | 7 % |
| Alluvium | 1 % |

In some places hard unaugerable Sandstone was encountered within 35cm and elsewhere it was soft sand to 80cm depth of more. These are described under Rivington 1 association in the Soil Survey of England handbooks [2].

The Siltstone soils pass to dense clay loam, silty clay loam or silty clay at between 55 and 100cm depth (Ticknell series), but locally are lighter textured, bordering on fine Sandstones (Heapey series).

The most common parent material was grey non-swelling Carboniferous clay (Mudstone) becoming very dense within 1m depth, occasionally with coal seams.

About 15% of the profiles seem to be on land reinstated from former coal workings having subsoils of loam and clay which have re-structured reasonably well due to long arable use [2].

Although no Superficial Drift is indicated on BGS maps, there has been superficial mixing of sandstone-, siltstone- and mudstone-derived material commonly resulting in a loamy topsoil and loamy over clayey upper subsoil (Bardsey series), though the subsoil can be clayey within 30cm depth (Dale series). Table 3 illustrates the trend of heavier subsoil than topsoil.

Locally there are colluvial soils, especially below Sandstone ridges.

The BGS maps identify the sandstone outcrops fairly well whereas the Soil Association designations (Table 2b) are more 'broad brush'. Although giving similar overall % representation to observations in the field (Table 2a) they are unreliable at field scale, e.g. sandstone outcrops or disturbed profiles were common within Bardsey association, clayey profiles in Rivington association etc. The Associations do not attempt to distinguish silty from clayey profiles nor soft or fine sandstones from the harder, more droughty or coarser ones.

**Table 2b Region A: National soil map**

| Code | Association | Description | % |
|---|---|---|---|
| 511a | Aberford | Fine loamy over limestone. | 0.4 |
| 541f | Rivington 1 | Well drained coarse loamy soils over sandstone. | 14 |
| 711p | Dunkeswick | Slowly permeable fine loamy soils (over clay). Till | 1 |
| 712a | Dale | Slowly permeable clayey or fine silty on soft rock. | 11 |
| 713a | Bardsey | Slowly permeable medium loamy over clay or fine silty on soft rock. | 57 |
| 811b | Conway | Stoneless fine silty and clayey soils affected by groundwater. | 1 |
| 92c | Disturbed soils 3 | Restored coal workings. Fine loamy and clayey disturbed soils. | 16 |

For the purpose of analysing the data the hand-textures were grouped into 5 classes based on clay content as explained in Table 3. Note that **the generic 'fine silty' or 'fine loamy' categories for the purpose of this paper are divided into medium and heavier loams,** in accordance with Land Classification guidelines [3]. No distinction is here made for sand content versus silt content because clay content is the dominant influence.

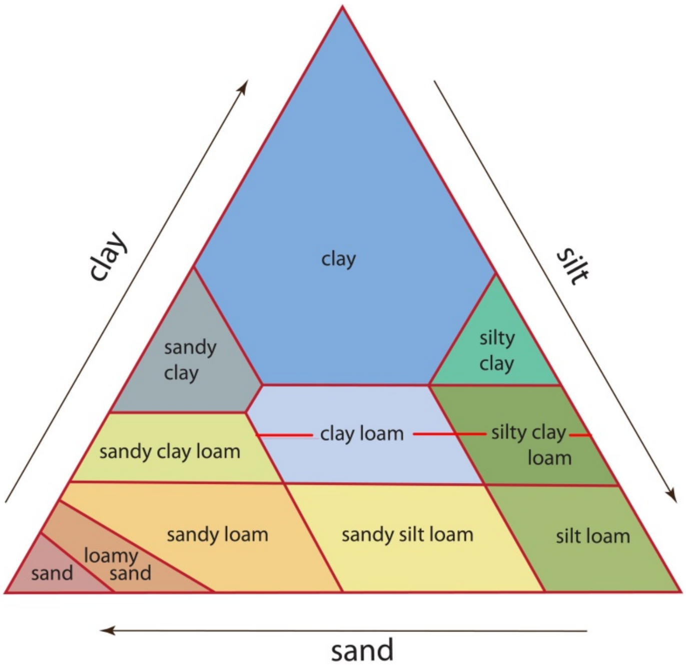



**Table 3. Region A: Soil Texture Summary (frequency)**

| **Texture Code** in data base | **Estimate** clay % | **Soil Textures** | Frequency **Topsoil** | Frequency **U. Subsoil** |
|---|---|---|---|---|
| 0 | 5 - 9 % | Very light (LS, S) | 1 % | 9 % |
| 1 | 10 -18 % | Light Loam (SL, fSL, SZL) | 22 % | 15 % |
| 2 | 18- 26 % | Medium (SCL, mCL, mZCL) | 40 % | 22 % |
| 3 | 27- 35 % | Heavier (SC, hCL, hZCL) | 31 % | 28 % |
| 4 | > 35 % | Clayey (ZC, C) | 6 % | 26 % |
| P | any | Peaty loam or sand (PL, PS) | - | - |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam, mCL = medium clay loam, mZCL = medium silty clay loam, hCL = heavy clay loam, hZCL= heavy silty clay loam, SC = sandy clay, ZC = silty clay, C = clay. Where upper subsoil contains two textures within 50cm the average is used e.g. mCL over C is treated as hCL (3).

In this region in 39% of profiles the upper subsoil was judged heavier (i.e. contained more clay) than the topsoil and in 17% the subsoil was lighter (sandier) than topsoil. The influence of this is examined especially with regard to potassium levels.

The survey showed that the scope to predict soil texture of topsoil or subsoil (and therefore RB209 soil type for nitrogen recommendations) is very limited if based on BGS or SSEW national maps. Field surveying is more reliable and able to define management boundaries where a major soil change occurs within the same field.

References

1 http://mapapps.bgs.ac.uk/geologyofbritain/home.html

2 Jarvis et al. (1984) Soils and their Use in Northern England. Soil Survey of England and Wales Bulletin 10 p104-106, 149-153, 159-161, 262-265,

3 MAFF (1988) Agricultural Land Classification of England and Wales

## 3. **Influence of sampling method; nutrient evaluation**

Region A: East Midlands to South Yorkshire

**Sampling techniques**

**1. The corer method**

- topsoil sample to standard depth (0-20/22cm) by a 1.5cm wide hand corer
- subsoil sample from 25cm-30cm* to 50cm by a 1cm diameter gouge auger

  * material from 25-30cm depth could be excluded if topsoil.

**2. Auger method**

- representative sample of topsoil removed from Dutch auger
- representative sample from auger of upper subsoil (to 50cm)

Each sample was a composite from 5 places at and within 10 m of surveying point.

The average depths of 'topsoil' and 'subsoil' are shown in Table 4

**Table 4. Region A: Depth of topsoil for purposes of analysis**

| **cm** | **Arable** | | **cm** | **Grass** | |
|---|---|---|---|---|---|
| mean | median | 10 - 90% | mean | median | 10 - 90% |
| 29 | 29 | 25 – 35 | 28 | 27 | 20 – 32 |

Median topsoil depth was 28cm by corer method and 30cm by auger.

A significant proportion arable land has topsoil deeper than 30cm due to historical deep cultivation, and it seems that most of the grassland historically has been ploughed (to at least 25cm) at some point.

**Table 5. Region A: Sampling method and soil results**

| Method | OM % | | pH | | P mg/l | | K mg/l | | Mg mg/l | |
|---|---|---|---|---|---|---|---|---|---|---|
| | mean | med. | mean | med. | mean | med. | mean | med. | mean | med. |
| **Topsoil** | | | | | | | | | | |
| Corer * | 5.2 | 4.1 | 6.7 | 6.8 | 17.3 | 14.3 | 123 | 108 | 206 | 192 |
| Dutch Auger | 4.8 | 4.0 | 6.9 | 6.9 | 16.5 | 13.4 | 129 | 117 | 210 | 182 |
| **U. Subsoil** | | | | | | | | | | |
| Corer * | 3.2 | 2.2 | 7.0 | 7.1 | 9.4 | 7.5 | 83 | 69 | 234 | 197 |
| Dutch Auger | 2.9 | 1.8 | 7.0 | 7.1 | 7.5 | 5.6 | 78 | 71 | 237 | 200 |

* one sample of very high PK excluded. 136 and 85 were by corer and auger respectively.

The Corer technique obtained marginally higher topsoil Organic Matter (OM) and P than the Auger method. In the subsoil the differences were more significant (∆0.3% OM, ∆2 mg/l P).

Conversely the auger obtained a marginally higher topsoil pH and K but no significant difference in subsoil values. There was no difference in Mg levels at either depth.

Such differences might be expected because the corer method always includes the surface layer in the topsoil sample, and its subsoil sample can contain some transitional material (or deep topsoil) at 25-35cm whereas the auger method generally selects 'pure' subsoil.

Generally speaking the data values are representative of upper subsoil 28-50cm. Obviously nutrient gradients occur over this depth but the data provides a good estimate of what roots are 'likely to encounter' as they venture deeper down.

The foregoing sections show that topsoil: subsoil correlation plots do not differ significantly according to sampling method, though the corer technique tends to better $r^2$ values.

**Sampling times**

Surveys were authorised at various times throughout the period August 2018 to August 2019. It is possible some soil samples may have been taken close to a recent fertiliser application, however the 20-30cm depth of topsoil sampling should mitigate exaggeration effects. From September onwards, soils were always moist at sampling.

**Nutrient evaluation**

All samples were analysed for pH, Olsen Phosphorus, Potassium (K) and Magnesium (Mg) by 10:1 extraction with 1M Ammonium Nitrate (ADAS method) at NRM Laboratory. The cluster samples were also analysed for total Nitrogen by Dumas method.

Each result was classified according to the index system in The Fertiliser Manual RB209 [1] which ascribes the result to an index category.

| **Interpretation** | **Index** P, Mg | **P** Olsen mg/l | **Mg** mg/l | | **Index** K | **K** mg/l |
|---|---|---|---|---|---|---|
| Very low | 0 | 0-9 | 0-25 | | 0 | 0-60 |
| Low | 1 | 10-15 | 26-50 | | 1 | 61-120 |
| Moderate | 2 | 16-25 | 51-100 | | 2- | 121-180 |
| Good | 3 | 26-45 | 101-175 | | 2+ | 181-240 |
| High | 4 | 46-70 | 176-250 | | 3 | 241-400 |
| Very High | 5 | 71-100 | 251-350 | | 4 | 401-600 |
| Extreme | 6 | 101-140 | 351-600 | | 5 | 601-900 |
| | 7 | 141-200 | 601-1000 | | 6 | 901- |

In principle moderate is the *Target level* for arable and grass; "good" is target for rotations with vegetable crops. K index 2 is subdivided in RB209. Iin some parts of the report other P or K indices are divided into upper (+) and lower (-) parts for the purpose of discussion. Extremely high levels were very rare for P or K but common for Mg

1 AHDB (2017) The Fertiliser Manual RB209

# 4. Phosphorus

Region A: East Midlands to South Yorkshire

## 4.1 Overview of phosphorus levels

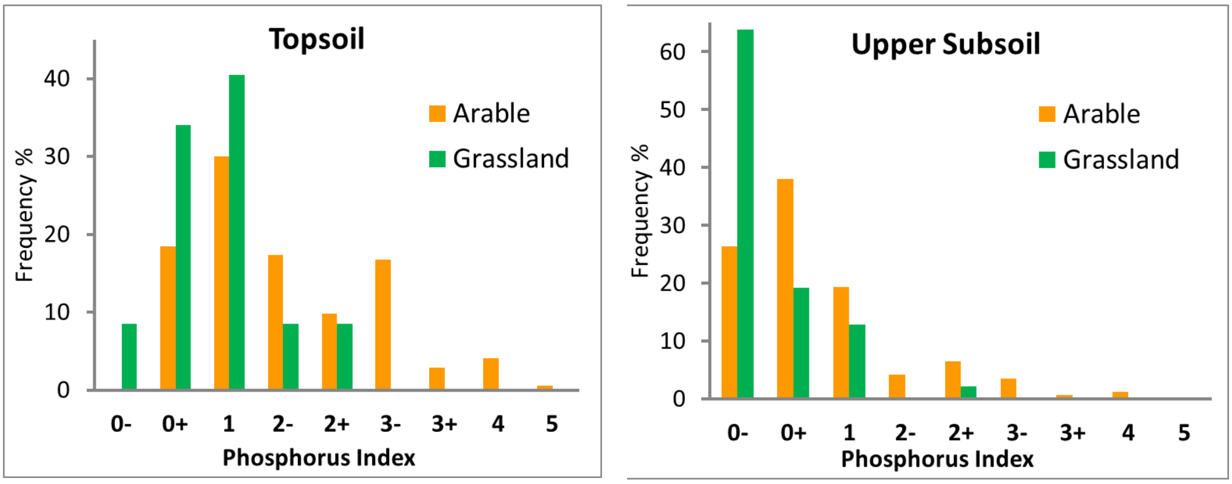



Figure 1a and 1b. Region A: Soil available Phosphorus

**Topsoil**

Arable land: P index 2 is considered optimal. 48% of samples were below this target level of which 18% were Index 0. Median was 16 mg P/l (lower 2). Few (6%) exceeded the lower half of index 3, indicating that excessive phosphate applications to land are rare. National laboratory data (PAAG 2019) reported only 22% below target and 50% at index 3 or above.

Grassland: more than half samples were Index 0 and median value 8.8 mg P/l. Only a quarter were target index or above (PAAG found 51%). In some cases the reason may be that they have been sampled at 20cm rather that the standard 7.5cm for permanent grass. However, in many cases deficiency may be due to neglect of testing and phosphate fertiliser application.

**Subsoil**

Arable land: the majority of subsoils (64%) were within index 0 and only 15% at Index 2 or higher.

Grassland; the majority of subsoils (64%) were in the *lower part* of Index 0 and only two samples attained Index 2.

The relationship of soil texture, topsoil P and subsoil P is examined in next section.

The four samples in woodland or amenity averaged 18 mg P/l in topsoil and subsoil.

## 4.2 Factors influencing subsoil phosphorous levels

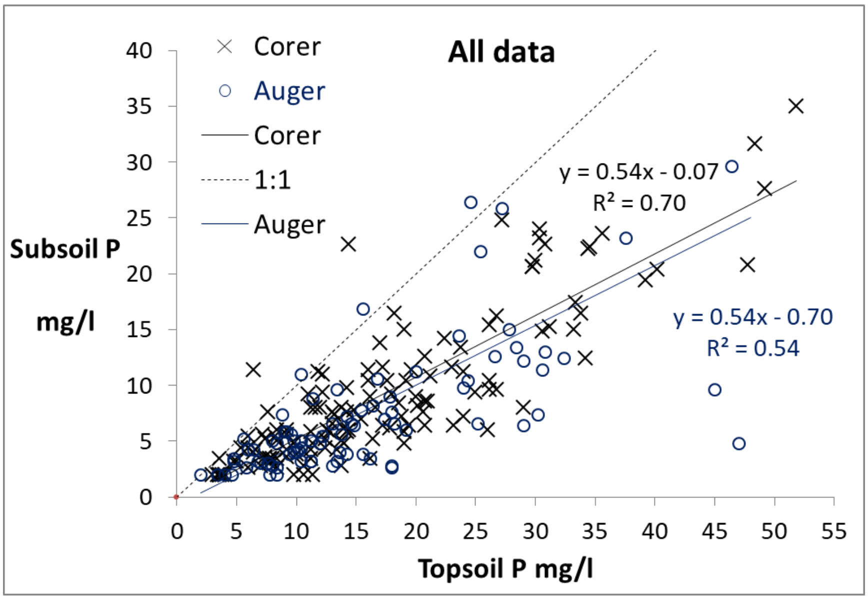


Figure 2. Region A: Phosphorus in Topsoil and Subsoil - effect of sampling method

Subsoil P is more strongly correlated with topsoil P using the coring technique ($r^2$ = 0.70) than the auger sampling method ($r^2$ = 0.54). However both give the same slope i.e. subsoil P 0.54x topsoil P. The corer data goes through the origin while the auger data is about 1 mg/l below origin. These differences are insignificant (see also Appendix 1.1).

The data is looked at in more detail below, with the arable set stratified according to topsoil texture in Figures 3a to 3c.

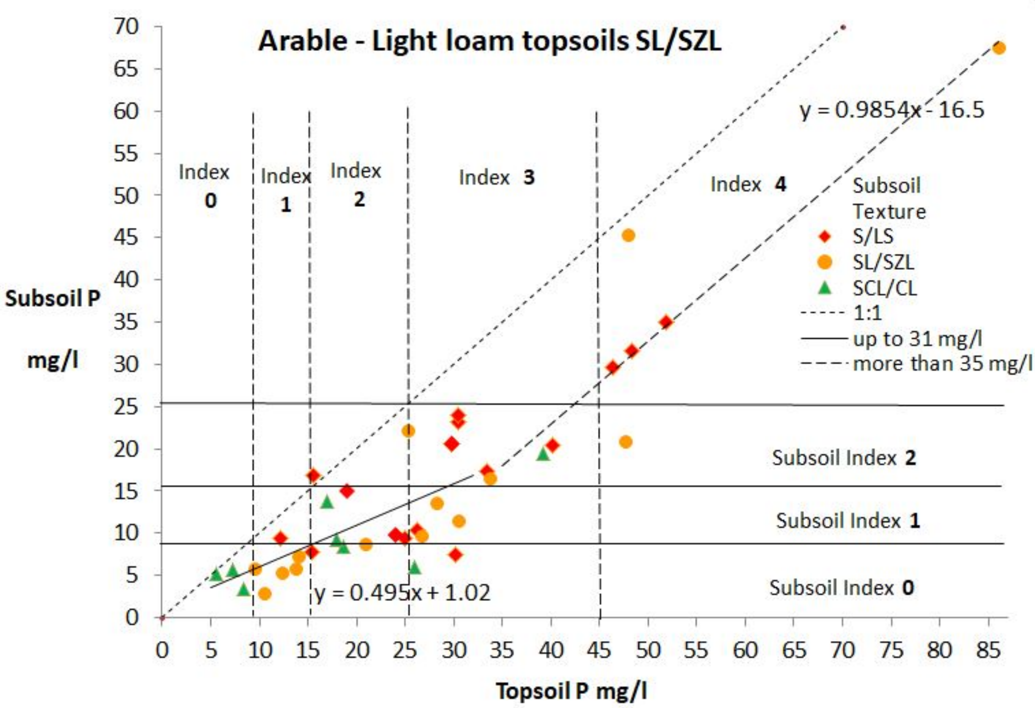


Figure 3a. Region A: Phosphorus in Topsoil and Subsoil - Light Loam topsoils

Figure 3a indicates a characteristic "change-point" relationship. Up to 35 mg/l topsoil P the subsoil P follows at about half the level ($r^2$ = 0.42) but above this point the subsoil increases

1:1 with topsoil P.  This trend looks likely even if the extremely high point (horticulture) were excluded from the correlation.

Transfer mechanisms to subsoil include earthworms, occasional deep ploughing and translocation of P in soluble organic and inorganic forms. Possibly the P retention capacity of the topsoil is substantially diminished once index rises into upper half of index 3.

Subsoil texture does not have an obvious influence, although few of the data had heavier subsoil.

Although light loam textured soils are expected to have adequate P levels, 26% of the data had topsoil index 1 or lower.

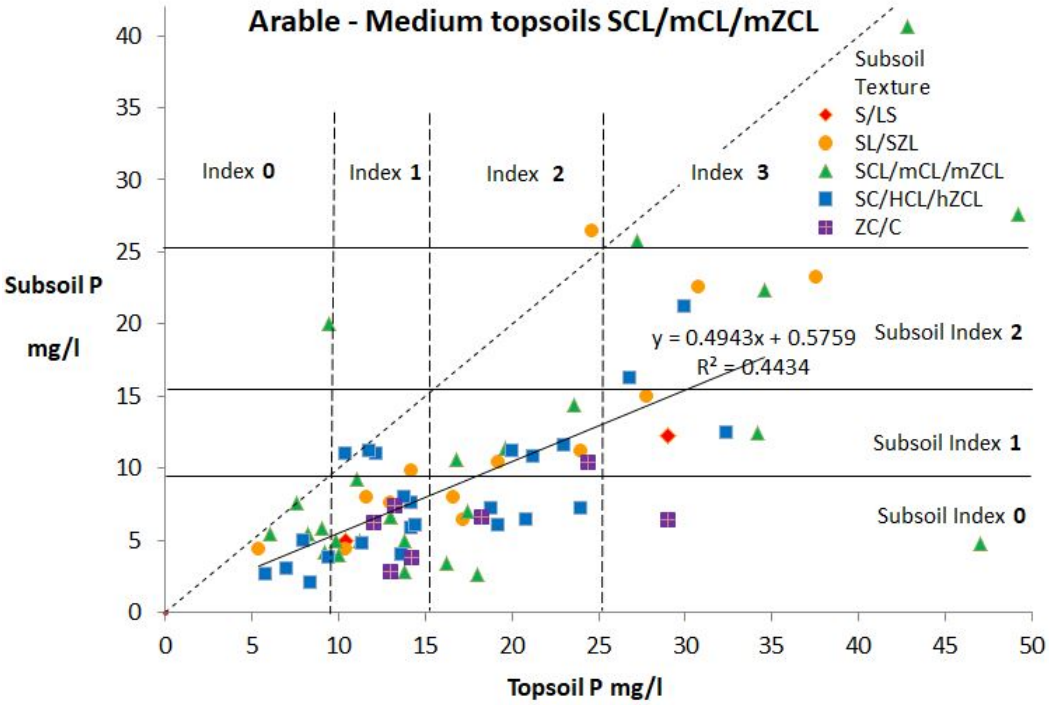



Figure 3b. Region A: Phosphorus in Topsoil and Subsoil  - **Medium textured** topsoils

For medium textured topsoils data up to 35 mg P/l fits to a similar line to Figure 3a. Athough subsoil varies from light loam to clay there is no clear difference.

Above index mid 3 it is possible the line may climb steeper but the data is too few and scattered to draw any conclusions.

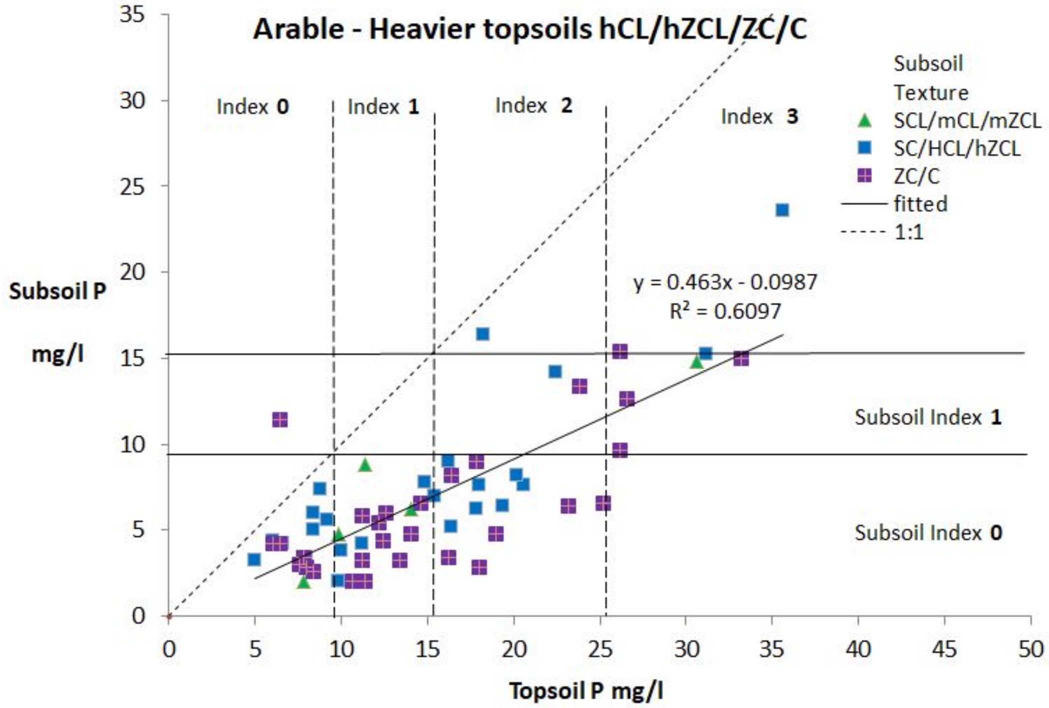



Figure 3c. Region A: Phosphorus in Topsoil and Subsoil - **heavier textured** topsoils

For heavier topsoil (Figure 3c) subsoil P is slightly less than half the topsoil P. Less textural contrast topsoil:subsoil may explain the better correlation compared to Figure 3b.

**Grassland P**

All data is in Figure 4. The one point above 35 mg P/l is excluded from the correlation. There is a higher incidence of low P and heavier subsoils than in the arable data set.

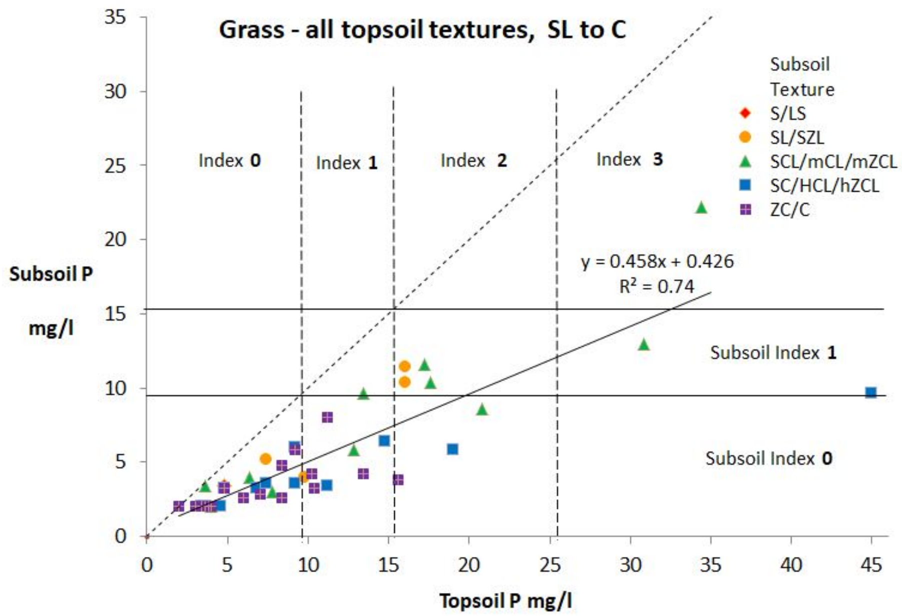



Figure 4: Region A: Phosphorus in Topsoil and Subsoil - Grassland

The correlation of topsoil P with subsoil P is good, with the line lying marginally lower than for arable fields. Lighter subsoils might be higher in P.

**Correlation of P with other factors**

Multiple regression shows that subsoil P is very strongly related to topsoil P and significantly related to topsoil texture but no other topsoil factor (Appendix 9.1).

*Subsoil* texture was of weaker influence, subsoil Organic Matter stronger (Appendix 9.2).

There was no significant effect of soil pH or stoniness.

**Organic Matter Influence**

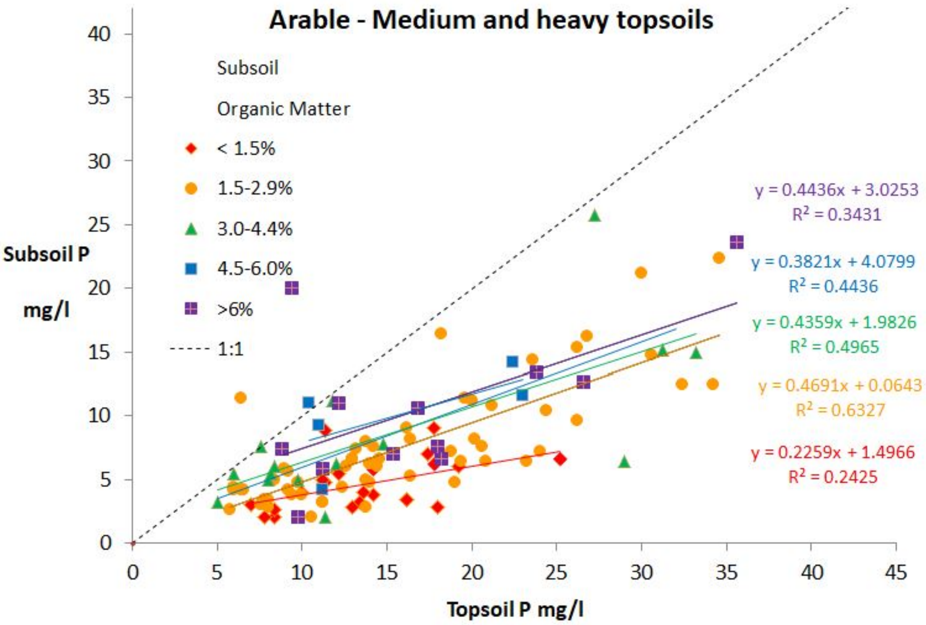



Figure 5. Region A: Phosphorus in Topsoil and Subsoil P - effect of Subsoil Organic Matter. The plots exclude light loam topsoils and topsoils >35 mg P/l

The higher the subsoil OM, the greater the available P for the same topsoil P. See table 5..

**Table 5. Region A: Arable, influence of subsoil organic matter on phosphorus**

| **Subsoil OM %** | **Topsoil** mean P mg/l | **Subsoil** mean P mg/l |
|---|---|---|
| < 1.5% | 13.8 | 4.6 |
| 1.5 - 2.9% | 15.8 | 7.8 |
| 3.0 - 4.5% | 14.9 | 8.5 |
| 4.6 - 6.0% | 15.6 | 10.0 |
| > 6 % | 17.2 | 10.6 |

In order to ensure subsoil P is not in the lower part of index 0 (<5 mg/l), the subsoil OM should be above 1.5%. Where poorer rooting crops are grown possibly 3% should be target.

Multiple regression analysis is given in Appendix 1.2. Subsoil OM was capped at 6% since no consistent benefit was seen above this level and some of the high values were due to coal fragments in the sand fraction.

Disregarding subsoil OM:-

Arable:Subsoil P = 0.46 x Topsoil P - 0.83 x Subsoil Texture + 2.56 $r^2 = 0.52$

Grass: Subsoil P = 0.43 x Topsoil P - 0.56 x Subsoil Texture + 2.07 $r^2 = 0.76$

Including Subsoil OM:-

Arable: Subsoil P = 0.45 x Topsoil P - 1.2 x Subsoil Texture + 0.93 x Subsoil OM + 1.67 $r^2 = 0.61$

Grass: Subsoil P = 0.43 x Topsoil P - 0.61 x Subsoil Texture + 0.29 x Subsoil OM + 1.65 $r^2 = 0.77$

Organic Matter in the subsoil has some influence: a 0.3 – 0.9 mg /l increase in Subsoil P with every % of OM up to 6%. This fits with Table 5.

Each category of texture (~9% clay content increase) reduces Subsoil P by 0.6 - 1.2 mg/l.

## 4.3 Agronomic conclusion: phosphorus levels on Carboniferous soils

Subsoil P shows a strong relationship to Topsoil P and there is also some influence of topsoil or subsoil texture and subsoil organic matter. Increasing clay content has a small negative effect on the available P; OM has a slight positive effect. pH seems irrelevant..

For topsoil Olsen P levels up to 35 mg P / l the following simple relationships can be used for Arable and Grassland respectively on agricultural soils on Carboniferous rocks.

**Table 5: Prediction of subsoil phosphorus (arable and grassland respectively)**

| Class | Topsoil Texture | Regression equation Subsoil P = | | at Topsoil P mg/l 10 | 20 | 30 |
|---|---|---|---|---|---|---|
| 0 | LS, S | 0.46 x Topsoil P + 2.6 | | 7 | 12 | 16 |
| | | 0.43 x Topsoil P + 2.1 | | 6 | 11 | 15 |
| 1 | SL, fSL, SZL | 0.46 x Topsoil P + 1.7 | | 6 | 11 | 15.5 |
| | | 0.43 x Topsoil P + 1.5 | | 6 | 10 | 14 |
| 2 | SCL,mCL,mZCL | 0.46 x Topsoil P + 0.9 | | 6 | 10 | 15 |
| | | 0.43 x Topsoil P + 0.95 | | 5 | 10 | 14 |
| 3 | SC,hCL,hZCL | 0.46 x Topsoil P - 0.1 | | 5 | 9 | 13 |
| | | 0.43 x Topsoil P + 0.4 | | 5 | 9 | 13 |
| 4 | C,ZC | 0.46 x Topsoil P - 0.8 | | 4 | 8 | 13 |
| | | 0.43 x Topsoil P - 0.17 | | 4 | 8 | 13 |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam, mCL = medium clay loam, mZCL = medium silty clay loam, hCL = heavy clay loam, hZCL= heavy silty clay loam, SC = sandy clay, ZC = silty clay, C = clay. Where upper subsoil contains two textures within 50cm the average is used e.g. mCL over C is treated as hCL (3).

Improved equations are given for when subsoil texture and organic matter are known (see previous section). Note subsoil P could be about 1 mg/l lower where the auger technique is used rather than corer.

**Agronomic relevance**

- For topsoil levels up to 20 mg P/l (mid Index 2) the subsoil P is likely to be index 0, except light loam and sandy soils where the subsoil may be index 1.
- When topsoil P is in range 20 to 30 mg P/l (lower index 3) subsoil P is likely index 1.
- When topsoil P is below 10 mg / l (index 0) the subsoil is likely to be in the lower half of index 0 on medium and heavier soils.
- As topsoil P rises above 35 mg / l the subsoil P starts to climb sharply (1:1) on light loamy and sandy soils, but such high levels were rare in medium and heavy soils and no conclusions could be drawn.
- On these Carboniferous soils half the arable topsoils were below Target Index (2) and half the Grassland was Index 0. This should be of concern, especially because levels in upper subsoil are decreased proportionately.
- Clay subsoils tend to have very low levels of available P suggesting that risk of transmission into under drains is minimal. Carboniferous clays are non-swelling and less liable to crack in summer than swelling clays on Jurassic geologies and later.

# 5. Potassium

### Region A: East Midlands to South Yorkshire

### 5.1 Overview of potassium levels

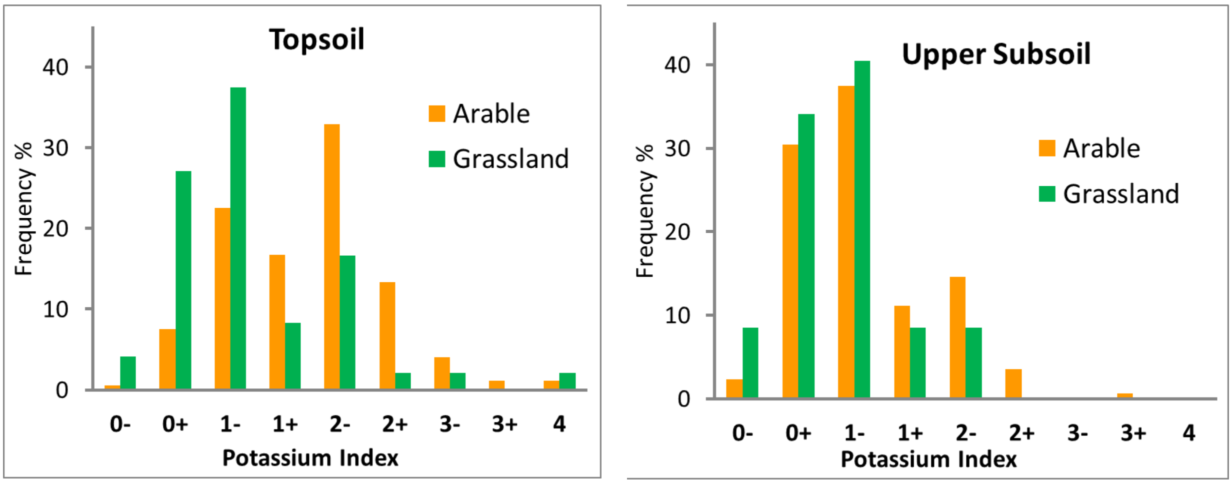



Figure 6a and 6b. Region A Soil available Potassium

**Topsoil**

Arable land: K index 2- is considered optimal. 49% of samples were below this Target level of which 9% were Index 0. Median was 124 mg K / l (low end of 2-). 19% of samples exceeded target though very few were index 3 or 4, indicating that excessive potassium applications are rare. Levels are far lower than PAAG (2019) reports - only 24% below index 2- and 24% at index 3 or higher.

Grassland: 77% of samples were below target index (2-) of which 34% were index 0. Median was 74 mg K /l. Topsoil was sampled to 20cm+ rather than 7.5cm standard for permanent grassland or 15cm for leys, however levels unlikely to be adequate even if sampled to shallower depth. In many cases deficiency may be due to lack of testing and neglect of potassium fertiliser application to replace K offtake in hay or silage. PAAG (2019) reported 44% of grassland was below target index (albeit sampled to shallower depth than here).

**Subsoil**

Arable land: most upper subsoils were index 1 (48%) or index 0 (32%); only 20% were Index 2- or higher.

Grassland; 74% of subsoils were in the range index 0+ to 1-.

The relationship of topsoil K and subsoil K is examined in next section.

The four samples in woodland or amenity averaged 161 mg K/l in topsoil and 112 in subsoil - higher than much of the farmed land.

## 5.2 Factors influencing potassium levels in subsoil

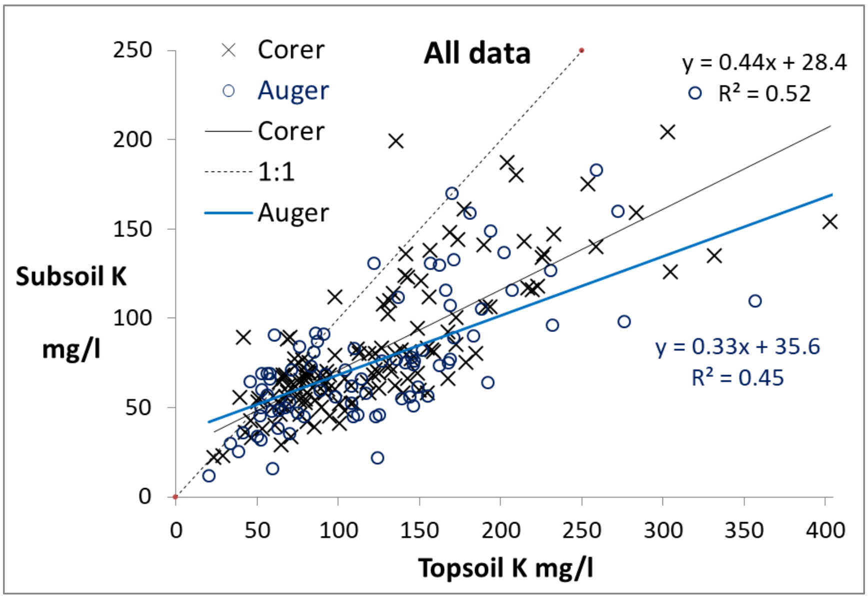



Figure 7. Region A: Potassium in Topsoil and Subsoil - effect of sampling method

The correlation of topsoil and subsoil potassium is weaker than with phosphorus.

The corer technique gives a lower slope but this is strongly influenced by relatively few high values. For the rest of the samples there is no discernible difference due to method.

In a few cases the auger method result is representative of a deeper topsoil than the corer method which sets a maximum of 30cm.

The arable data is stratified according to topsoil texture in Figures 8a-c.

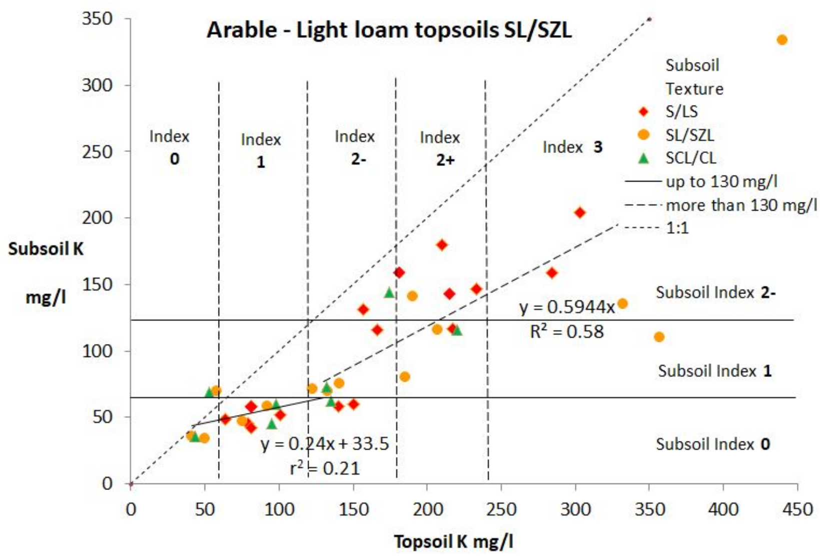



Figure 8a. Region A: Potassium in Topsoil and Subsoil - Light Loam topsoils

As with phosphate Figure 8a suggests a "change-point" relationship. Up to 130 mg/l topsoil K the subsoil K is very weakly related and usually index 0 (median 50 mg/l). Above 130 mg/l the subsoil K increases at about 60% of the increase in topsoil K. Whether *subsoil* texture is sandy or medium does not significantly alter the relationship.

RB209 states that sandy loam soils can be maintained at 150 mg/l, beyond which leaching loss occurs. The data suggests farmers can "maintain" topsoil at higher levels (by applying generous amounts) but a significant proportion may move into the upper subsoil, and very likely deeper K will move further if *lower* subsoil is sandy.

In some of the above cases, occasional deep ploughing may have encouraged transfer of K into subsoil.

The advantage (in lighter soils) of maintaining topsoil at Index 2+, somewhat above target, is that the upper subsoil is thereby maintained within index 2-. Accordingly, in dry periods when K uptake from the topsoil has been suspended, the crop could obtain adequate potassium from the subsoil (until more rain arrives).

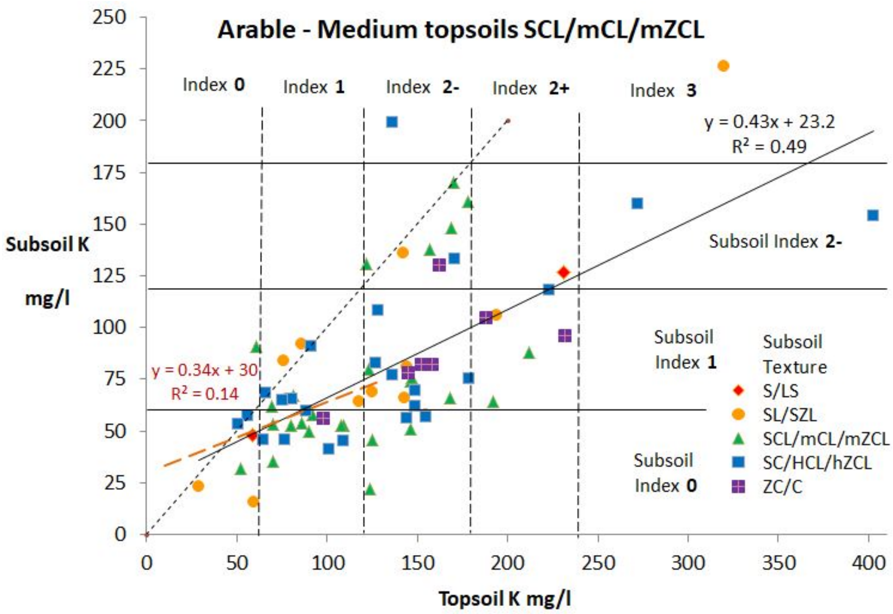



Figure 8b. Region A: Potassium in Topsoil and Subsoil - **Medium** textured topsoil

Data with medium *topsoils* is plotted in Figure 8b. There may be a slight change-point around 130 mg/l, but below this level there is poor correlation of subsoil with topsoil K

Clearly subsoil K is far from predictable from the topsoil K: in some cases it is equal while in others may be 70% less.

Subsoil texture does not have an obvious influence. The minimum K level may be higher on heavier subsoils (blue and mauve) than medium or light ones.

This is examined in next section.

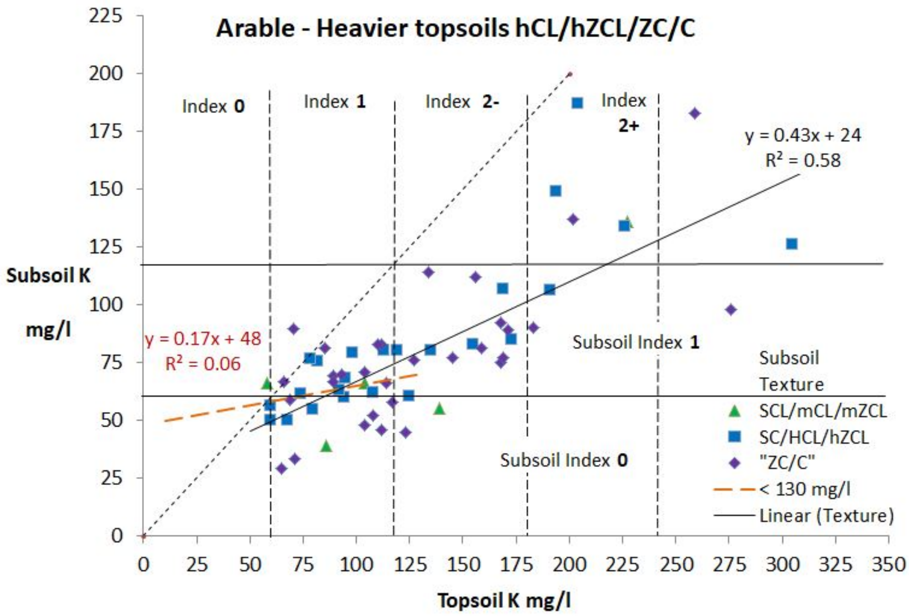



Figure 8c. Region A: Potassium in Topsoil and Subsoil - **heavier textured** topsoil

Where topsoil is heavier (Figure 8c) the data fits an identical regression line to medium topsoils, but there is no correlation below 130 mg K/l in topsoil (brown line).

Heavy loam and clayey topsoils never registered K Index 0 but subsoil can be Index 0 even if clay-textured. However, topsoil index 2- usually guaranteed the subsoil was index 1.

**Grassland K**

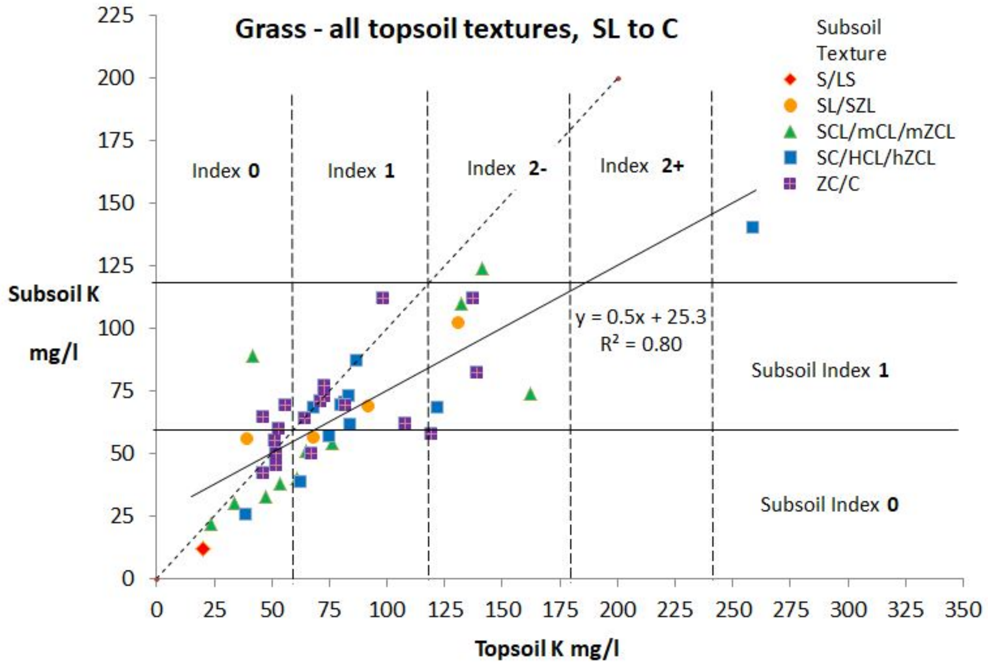



Figure 9: Region A - Potassium in Topsoil and Subsoil - Grassland

One very high point is excluded (529 mg/l topsoil and 123 mg/l subsoil). Apart from this, the relationship between topsoil and subsoil K is very good, with a slope marginally higher than arable data.

When topsoil is index 0 the subsoil can be in *lower* half of index 0 in light and medium soils.

**Correlation analysis of factors influencing potassium**

Based on above Figures the data was partitioned as follows:

a) topsoil texture - sandy and light loams versus medium and heavy

b) above versus below 130 mg / l topsoil K.

Grassland and arable data were pooled with grass/arable as a variable (0 or 1), texture class as a variable 0-4 based on estimated clay content (see table 5). Stone class (0-3) was based on surveyors' estimates of >2mm material: see table 7.

**Factors affecting Topsoil K** (appendix 9.3)

a) on light loam topsoils there was a significant difference arable to grass (61 mg K/l less). The following relationships are not statistically proven ($P$ <.05), but have a logical basis:

- autumn/winter vs sampling in spring while crops are going (39 mg/l less, $P$ = .3)
- topsoil stones (+30 mg K/l per 10% stones $P$ = .22)
- pH (+ 28 mg/l per pH unit, $P$ = .2)

There was no effect of topsoil organic matter or annual average rainfall.

b) on medium and heavy topsoils grass was less than arable by 42 mg K/l.

- autumn/winter versus spring sampling was (-22 mg/l, $P$ = .02)
- topsoil organic matter up to 10% max. (+ 3.8 mg K/l per 1% SOM, $P$ = .01)

There was no effect of pH, stones or annual average rainfall.

For all textures topsoil K correlated with topsoil phosphorus. See Appendix 9.1

**Factors effecting Subsoil K** (appendix 9.4)

Correlation analysis indicated that subsoil organic matter and subsoil texture were influential.

Lighter subsoil class showed *increased* the available K presumably because less K is held in non-extracted forms as clay content increases

Raised subsoil organic matter may be indicative of deepened topsoil or earthworm burrowing. Its inclusion significantly improves the prediction.

On medium and heavy topsoils there was no effect of subsoil texture on the subsoil K but a significant influence of subsoil organic matter.

Disregarding subsoil OM (topsoil K up to 400 mg/l):-

Light loam and sandy topsoils: $r^2 = 0.74$
Subsoil K = Topsoil K x 0.544 + 12.7

Medium and heavy topsoils
Subsoil K = Topsoil K x 0.42 + 20 $r^2 = 0.50$

If Subsoil OM is known (up to a maximum of 6%):-

Light loam and sandy topsoils: $r^2 = 0.81$
Subsoil K = Topsoil K x 0.52 - Subsoil Texture Class x 10.4 + Subsoil OM % x 12.8 + 0.9

Medium and heavy topsoils
Subsoil K = Topsoil K x 0.41 + Subsoil OM % x 4.3 + 16 $r^2 = 0.54$

Table 7 shows that very low K (< 60 mg K/l) could be found in topsoil and subsoil of all textural classes in this region.

**Table 7. Region A: comparison of texture with lowest K values and typical stoniness.** Lowest 10% percentile and least K values in parenthesis. Mean stone class.

| **Texture** topsoil or subsoil | **Topsoil** mg K/ l | **Subsoil** mg K/ l | **Topsoil** Stone Class | **Subsoil** Stone Class |
|---|---|---|---|---|
| LS, S | - | (12) 48 | - | 1.4 |
| SL, SZL | 48 | (23) 34 | 0.8 | 1.2 |
| SCL, mCL,mZCL | 52 | (22) 33 | 0.6 | 0.7 |
| SC, hCL, hZCL | 68 | (25) 46 | 0.3 | 0.8 |
| ZC, C | 49 | (29) 46 | 0.5 | 0.5 |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam, mCL = medium clay loam, mZCL = medium silty clay loam, hCL = heavy clay loam, hZCL= heavy silty clay loam, SC = sandy clay, ZC = silty clay, C = clay. Where upper subsoil contains two textures within 50cm the average is used e.g. mCL over C is treated as hCL.

Stone Class 0 = < 5% by volume, Class 1 = 5-14%, 2 = 15-24%, 3 = 25%+.

**Influence of stones on available K**

These Carboniferous soils contain variable amounts of >2mm material: sandstone, drift stones and small siltstone, ironstone or coal fragments.

Table 7 indicates the average stone class in sandy subsoils was 1.4 representing ~15% stones: this corresponds to a 15% reduction in available K. Furthermore, in some cases hard sandstone prevented sampling to the full 50cm. The stone dilution effect was less (typically < 8% by volume) on medium and heavy soils. It was not possible to fit stoniness into a satisfactory regression formula.

## 5.3 Agronomic conclusion: potassium levels in Carboniferous soils

Subsoil K shows a clear relationship to topsoil K, similar for arable or grassland soils. Grassland tends to be lower K status (Index 1 or 0) but there was also a large number (48%) of arable samples below 120 mg K/l.

Compared to medium and heavy topsoils, light loams (SL/SZL) and sands (LS) behave differently with a higher proportionate amount of K registering in the subsoil. This may due to increased leaching, especially when topsoil K rises above 130 mg K / l, with LS subsoils showing *higher* K levels than SL subsoils.

In some cases stoniness and hard sandstone within 50cm nay 'dilute' the actual amount of K available to roots in the subsoil.

RB209 states that sandy loam soils can be maintained at 150 mg/l, beyond which leaching occurs. This data suggests that when farmers maintain the topsoil at higher levels (by applying generous amounts of potash) but some moves to the upper subsoil, and likely moves into the lower subsoil if sandy.

On medium and heavy soils, the topsoil : subsoil relationship is unaffected by topsoil or subsoil texture class, though it is rare for the topsoil to be index 0 if it is hCL/hZCL textured.

It was not common to get subsoil values as low as 45 mg K/l even where clayey textured. Carboniferous clay tends to be more kaolinitic than other UK clays and is cited in RB209 as an example of a "non-releasing clay". It will be interesting to compare this with Triassic, Jurassic and Cretaceous Clays in other regions of the study.

Subsoil organic matter is associated with improved subsoil K, especially on lighter soils. This may be because deep ploughing or earthworm activity takes K down into subsoil and an increased is "easily exchanged" K sites on the organic matter.

For topsoil K levels up to 400 mg K / l the following simplified relationships were found for agricultural soils on Carboniferous rocks.

**Table 8a: Prediction of subsoil potassium (arable and grassland)**

| Class | Topsoil Texture | Regression equation Subsoil K = | at Topsoil K mg/l 60 | 90 | 150 | 240 | 320 |
|---|---|---|---|---|---|---|---|
| 0,1 | LS,SL,fSL,SZL | 0.54 x Topsoil K + 14 | 46 | 63 | 95 | 144 | 188 |
| 2-4 | medium & heavy | 0.42 x Topsoil K + 20 | 45 | 58 | 83 | 121 | 154 |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam

Accordingly for topsoil levels around 150 mg K/l (target = mid Index 2- ) the subsoil K is likely to be mid index 1 and where topsoil is index 1 subsoil is borderline index 0/1. At raised topsoil index 2+ or 3, the subsoil K is likely to be higher in lighter soils than other textures.

Heavy textured subsoils are common but do not seem to help potassium availability here and the topsoil target should not be reduced from index 2- for arable nor grassland.

**Caution:** there is considerable scatter either side of the above regressions, for example differences in subsoil K of up to 40 mg/l. Improved predictions are available (in previous section) if subsoil OM is measured.

The data also suggests that soil K levels may be lower during the main growing season March to July. The lowest topsoil and subsoil K levels on an arable field were obtained on field growing oilseed rape sampled during May.

We do not know where there had been recent potassium fertiliser applications to the fields when sampled and this could have increased the topsoil K in relation to the subsoil.

For potassium response trials, it is advisable to *measure* both topsoil and subsoil K by a coring technique like the one used here.

**Footnote: is it safe to rely on measuring topsoil potassium alone?**

**Table 8b: uncertainty in subsoil potassium.** Number of samples in each topsoil K : subsoil K combination

Light loam topsoil (arable)

| | | Subsoil K | | | |
|---|---|---|---|---|---|
| **Topsoil K** | Index 0 | Index 1- | Index 1+ | Index 2- | Index 2+ |
| Index 0 | 3 | 2 | | | |
| Index 1- | 7 | | | | |
| Index 1+ | 4 | | | | |
| Index 2-(L) | 2 | 5 | | | |
| Index 2-(H) | | | 1 | 2 | |
| Index 2+ | | | 3 | 3 | |
| Index 3 | | | 1 | **1** | 1 |

Medium topsoil (arable)

| | | Subsoil K | | | |
|---|---|---|---|---|---|
| **Topsoil K** | Index 0 | Index 1- | Index 1+ | Index 2- | Index 2+ |
| Index 0 | **6** | | | | |
| Index 1- | 8 | **7** | 2 | | 1 |
| Index 1+ | 6 | 1 | 1 | | |
| Index 2-(L) | 6 | **13** | 1 | 3 | 1 |
| Index 2-(H) | | 2 | | 5 | |
| Index 2+ | | 1 | 4 | 2 | |
| Index 3 | | | | | 1 |

Heavy loam or clay topsoil (arable)

| | | Subsoil K | | | |
|---|---|---|---|---|---|
| **Topsoil K** | Index 0 | Index 1- | Index 1+ | Index 2- | Index 2+ |
| Index 0 | 2 | 1 | | | |
| Index 1- | 6 | 8 | | | |
| Index 1+ | 5 | **12** | | | |
| Index 2-(L) | 2 | **9** | 4 | | |
| Index 2-(H) | | | 1 | | |
| Index 2+ | | 1 | 1 | 2 | 1 |
| Index 3 | | | 1 | **1** | 1 |

Grassland – all textures

| | | Subsoil K | | | |
|---|---|---|---|---|---|
| **Topsoil K** | Index 0 | Index 1- | Index 1+ | Index 2- | Index 2+ |
| Index 0 | **12** | 3 | | | |
| Index 1- | 7 | **11** | | | |
| Index 1+ | 1 | **2** | 1 | | |
| Index 2-(L) | | 2 | **3** | 1 | |
| Index 2-(H) | | 1 | **1** | | |
| Index 2+ | | | | | |
| Index 3 | | | | | 1 |

In table 8b the grey shaded cases are probably satisfactory: at least index 2- in topsoil and index 1+ or more in upper subsoil. Orange indicates topsoil is 2- or 1+ but subsoil index 1-, pink index 0. Boxes with only 1 data are not shaded.

- At (topsoil) K index 0 (0-60 mg/l) subsoil is also index 0.
- At K index 1- (60-90 mg/l) subsoil is index 0 or 1- and very likely inadequate.
- At topsoil index 1+ (91-120 mg/l) subsoil is likely index 0 on sandy/light loam soils but 1- on medium and heavy soils. A policy of maintaining topsoil at only index 1+ looks highly dubious even on heavier soils.
- At topsoil in the lower half of index 2- (121-150 mg/l) there is still a strong likelihood subsoil is 1- (or 0).

- At topsoil in the *upper half* of index 2- (151-180 mg/l) the subsoil is likely to be index 1+ providing some insurance if the topsoil dries out.
- Notwithstanding, the above within topsoil index 2- the subsoil could vary widely from index 0 to 2-. In 4 cases the subsoil significantly was higher than the topsoil K *.
- At topsoil index 2+ the subsoil K is usually at least 1+.

* Anomalies explored

8 cases: medium or heavy topsoil where top = index 2- but subsoil 0:-

- 7 were by auger versus 1 by core technique (in 4 topsoil depth was >30cm).
- Subsoil textures: 1 SL and 1 C, others SCL/mCL and hCL.
- All sampled in autumn (Sept to Jan) mainly in cereals and 2 in WOSR
- Possibly topsoil K exaggerated by recent fertiliser application?

12 cases: medium and heavy topsoils where top = index 2 and subsoil 2-:-

- 6 by auger and 6 by corer technique
- subsoil textures mCL to C. One was ZL over C with subsoil K higher than topsoil.
- 3 sampled in May, the others in autumn
- 2 evidence of recent manure application which has boosted subsoil K.

# 6. Magnesium

Region A: East Midlands to South Yorkshire

## 6.1 Overview of magnesium levels

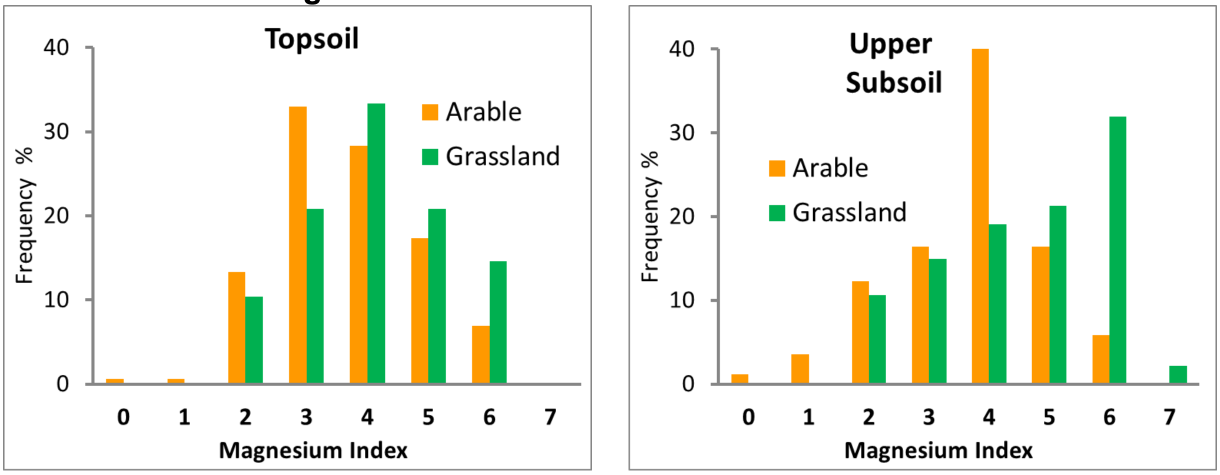



Figure 10a and 10b. Region A: Soil available Magnesium

**Topsoil**

Arable land: Mg index 2 is considered optimal for nearly all crops, with index 3 for specialised fruit and vegetable crops.

98% of samples were above target with a median value of 182 mg Mg / l (Index 4). 30% were Index 5 (very high) and 12% Index 6 (excessive). The national PAAG (2019) survey data shows fewer (59%) of soils above target and only 12% were index 5 or more.

Grassland; 90% of samples were above target Index (2) and tended to be slightly higher than arable samples (median 207 mg Mg / l).

**Subsoil**

Arable land: almost no subsoils were index 0 or 1. Compared to the topsoil fewer samples were index 2 but the median was similar (187 mg/l).

Grassland; no subsoils were index 1 or 0, the median was 262 mg Mg / l (Index 5) and 34% had excessive levels (Index 6 or 7).

The sources of magnesium in these soils can be fourfold

a) the parent clay minerals weather to release large amounts of Mg

b) subsoils contain 'dolomitised' carbonates (some Mg substituted for Calcium).

c) when the soils are limed they receive dolomitic material. A ridge of Dolostone rocks flanks this region to the east with many lime quarries.

d) under grassland there may be a net Mg return to land from grazing animals.

## 6.2 Factors influencing magnesium levels in subsoil

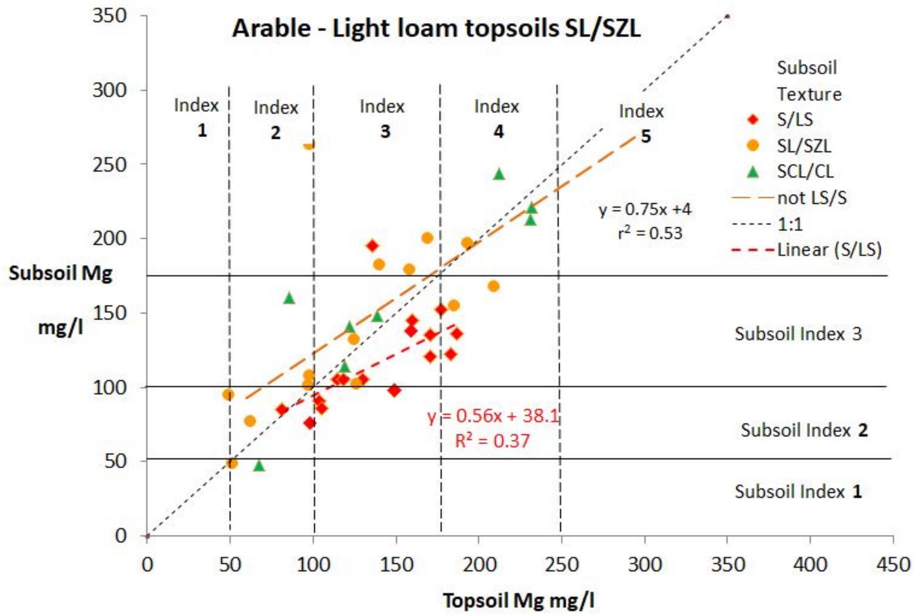



Figure 11a. Region A: Magnesium in topsoil and subsoils – Light loam topsoil

For lighter soil none exceeded 250 mg Mg/l. Subsoil makes some difference: sand subsoils are below the 1:1 line and light loam subsoils close to it.

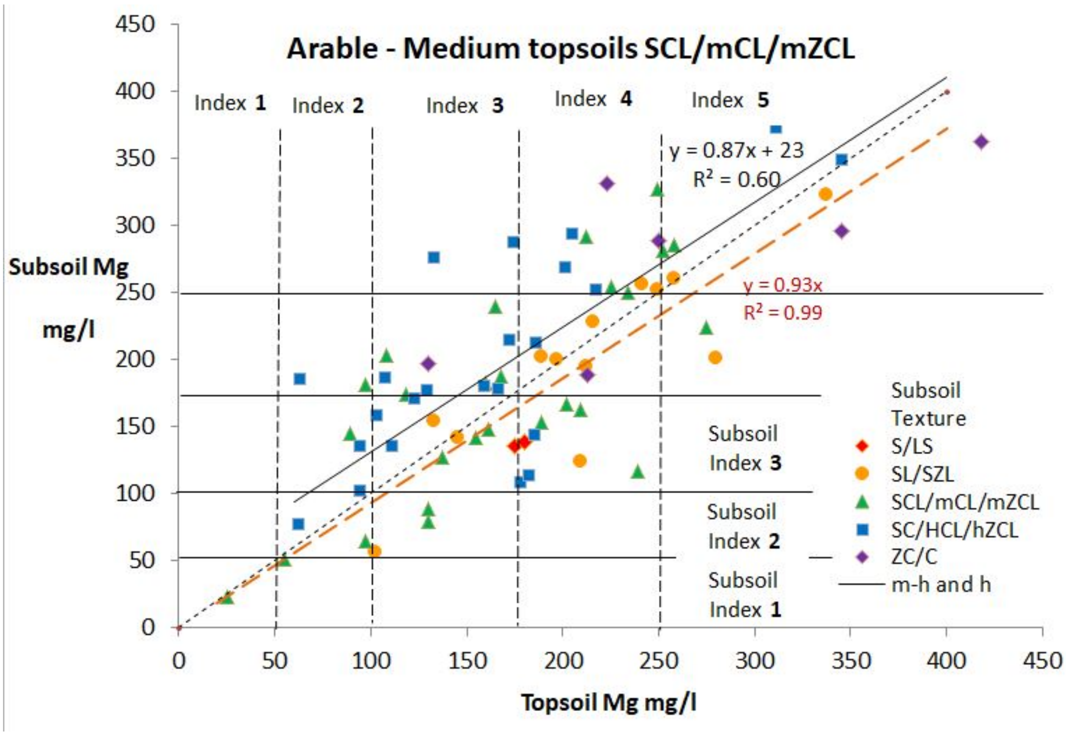



Figure 11b: Region A: Magnesium in topsoil and subsoil – **Medium** topsoils

As in Figure 11a gain there is a subsoil texture effect: heavy loam and clay subsoils higher in Mg than their topsoils. For medium and light loam soils the fit is marginally below 1:1.

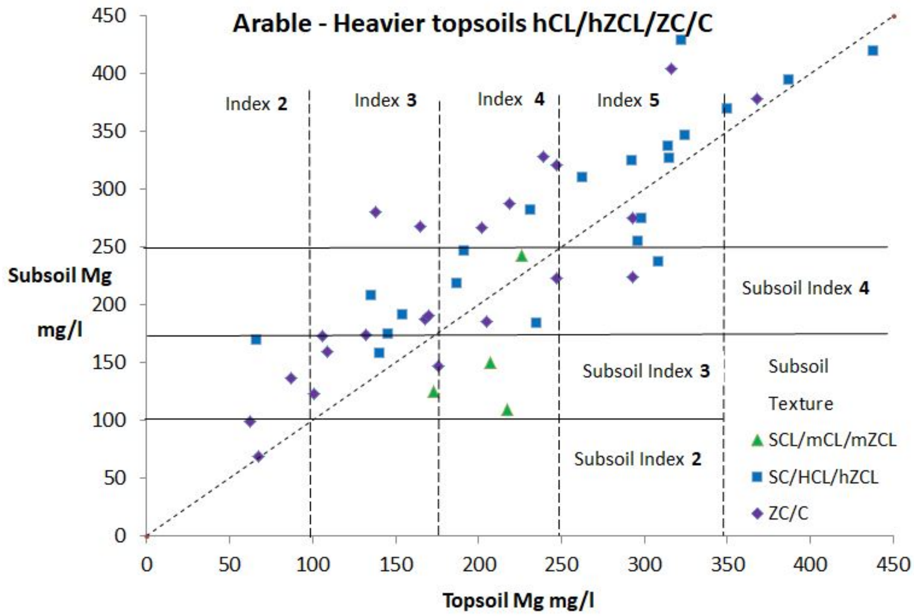



Figure 11c. Region A: Magnesium in topsoil and subsoil - **heavier textured** topsoils

Mg index 5 is more is commoner on heavier land. The subsoils tend to be above the 1:1 line except where loamier. Possibly, into Index 6 subsoil Mg drops below topsoil Mg.

### Grassland Mg

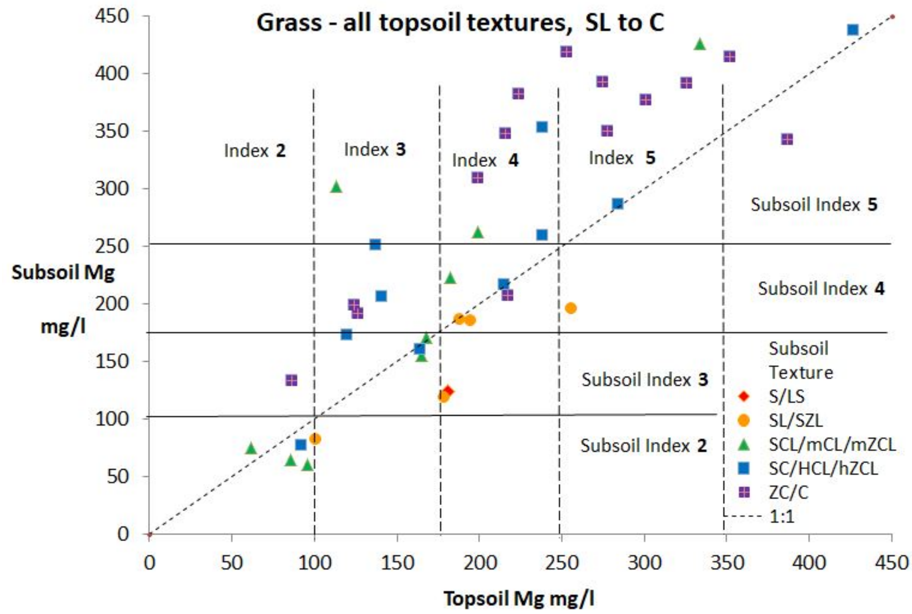



Figure 12. Region A: Magnesium in topsoil and subsoil **- Grassland**

Grassland data (Figure 12) shows a similar pattern to arable. Subsoil Mg is on or below the 1:1 line for medium and sandy soils and above the line for heavier subsoils.

### Correlation with other factors

Based on Figures 11a-c data was partitioned according to on subsoil texture class.

Data was restricted to the agronomically relevant range (Index 0 to 4), with a separate summary of trends for heavier soils at index 5.

Regression showed topsoil Mg showed marginal influence of topsoil texture class ($P$ = 0.46) and pH ($P$ = 0.25), both not statistically significant.

Grouping data according to *subsoil* texture gave the following relationships:

**Table 9: Prediction of subsoil magnesium where topsoil ≤ 250 mg/l Mg (Index 0-4).**

| Class | **Subsoil Texture** | Regression equation Subsoil Mg = | at Topsoil Mg mg/l **25** | **50** | **100** | **175** |
|---|---|---|---|---|---|---|
| 0 | LS, S | 0.8 x Topsoil Mg | 20 | 40 | 80 | 95 |
| 1 | SL, SZL | 1.0 x Topsoil Mg | 25 | 50 | 100 | 175 |
| 2 | SCL, mCL,mZCL | " " | " | " | " | " |
| 3 | SC, hCL, hZCL | 1.17 x Topsoil Mg + 10 | 39 | 69 | 127 | 214 |
| 4 | ZC, C | 1.29 x Topsoil Mg + 19 | 51 | 84 | 148 | 245 |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam, mCL = medium clay loam, mZCL = medium silty clay loam, hCL = heavy clay loam, hZCL= heavy silty clay loam, SC = sandy clay, ZC = silty clay, C = clay. Where upper subsoil contains two textures within 50cm the average is used e.g. mCL over C is treated as hCL (3).

Plots are in Appendix 9.5. Although there was very few data <50 mg Mg/l (index 1), the agronomic conclusion is that if the topsoil Mg level is satisfactory, the subsoil will be sufficient also.

Where the topsoil Mg is >250 mg/l (Index 5 or 6) subsoil Mg is likely to be similar.

## 6.3 High magnesium levels

1) RB209 states that high soil magnesium can antagonise uptake of potassium, and this is often noted by agronomists. Criteria are not precisely specified but a minimum K:Mg ratio (mg/l:mg/l) of 0.5 is often cited.

2) There is some evidence that an undue proportion of magnesium on the exchange complex can make heavier soils 'harder to work', possibly because Mg destabilises the organic colloids bound to the clay.

In this data set the median ratio for topsoil is low, 0.55, and for subsoil very low at 0.33. Large numbers of topsoil and most subsoil samples are below the 0.5 ratio (Figure 13).

Most topsoils of K index 1 were below the 0.5 ratio. If target K index (2-) is attained then Mg index 4 will be tolerable but at Mg index 5 or 6 it might be better agronomic practice to maintain soils at K index 2+.

The reasons for high magnesium levels in these soils are discussed in the pH section.

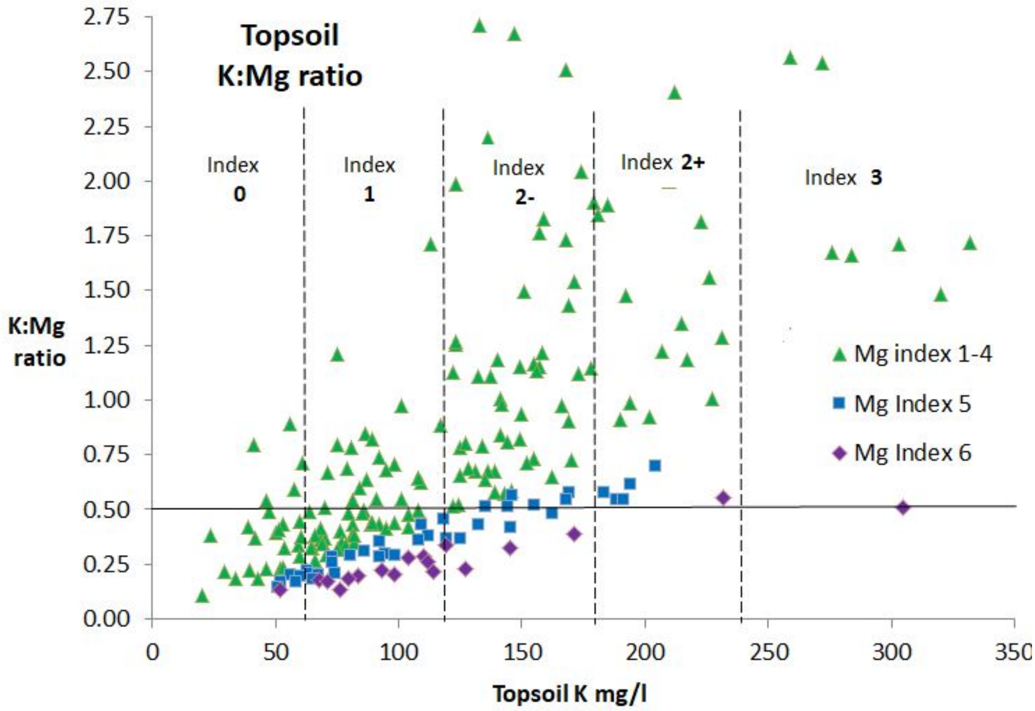


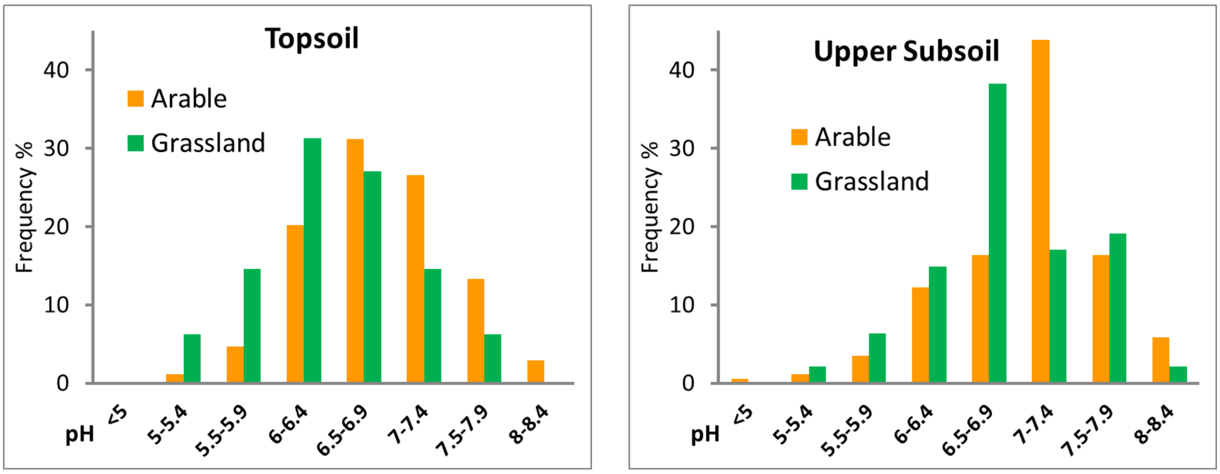

Figure 13: Region A: ratio of potassium to magnesium on a mg/l : mg/l basis.

Most of the index 6 profiles are on Carboniferous formations: only one was shallow over Dolostone – an organic sandy loam of 572 mg/l Mg. The author has included in the data record two other profiles on Dolostone near Conisburgh – a stony shallow medium topsoil Mg 437 mg/l and the associated valley soil (decalcified) of 359 mg/l. All three samples were index 6 and K:Mg ratio < 0.5.

# 7. pH

Region A: East Midlands to South Yorkshire

## 7.1 Overview of pH levels




Figures 14a and 14b. Region A : Soil pH (1 soil:2.5 water)

**Topsoil**

Arable land: 6.5-6.9 is considered optimal (RB209). 31% of samples were at target pH (modal) and only 6% were acid (< pH 6), less than found nationally by PAAG (2019) at 19% Median pH was 6.9. 27% of samples were very slightly alkaline (7-7.4) and 16% too alkaline (pH 7.5+).

Grassland; 6.0-6.4 is optimal for grass. Only 21% of samples were below target of which 13% were 5.5 (compared to 19% in PAAG data). Note that normally grass is sampled at shallower depth (7.5cm or 15cm) than the 20cm here, and it is quite likely that pHs where the most roots reside are slightly lower pH than Figure 14 implies.

**Subsoil**

Arable land: only 18% of samples were below target. The modal and median value (7.1) was slightly alkaline and 26% of samples were too alkaline (pH 7.5-8.5).

Grassland; only 8% were below pH 6.0. Median value was 6.9 and 22% of subsoils were too alkaline (>7.4).

The good pHs in this data set are in contrast to the phosphorus and potassium data where half the data were deficient.

The four samples in woodland and amenity averaged pH 6.7 in topsoil and 7.4 subsoil.

## 7.2 Factors influencing pH of subsoil

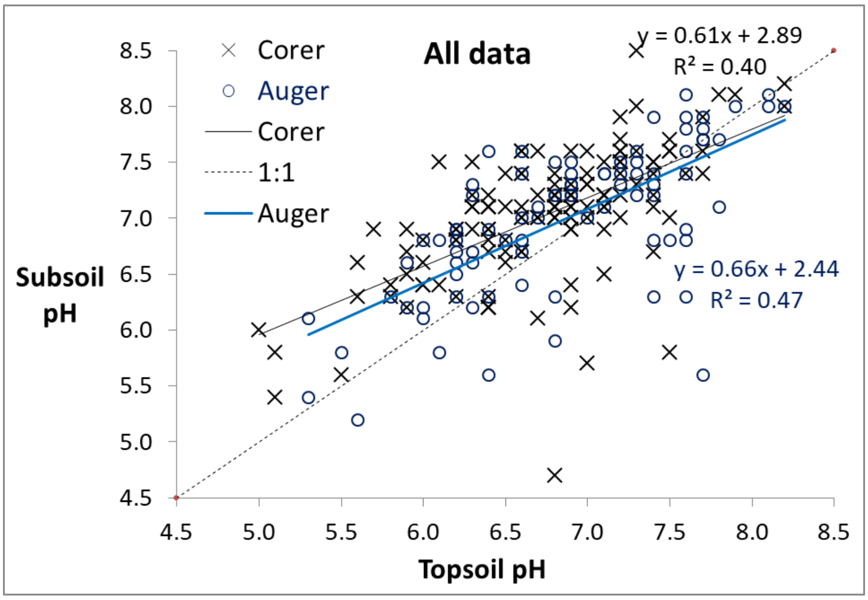



Figure 15. Region A: pH in Topsoil and Subsoil - effect of sampling method

Topsoil pH accounts for slightly more of the variance in subsoil pH using the corer ($r^2 = 0.47$) rather than the auger method ($r^2 = 0.40$). Figure 15 indicates that subsoil pH might be 0.1 higher by the auger method. This may because the corer method always includes the soil surface which is likely to be more acid whereas the auger method is not so specific. The method difference is small enough to be ignored for the data processing.

The subsoil pH is expected to be higher than topsoil pH (except where soils contain free carbonates) because leaching occurs, in both topsoil and subsoil.

For agronomic reasons the data was split pH up to 7.0 and below 7.0

The sample of topsoil pH 6.8 and subsoil 4.7 is excluded from the regressions (see later).

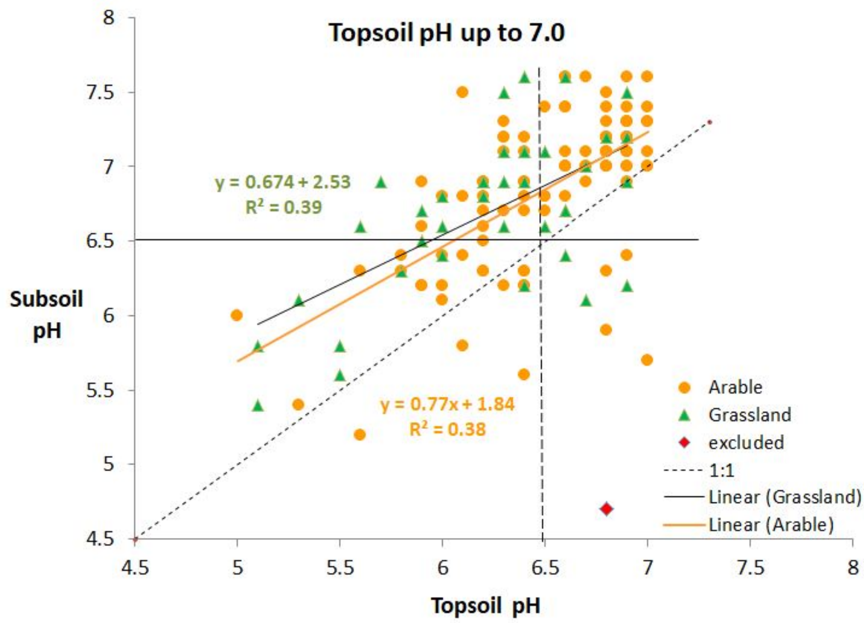



Figure 16a. Region A: Topsoil (pH up to 7.0) and Subsoil pH

Data confirms subsoil pH as usually greater than topsoil pH. Arable and grass data fit to similar regression lines with overall relationship :

Subsoil pH = topsoil pH x 0.72 + 2.17 $r^2 = 0.39$

So typically at topsoil pH 6.5 the subsoil pH is 6.9 and at pH 5.5 the subsoil is 6.1, i.e. an increase of 0.4 to 0.6.

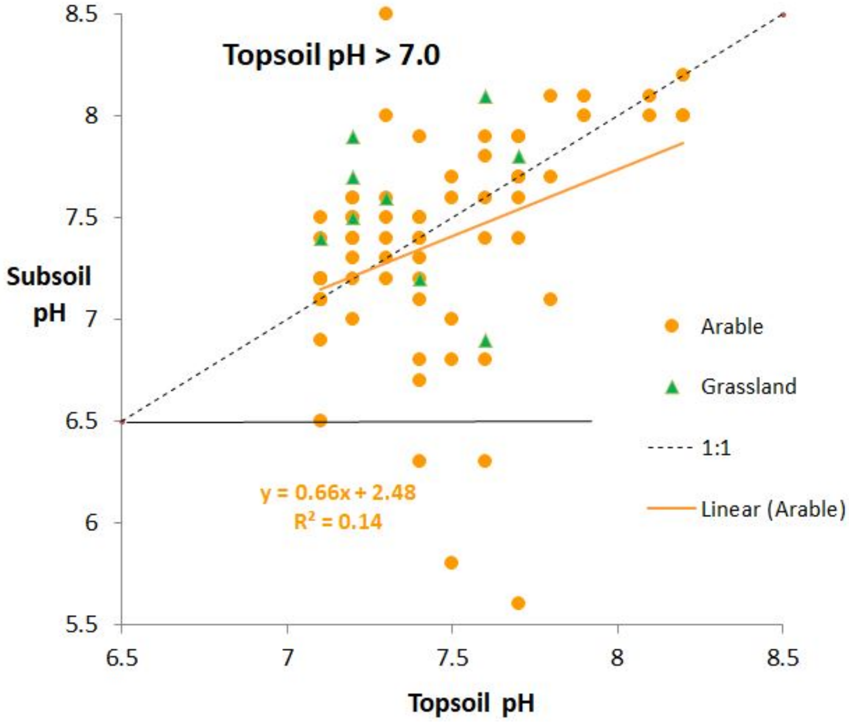



Figure 16b. Region A: pH in topsoil (above 7.0) and subsoil

At pH greater than 7 the subsoil pH is poorly related to topsoil pH, though broadly similar except in a few notable cases where subsoil pH is significantly lower.

In Figures 16a and 16b there were 17 cases where the subsoil pH was at least 0.5 less than the topsoil and below 6.5.

- All but three cases had heavy loam or clay textures (category 3 or 4).
- Six were obviously disturbed (remade) and six contained significant coal fragments.
- Five had subsoil organic matter > 6% (more correctly, organic carbon > 3.5 %)

The natural expectation is for subsoil pH to be higher due to leaching of bicarbonates, calcium and magnesium from the topsoil. The opposite would occur if :

a) soil sample was taken close to recent liming.

b) acidification reactions are taking place in the subsoil.

c) subsoil is usually wet and oxidation reactions occur when soil is exposed to air. These tend to lower the pH.

It is possible, that coal rich or organic layers may be prone to b) and so it may be worthwhile checking upper subsoil pH whenever the topsoil is tested, especially on remade land.

**Carbonates?**

pH above 7.5 suggests the presence of at least 1% free carbonate in the profiles. However, when surveyed very few gave a positive reaction to 10% HCl. Dolomotised lime is slower to react and therefore might have gone undetected in some cases.

However, there is no correlation between subsoil Mg and pH (Figure 16b). So the variation in exchangeable Mg seems due primarily to clay content and clay mineralogy

The very weak relationship of Mg to topsoil pH might be linked to history of use of Magnesian lime though Calcitic lime (or sugar beet lime) may have been used on some fields

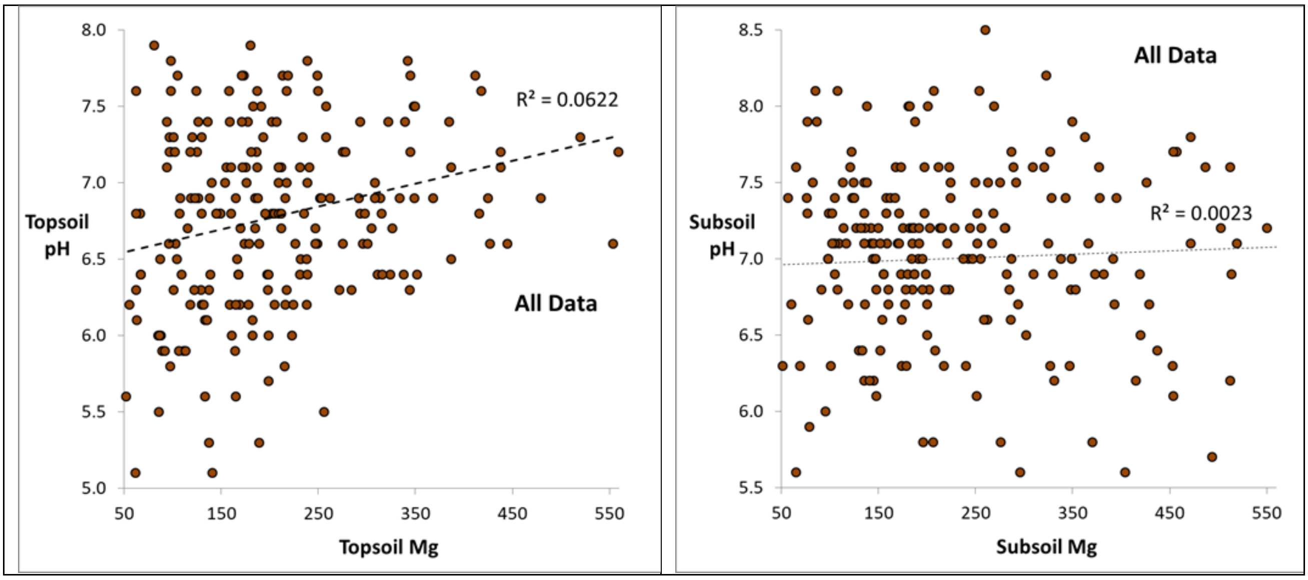


Figure 17: Region A: Magnesium versus pH in a) topsoil and b) subsoil

## 7.3 Agronomic conclusion: pH levels in Carboniferous soils

pH: 6.5-6.9, the optimum for arable land comprised 31% of the topsoils;.20% were pH 6 – 6.4 and only 6% below pH 6.0. 43% were (slightly) alkaline. Only 21% of grassland topsoils were below target pH 6.0 though if only the surface 7.5cm had been sampled (normal for permanent grass) more samples would have registered as acid.

Only 18% of arable upper subsoils were below pH 6.5 and 8% of grass subsoils below 6.0.

Because soils are subject to downward leaching of calcium, magnesium and bicarbonate, the expectation is that the pH of the subsoil will be higher than the topsoil.

The data base upholds this. Grass and arable data for topsoil pH below 7.1

Subsoil pH = topsoil pH x 0.72 + 2.17 $r^2 = 0.39$

Accordingly subsoil pH is about 0.5 higher than topsoil although there is considerable variation.

Above pH 7 there was no clear relationship which would be expected if carbonates are present to any extent. It is postulated that dolomotised material could be present, though the exchangeable Mg in the subsoil does not correlate with pH.

The agronomically important finding was that in only 20 cases was the subsoil pH *less* than the topsoil pH and less than 6.5.

In examining 17 cases where the reduction was at least 0.5, most had heavy subsoils and in several coal fragments were present. In the worse example topsoil pH was 6.8 and subsoil 4.7. The following guidance is suggested:-

- Sampling of upper subsoil for pH is worthwhile on remade / disturbed or naturally coal-rich profiles.
- In all other cases sampling of topsoil (to 20cm) only should be sufficient to calculate lime required. However if the topsoil pH is below 5.5 it is likely the upper subsoil to 50cm is acid (6 or below) and therefore additional lime is appropriate:

  a) over-lime the topsoil (to above 7) to accelerate leaching of bicarbonate, or

  b) "plough under" some extra lime as well as applying standard amount to topsoil or apply more lime the following autumn

Note: the standard depth of action of a lime recommendation is 20cm for arable land. The usual liming 'buffer' factors could be reduced where subsoil organic matter is much lower than 3% but might need to be increased to 25cm depth of action, so no alteration is needed.

## 8. Organic Matter

### Region A: East Midlands to South Yorkshire

### 8.1 Overview of soil organic matter levels

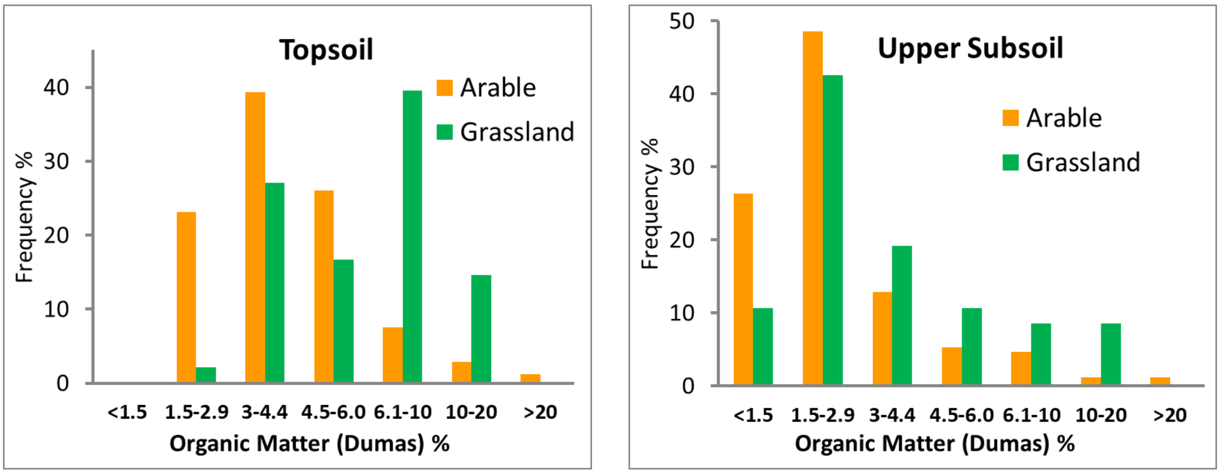



Figure 18a and b. Region A: Soil Organic Matter (% Carbon by Dumas method x 1.72)

**Topsoil**

The above categories are as specified in Soil Survey of England and Wales manual with 3-4.4% designated moderate and > 6% OM as very high (here termed 'high'; the intermediate 4.5-6% range is termed 'good').

RB209 distinguishes organic soils 10-20% and peaty soils (>20% OM). Agronomic limits have been set using the Walkley Black (WB) method. The Dumas method used here gives equal or slightly lower values than WB whereas the Loss on Ignition gives much higher values on heavier soils (due to loss of water of hydration) and is not comparable. Ref can be supplied.

Arable land: the median (3.8%) and modal category is 'moderate.' 26% of samples are considered Good OM (4.4-6.0%) but only 12% are above this level. None are very low.

Grassland; the median value is 6.5% (high) though the distribution is bimodal with 27% of samples as moderate – possibly shorter term leys.

**Subsoil**

Arable land: levels are distributed around the median (1.9% = low). 26% of samples are very low. The tail of higher values is largely due to coal fragments in upper subsoil.

Grassland; the median is 2.7%, about 0.8% higher than in arable data. Only 11% of grass subsoils were very low (<1.5%) The tail of higher samples is due to coal or wet subsoil.

The four samples in woodland or amenity were 4-7% in topsoil and 2-15% in subsoil (the latter included 'clinker').

## 8.2 Factors influencing organic matter levels in subsoil

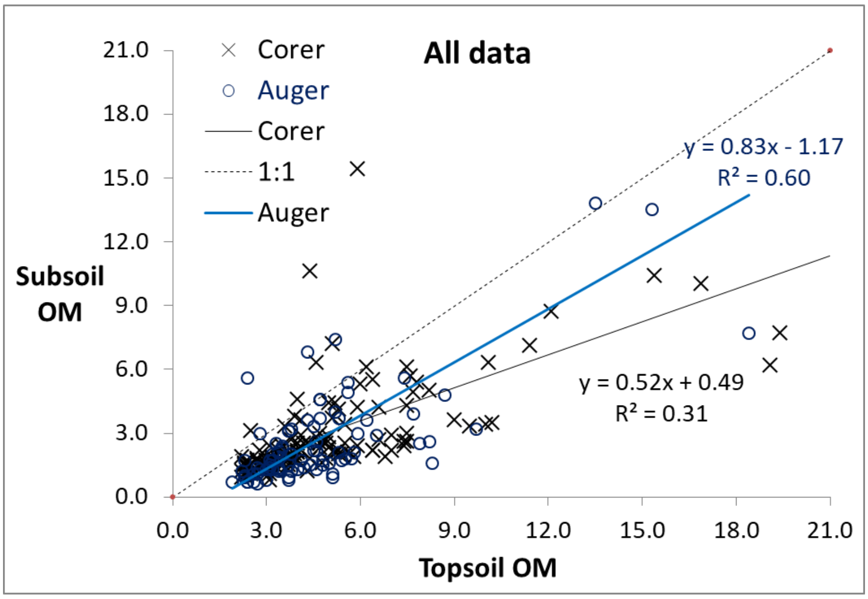



Figure 19a. Region A: Organic Matter in Topsoil and Subsoil - effect of sampling method

Both plots are skewed by outliers and by instances where subsoil OM appears higher because of coal. This can be misleading because coal is >90% organic compared to the 58% standard conversion used for SOM.

For correlation purposes it was decided to exclude samples of topsoil OM above 10% or where subsoil OM is more than 2% greater than topsoil due to the presence of coal.

In Figure 20 the data has been 'cleaned' as above and only arable points are plotted.

The auger method appears worse correlated but this may be due to its lack of data in the 6-10% range. Both methods have similar slopes and a small difference in intercept which are not statistically significant. Therefore method difference is assumed insignificant.

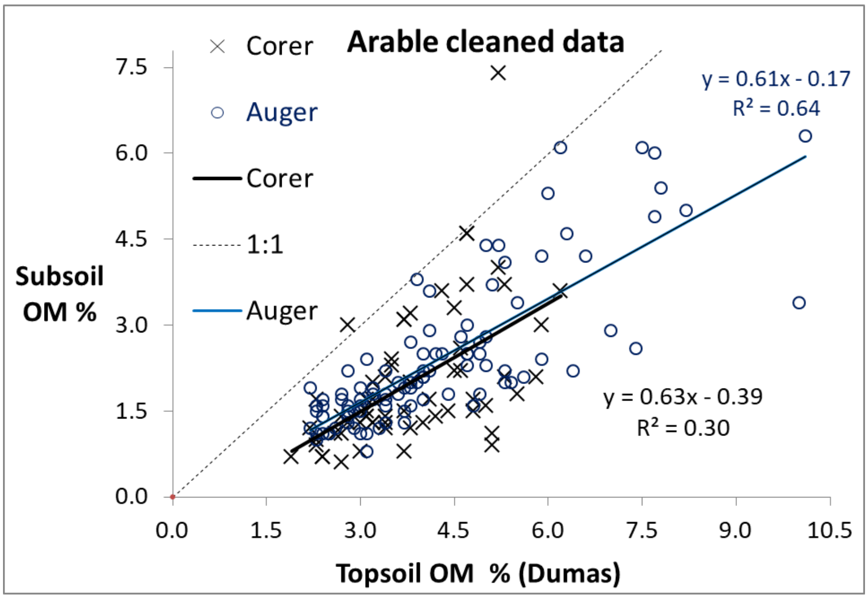



Figure 19b. Region A : OM in Topsoil and Subsoil - cleaned data.

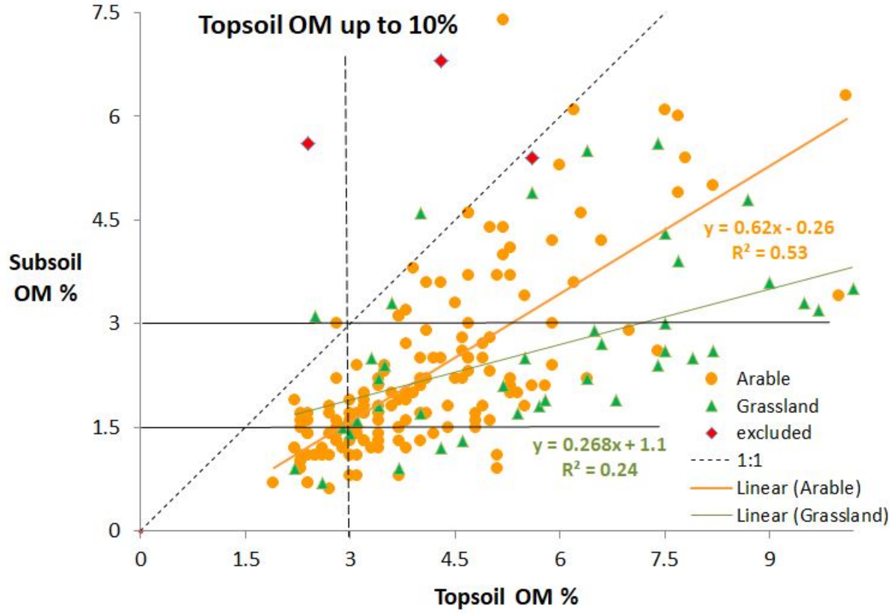



Figure 20. Region A: Organic Matter in Topsoil and Subsoil - Arable versus Grassland

On arable data the topsoil versus subsoil relationship is useable ($r^2$ = 0.53) and seems to be linear with subsoil P a little over half the topsoil P, though there is significant scatter. When forced through origin equation is y = 0.56 x, $r^2$ = 0.52.

Under grassland the relationship is poor ($r^2$ = 0.24) nevertheless Figure 20 seems to suggest that raised P in the topsoil gives a proportionately lower increase in subsoil P than arable land. This is to be expected because under grass the organic matter is more likely to concentrate in the topsoil (here sampled to 20cm) than under arable cultivation.

For the arable data set the influence of texture is analysed in Figures 21a and 21b.

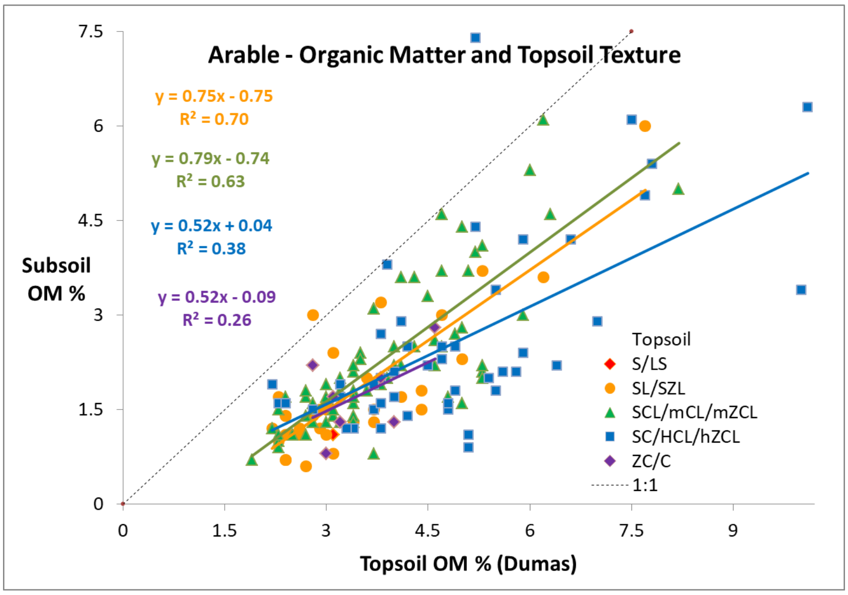



Figure 21a. Region A: Organic Matter in Topsoil and Subsoil – effect of **Topsoil** Texture

Light loamy and medium topsoils fit to a similar line and heavy loam and clay topsoils fit to another (with a weaker correlation). Heavier loam topsoils more frequently overlie clayey subsoils, so the effect of subsoil texture is tested in Figure 21b.

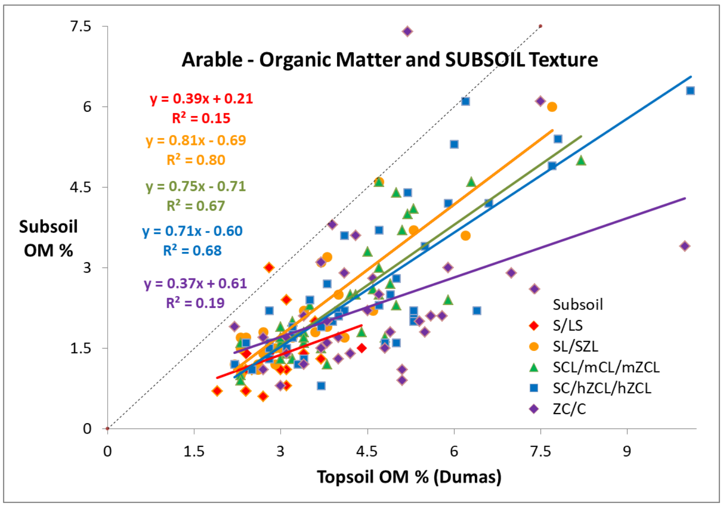



Figure 21b. Region A: Organic Matter in topsoil and subsoil – effect of **Subsoil** Texture

Apart from sandy subsoils which cover a limited OM range, for the light loamy, medium *and heavier loam subsoils* fit the same line. It seems to be clay subsoil that is causing a marked change in behaviour. This might be expected because:-

a) clay subsoil has (historically) limited deeper ploughing

b) clayey subsoils usually have a higher packing density limiting lateral rooting and earthworms are less able (or unable) to take topsoil material downwards into the subsoil.

### Grassland OM

All data is in Figure 20. There is a higher incidence of low P and heavier subsoils than in the arable data.

### Factors effecting Soil Organic Matter

**Table 10. Region A: Median Organic Matter values** (and 10-90% percentile values).

| Texture | Topsoil OM % | | n | Subsoil OM % | | n |
|---|---|---|---|---|---|---|
| LS, S | - | - | 1 | 1.3 | 0.7 – 2.0 | 19 |
| SL, SZL | 3.0 | 2.4 – 4.8 | 36 | 1.7 | 1.2 – 3.7 | 26 |
| SCL, mCL,mZCL | 3.7 | 2.5 – 5.3 | 61 | 2.0 | 1.3 – 4.3 | 35 |
| SC, hCL, hZCL | 4.8 | 3.2 – 7.8 | 50 | 2.1 * | 1.3 – 4.8 | 24 |
| ZC, C | 3.8 | 2.9 – 20 | 8 | 2.0 * | 1.2 – 3.5 | 35 |

S = sand, LS = loamy sand, SL = sandy loam, fSL = fine sandy loam, SZL = sandy silt loam, mCL = medium clay loam, mZCL = medium silty clay loam, hCL = heavy clay loam, hZCL= heavy silty clay loam, SC = sandy clay, ZC = silty clay, C = clay. Where upper subsoil contains two textures within 50cm the average is used e.g. mCL over C is treated as hCL.

* Samples with OM > 10% and/or coal fragments are included in topsoil data above but excluded from subsoil because some of the coal is elemental and not part of the active OM in soil.

Table 10 indicates that OM tends to be similar in medium or heavy topsoils but about 1% lower in light loams. Subsoil OM decreases in order medium, heavy > light loams > sandy in steps of about 0.3%. High topsoil OM% is found in some heavy loams and clays and in some, but not all cases, this is due to incorporation of coal residues into the organic matter.

About 10% of the subsoils are below 1.3% OM in all textures, with lower minima in sands.

These findings are not unexpected.

Stoniness tends to be lower in lighter subsoils (Table 6) but this is not concentrating the organic matter. There is no correlation between subsoil stones and subsoil OM% ($r^2 = 0.00$).

Regression analysis in Appendix 3 produces the following equations for predicting subsoil OM% from measurement of topsoil OM

Topsoil texture: sandy, light loam or medium $r^2 = 0.66$
Subsoil OM = Topsoil OM x 0.79 - 0.8

Topsoil texture: heavy loam and clay $r^2 = 0.41$
Subsoil OM = Topsoil OM x 0.523

*Subsoil* texture: any apart from clay $r^2 = 0.70$
Subsoil OM = Topsoil OM x 0.73 - 0.62

*Subsoil* texture: clays
Subsoil OM = Topsoil OM x 0.61 + 0.37 $r^2 = 0.19$

We have some confidence in prediction of subsoil OM in sandy to medium topsoils and all cases known *not* to have a clay subsoil (i.e. 25-50cm depth is mainly clay or silty clay textured).

For Grassland the correlations are poor especially for medium and light soils :-

Topsoil texture: sandy, light loam or medium
Subsoil texture: any apart from clay $r^2 = 0.20$
Subsoil OM = Topsoil OM x 0.23 + 1.36

Topsoil texture: heavy loam and clay
Subsoil texture: clay only $r^2 = 0.30$
Subsoil OM = Topsoil OM x 0.46 + 0.44

## 8.3 Agronomic conclusion: organic matter levels in Carboniferous soils

The categories are as specified in Soil Survey of England and Wales handbooks except high is her designated "Good" and Very High as "High". > 10% OM is termed 'organic'.

Overall arable topsoils are 'average' for UK the modal and median level is 'moderate' (3.8%), 12% of samples were high or organic and none very low. For grass the median value was high (6.5%).

As expected subsoils had less OM than topsoil (median1.9% arable and 2.7% grass). 26% of arable subsoils and 11% of grassland had subsoil OM below 1.5%

A minority of arable and grass samples have relatively high subsoil values due to the incorporation of coal fragments, and these (and all samples of topsoil OM > 10%) were excluded from the main regressions.

There is a significant relationship of topsoil and subsoil OM% on arable land ($r^2 = 0.53$). There was a weaker relationship for grassland ($r^2 = 0.24$) though the positive relationship (slope) was highly significant.

Light and medium topsoil behave differently to heavier loam and clay topsoils. The main determinant appears to be whether the upper subsoil is clay or not (more strictly if the majority texture 25-50cm is clay/silty clay, since some profiles are duplex).

In most cases it seems that as topsoil organic matter increases, some gets carried down by either (historically) deep cultivation and/or earthworms or other soil forna and, this results in significant increases in the subsoil OM. Clay subsoils are exceptional because

a) are (historically) less likely to have been deep ploughed (deeper than 20-25cm).

b) higher packing density limits lateral rooting and earthworms are less able (or unable) to carry topsoil material downwards into the subsoil.

The structural condition of clay subsoils will vary greatly with soil management (including use of organic manures and ley breaks which encourage earthworms). This might explain why subsoil OM is less predictable where there is a clay subsoil.

Regressions are summarised in Table 10. For arable land at topsoil OM of 3.0% the subsoil is about half (1.5%) irrespective of texture but as the topsoil is raised into the "Good" and "High" categories there is sharp rise in the subsoil OM, except in the case of clay subsoils where the rise is difficult to predict and generally lower.

For grassland, increased topsoil OM% is accompanied by raised subsoil OM%: as a guide at topsoil OM% 4.5 the subsoil is 2.5% but with a large degree of uncertainty in prediction at higher topsoil OM%. The latter might be expected in view of variation in the time since the land was cultivated and the depth of cultivation, length of ley. Some fields may not have been reseeded for decades.

**Table 11: Prediction of subsoil Organic Matter in Arable subsoils**

| Class | Topsoil | Equation Subsoil OM % = | at Topsoil OM% 2.0 | 3.0 | 4.5 | 6.0 | 10 |
|---|---|---|---|---|---|---|---|
| 0,1,2 | sandy to medium | 0.79 x Topsoil OM - 0.8 | 0.8 | 1.6 | 2.8 | 3.9 | 7.1 |
| 3,4 | heavy loam, clay | 0.523 x Topsoil OM | 1.0 | 1.6 | 2.4 | 3.1 | 5.2 |

| Class | Subsoil (if known) | Equation Subsoil OM % = | at Topsoil OM% 2.0 | 3.0 | 4.5 | 6.0 | 10 |
|---|---|---|---|---|---|---|---|
| 0-3 | any apart from clay | 0.73 x Topsoil OM - 0.62 | 0.8 | 1.6 | 2.7 | 3.8 | 6.7 |
| 4 | clay/ silty clay ^ | 0.61 x Topsoil OM + 0.37 | *1.6* | *2.2* | *3.1* | *4.0* | *6.5* |

**Table 12: Prediction of subsoil Organic Matter in Grassland subsoils**

| Class | Topsoil | Equation Subsoil OM % = | at Topsoil OM% **2.0** | **3.0** | **4.5** | **6.0** | **10** |
|---|---|---|---|---|---|---|---|
| Top<br>Sub | sandy to medium ^<br>any apart from clay | 0.23 x Topsoil OM +1.36 | n/a | 2.1 | 2.4 | 2.7 | 3.7 |
| Top<br>Sub | heavy loam, clay<br>silty clay/clay | 0.46 x Topsoil OM +0.44 | n/a | 1.8 | 2.5 | 3.2 | 5.0 |

^ correlations very poor ($r^2 < 0.25$) and in these instances upper subsoil OM% must be directly measured.

## 8.4 Methodology of assessing organic matter in topsoil and subsoil

Soil organic matter level in subsoil is quite strongly related to topsoil OM and raising the latter above normal results in disproportionate improvement in subsoil OM, though less with a clay subsoil (sometimes indicated by a heavy loam topsoil) and less under grassland.

The Dumas method must be used to interpret meaningfully the results (Loss of Ignition method can give exaggerated results on heavier soils because of loss of structural water).

"Good" topsoil OM% (>4.5%) typically results in at least 3.0% OM in upper subsoil (this is an average because subsoil OM decreases with depth over the 25/30-50cm range).

For measurement of OM in the upper subsoil it may be best to standardise sampling depth at 25-50cm even if this includes part of a former plough layer. It is not worthwhile sampling subsoil if the topsoil is regularly cultivated to 35cm or more (for root crops).

Subsoil OM can be approximated from topsoil OM% provided it is ascertained whether there is clay upper subsoil (Table 9). Farmers need to find out whether the field or zone has clay subsoil starting within 40cm and at least 40cm thick in order to use the correct nitrogen recommendation category in RB209 (Deep Clay).

Measurement of subsoil OM is useful on arable land (and ley rotations) when :

- clay subsoil
- reinstated profiles
- topsoil OM% is high (>6%) or being increased by regular manuring.
- experimental trials, especially those testing organic amendments.

A suitable level to aim for.in subsoil to 50cm depth is at least 3.0% (Dumas method). This will improve potash retention and soil structure. Above 4.5% might be of dubious benefit and could raise issues of enhanced phosphate transfer to drains.

Auger sampling tended to give OM values ~0.3% lower and P ~2 mg/l lower than corer technique. For future measurement of OM, pH and nutrients in the profile it may be best to use a corer technique for sampling for both arable and grassland and use standardised sampling depths :

A. 0-25cm and 25-50cm * OR

B. 0-20cm, 20-40cm* and 40-50cm

* even where the latter includes part of a (former or current) plough layer

Since OM and phosphorus are likely to decrease steadily with depth, if their transmission into drains is the main issue in view the B protocol is best because it isolates the 40-50cm horizon where mole drains, subsoiler channels or shallow drains are likely to reside.

**Carbon stocks** in soil are <u>not</u> proportional to OM% because they also depend on horizon depths, stones and bulk density. Density is higher on sandy or compact soils.

A method is proposed to adjust for above. This needs verification before reporting but preliminary estimates for this region are mean Carbon to 50cm depth is **125** t/ha on arable land and **170** t/ha in grassland.

# 9. Appendix – Multiple Regression (Region A)

Correlation coefficients (*P*) are shown in matrix tables; higher means stronger relationship. In analysis of regression *P* <0.05 means high certainty the variable is significant, but greater values are considered if overall $r^2$ is improved by including the factor. Texture and stones are classes 0-4 and 0-3

## 9.1 : Influence of topsoil parameters on subsoil Phosphorus

All arable data excluding topsoils of > 35 mg P/l

Organic Matter max. values set at 10% topsoil and 7.5% subsoil

| | *Method* | *Top Depth* | *Top Texture* | *Top stone* | *Top OM* | *Top pH* | *Top P* | *Top K* | *Top Mg* | *Sub P* |
|---|---|---|---|---|---|---|---|---|---|---|
| Method | 1 | | | | | | | | | |
| Top Depth | -0.41 | 1 | | | | | | | | |
| Top.Texture | 0.01 | -0.04 | 1 | | | | | | | |
| Top stone | 0.14 | -0.21 | -0.22 | 1 | | | | | | |
| Top OM | 0.06 | 0.36 | 0.03 | -0.23 | 1 | | | | | |
| Top pH | -0.08 | 0.10 | 0.01 | 0.29 | -0.08 | 1 | | | | |
| Top P | 0.08 | 0.08 | -0.32 | 0.05 | -0.11 | 0.22 | 1 | | | |
| Top K | -0.11 | 0.05 | -0.08 | 0.03 | 0.12 | 0.27 | 0.35 | 1 | | |
| Top Mg | 0.02 | -0.16 | 0.51 | -0.01 | 0.09 | 0.25 | -0.08 | 0.03 | 1 | |
| Sub P | 0.14 | 0.12 | -0.34 | -0.08 | -0.07 | 0.06 | 0.71 | 0.13 | -0.18 | 1 |

**Conclusions**

Auger method (0) gets deeper topsoils than corer method (1)

**Topsoil P** correlates only with Topsoil texture class (negatively) and Topsoil K

There may be a small positive influence of Topsoil pH.

**Subsoil P** correlates only with Topsoil P and Topsoil Texture Class (negatively)

These two factors were isolated for regression analysis below

| | |
|---|---|
| Multiple R | 0.72 |
| R Square | 0.52 |
| Adjusted R Squ | 0.51 |
| Standard Error | 3.75 |
| Observations | 158 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 2 | 2378.04 | 1189.02 | 84.34 | 1.65E-25 |
| Residual | 155 | 2185.14 | 14.10 | | |
| Total | 157 | 4563.18 | | | |

| | *Coefficients* | *tandard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 2.56 | 1.27 | 2.02 | 0.05 | 0.05 | 5.06 | 0.05 | 5.06 |
| Topsoil P | 0.46 | 0.04 | 11.45 | 0.00 | 0.38 | 0.54 | 0.38 | 0.54 |
| Topsoil Textur | -0.83 | 0.38 | -2.18 | 0.03 | -1.57 | -0.08 | -1.57 | -0.08 |

**Equation** Subsoil P = 0.46 x Topsoil P - 0.83 x Texture Class + 2.56 $r^2 = 0.52$

| Texture Class | |
|---|---|
| LS | Subsoil P = 0.46 x Topsoil P + 2.6 |
| SL | Subsoil P = 0.46 x Topsoil P + 1.7 |
| SCL | Subsoil P = 0.46 x Topsoil P + 0.9 |
| hCL | Subsoil P = 0.46 x Topsoil P - 0.1 |
| C | Subsoil P = 0.46 x Topsoil P - 0.8 |

All Grassland samples excluding one > 45 mg P/l

| | Method | Top Depth | Top.Texture | Top stone | Top OM | Top pH | Top P | Top K | Top Mg |
|---|---|---|---|---|---|---|---|---|---|
| Method | 1 | | | | | | | | |
| Top Depth | -0.42 | 1.00 | | | | | | | |
| Top Texture | -0.15 | 0.18 | 1.00 | | | | | | |
| Top stone | 0.07 | 0.11 | -0.31 | 1.00 | | | | | |
| Top OM | 0.15 | -0.30 | 0.30 | -0.10 | 1.00 | | | | |
| Top pH | -0.21 | 0.35 | 0.30 | -0.14 | -0.24 | 1.00 | | | |
| Top P | 0.11 | -0.11 | -0.40 | 0.29 | -0.14 | -0.06 | 1.00 | | |
| Top K | 0.18 | -0.17 | 0.10 | 0.17 | 0.29 | 0.05 | 0.27 | 1.00 | |
| Top Mg | -0.21 | 0.04 | 0.25 | -0.21 | 0.01 | 0.47 | -0.11 | 0.14 | 1.00 |
| Sub P | 0.15 | -0.11 | -0.45 | 0.22 | -0.24 | -0.10 | 0.86 | 0.05 | -0.15 |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.87 |
| R Square | 0.76 |
| Adjusted R Squ | 0.75 |
| Standard Error | 1.99 |
| Observations | 46 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 2 | 536.62 | 268.31 | 67.51 | 5.42E-14 |
| Residual | 43 | 170.89 | 3.97 | | |
| Total | 45 | 707.51 | | | |

| | *Coefficients* | *andard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 2.07 | 1.16 | 1.79 | 0.08 | -0.26 | 4.40 | -0.26 | 4.40 |
| Topsoil Textur | -0.56 | 0.36 | -1.58 | 0.12 | -1.28 | 0.16 | -1.28 | 0.16 |
| Topsoil P | 0.43 | 0.04 | 9.91 | 0.00 | 0.34 | 0.52 | 0.34 | 0.52 |

Introduction of Topsoil stone category had stone co-efficient of -0.43 (illogical) and P value high (0.47)

Addition of Topsoil OM% had a negligible co-efficient (-0.1 per %)

So only Topsoil P and texture are relevant (as found on arable data set)

**Equation** Subsoil P = 0.43 x Topsoil P - 0.56 x Texture Class + 2.07 $r^2 = 0.76$

## 9.2 : Influence of Subsoil parameters on subsoil Phosphorus

All arable data except Topsoil P exceeding 35 mg/l

| | Top P | Sub texture | Sub stone | Sub OM | Sub pH | Sub P | |
|---|---|---|---|---|---|---|---|
| Top P | 1.00 | | | | | | |
| Sub texture | -0.28 | 1.00 | | | | | |
| Sub stone | -0.06 | -0.37 | 1.00 | | | | |
| Sub OM | -0.07 | 0.22 | -0.08 | 1.00 | | | OM limited to 6% max |
| Sub pH | 0.22 | -0.08 | 0.10 | -0.30 | 1.00 | | |
| Sub P | 0.71 | -0.41 | 0.00 | 0.15 | 0.09 | 1.00 | |

| | Top P | Sub texture | Sub stone | Sub OM | Sub pH | Sub P | |
|---|---|---|---|---|---|---|---|
| Top P | 1 | | | | | | |
| Sub texture | -0.28 | 1.00 | | | | | |
| Sub stone | -0.06 | -0.37 | 1.00 | | | | |
| Sub OM | -0.06 | 0.22 | -0.07 | 1.00 | | | OM limited to 4.5% max |
| Sub pH | 0.22 | -0.08 | 0.10 | -0.29 | 1.00 | | |
| Sub P | 0.71 | -0.41 | 0.00 | 0.17 | 0.09 | 1 | |

Subsoil OM capped at 4.5% gives a slightly better Pearson coefficient to 6% cap
No effect of subsoil stoniness Class or pH
Subsoil Texture Class has a stronger coefficient than Topsoil Texture (-0.34)

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.71 |
| R Square | 0.51 |
| Adjusted R Square | 0.50 |
| Standard Error | 3.80 |
| Observations | 158 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 1 | 2311.01743 | 2311.017 | 160.0764 | 1.07E-25 |
| Residual | 156 | 2252.16637 | 14.43696 | | |
| Total | 157 | 4563.1838 | | | |

| | *Coefficients* | *tandard Erro* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.26 | 0.71 | 0.36 | 0.72 | -1.15 | 1.66 | -1.15 | 1.66 |
| Topsoil P | 0.49 | 0.04 | 12.65 | 0.00 | 0.41 | 0.57 | 0.41 | 0.57 |

r2 = 0.51 based on topsoil texture alone
r2 = 0.17 based on topsoil texture class alone
r2 = 0.02 based on OM alone

continued

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.74 |
| R Square | 0.54 |
| Adjusted R Square | 0.54 |
| Standard Error | 3.66 |
| Observations | 158 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 2 | 2482.74 | 1241.37 | 92.49 | 3.66E-27 |
| Residual | 155 | 2080.45 | 13.42 | | |
| Total | 157 | 4563.18 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | -1.62 | 0.86 | -1.88 | 0.06 | -3.33 | 0.09 | -3.33 | 0.09 |
| Topsoil P | 0.50 | 0.04 | 13.32 | 0.00 | 0.42 | 0.57 | 0.42 | 0.57 |
| Subsoil OM | 0.72 | 0.20 | 3.58 | 0.00 | 0.32 | 1.12 | 0.32 | 1.12 |

Topsoil P and subsoil texture improves r2 to 0.54 but negative intercept, so illogical

SUMMARY OUTPUT

| | |
|---|---|
| Multiple R | 0.74 |
| R Square | 0.55 |
| Adjusted R Square | 0.55 |
| Standard Error | 3.63 |
| Observations | 158 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 2 | 2522.57 | 1261.28 | 95.80 | 8.19E-28 |
| Residual | 155 | 2040.61 | 13.17 | | |
| Total | 157 | 4563.18 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 3.33 | 1.02 | 3.25 | 0.00 | 1.31 | 5.36 | 1.31 | 5.36 |
| Topsoil P | 0.45 | 0.04 | 11.58 | 0.00 | 0.37 | 0.52 | 0.37 | 0.52 |
| Subsoil Text Class | -0.96 | 0.24 | -4.01 | 0.00 | -1.43 | -0.49 | -1.43 | -0.49 |

**Subsoil P = 0.45 x Topsoil P - 1.0 x Subsoil Texture Class + 3.33** **$r^2$ = 0.55**

Topsoil P plus Subsoil Text Class improves $r^2$ to 0.55 which can be improved by allowance for SOM as below

continued

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.78 |
| R Square | 0.61 |
| Adjusted R Square | 0.61 |
| Standard Error | 3.38 |
| Observations | 158 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 3 | 2799.39 | 933.13 | 81.47 | 1.28E-31 |
| Residual | 154 | 1763.79 | 11.45 | | |
| Total | 157 | 4563.18 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.67 | 1.01 | 1.65 | 0.10 | -0.33 | 3.67 | -0.33 | 3.67 |
| Topsoil P | 0.45 | 0.04 | 12.41 | 0.00 | 0.37 | 0.52 | 0.37 | 0.52 |
| Subsoil Texture C | -1.20 | 0.23 | -5.26 | 0.00 | -1.65 | -0.75 | -1.65 | -0.75 |
| Subsoil OM % | 0.93 | 0.19 | 4.92 | 0.00 | 0.56 | 1.31 | 0.56 | 1.31 |

**SOM capped at 6.0%**

**Subsoil P = 0.45 x Topsoil P - 1.2 x Subsoil Texture Class + 0.93 x Subsoil OM + 1.67** **$r^2$ = 0.61**

Intercept is below NRM detection limit < 2.5 mg P/l but above zero, so logical.

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.79 |
| R Square | 0.62 |
| Adjusted R Square | 0.61 |
| Standard Error | 3.35 |
| Observations | 158 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 3 | 2836.12 | 945.37 | 84.30 | 2.54E-32 |
| Residual | 154 | 1727.06 | 11.21 | | |
| Total | 157 | 4563.18 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.03 | 1.04 | 0.99 | 0.33 | -1.03 | 3.08 | -1.03 | 3.08 |
| Topsoil P | 0.45 | 0.04 | 12.55 | 0.00 | 0.38 | 0.52 | 0.38 | 0.52 |
| Subsoil Text Class | -1.20 | 0.23 | -5.35 | 0.00 | -1.65 | -0.76 | -1.65 | -0.76 |
| Subsoil OM % | 1.28 | 0.24 | 5.29 | 0.00 | 0.80 | 1.75 | 0.80 | 1.75 |

SOM capped at 4.5%

Subsoil P = 0.45 x Topsoil P - 1.2 x Texture Class + 1.28 x Subsoil OM + 1.03 $r^2$ = 0.62

Intercept more uncertain and OM weighting possibly too high

All Grassland data except one sample of topsoil > 35 mg P/l. Subsoil OM capped at 6%

| | Top P | Sub texture | Sub stone | Sub OM | Sub pH | Sub P |
|---|---|---|---|---|---|---|
| Top P | 1.00 | | | | | |
| Sub texture | -0.40 | 1.00 | | | | |
| Sub stone | 0.20 | -0.22 | 1.00 | | | |
| Sub OM | 0.06 | 0.24 | -0.03 | 1.00 | | |
| Sub pH | -0.02 | 0.14 | 0.04 | -0.28 | 1.00 | |
| Sub P | 0.86 | -0.46 | 0.06 | 0.13 | -0.15 | 1.00 |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.87 |
| R Square | 0.76 |
| Adjusted R Sq | 0.75 |
| Standard Error | 1.99 |
| Observations | 46 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 537.7279 | 268.8639 | 68.0942 | 4.71E-14 |
| Residual | 43 | 169.7817 | 3.948412 | | |
| Total | 45 | 707.5096 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 2.09 | 1.12 | 1.88 | 0.07 | -0.16 | 4.34 | -0.16 | 4.34 |
| Topsoil P | 0.43 | 0.04 | 9.95 | 0.00 | 0.34 | 0.52 | 0.34 | 0.52 |
| Subsoil P Class | -0.48 | 0.29 | -1.67 | 0.10 | -1.06 | 0.10 | -1.06 | 0.10 |

Seems adequate

**Subsoil P = 0.43 x Topsoil P - 0.48 x Subsoil Texture Class + 2.1** **$r^2$ = 0.76**

continued overpage

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.88 |
| R Square | 0.77 |
| Adjusted R Sq | 0.76 |
| Standard Error | 1.95 |
| Observations | 46 |

ANOVA

| | df | SS | MS | F | gnificance F |
|---|---|---|---|---|---|
| Regression | 3 | 547.84 | 182.61 | 48.04 | 1.23E-13 |
| Residual | 42 | 159.67 | 3.80 | | |
| Total | 45 | 707.51 | | | |

| | Coefficients | andard Err | t Stat | P-value | Lower 95% | Upper 95% | ower 95.0% | pper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.65 | 1.13 | 1.46 | 0.15 | -0.63 | 3.92 | -0.63 | 3.92 |
| Topsoil P | 0.42 | 0.04 | 9.70 | 0.00 | 0.33 | 0.50 | 0.33 | 0.50 |
| Subsoil Textur | -0.61 | 0.29 | -2.10 | 0.04 | -1.20 | -0.02 | -1.20 | -0.02 |
| Subsoil OM | 0.29 | 0.18 | 1.63 | 0.11 | -0.07 | 0.66 | -0.07 | 0.66 |

Inclusion of subsoil OM improves correlation only marginally and is a small effect

**SOM capped at 6.0%**

**Subsoil P = 0.43 x Topsoil P - 0.61 x Subsoil Texture Class + 0.29 x Subsoil OM + 1.65** **$r^2$ = 0.77**

Inclusion of pH does not improve r2 and results in a very high intercept (7 mg/l)

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.88 |
| R Square | 0.77 |
| Adjusted R Sq | 0.75 |
| Standard Error | 1.97 |
| Observations | 46 |

ANOVA

| | df | SS | MS | F | gnificance F |
|---|---|---|---|---|---|
| Regression | 3 | 545.19 | 181.73 | 47.02 | 1.74E-13 |
| Residual | 42 | 162.32 | 3.86 | | |
| Total | 45 | 707.51 | | | |

| | Coefficients | andard Err | t Stat | P-value | Lower 95% | Upper 95% | ower 95.0% | pper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.51 | 1.18 | 1.28 | 0.21 | -0.88 | 3.89 | -0.88 | 3.89 |
| Topsoil P | 0.42 | 0.04 | 9.88 | 0.00 | 0.34 | 0.51 | 0.34 | 0.51 |
| Subsoil Textur | -0.58 | 0.29 | -1.99 | 0.05 | -1.17 | 0.01 | -1.17 | 0.01 |
| Subsoil OM | 0.31 | 0.22 | 1.39 | 0.17 | -0.14 | 0.77 | -0.14 | 0.77 |

SOM capped at 4.5% is no improvement

## 9.3 : Influence of Various parameters on topsoil Potassium

**LIGHT LOAM and SANDY TOPSOILS**

**Factors influencing Potassium in Topsoil**

| | *Arable-Gras* | *Time of Seas* | *Annual Ra* | *op. Textur* | *Top Stones* | *Top. OM* | *Top. pH* | *Top. P* | *Top. Mg* | *Top K* |
|---|---|---|---|---|---|---|---|---|---|---|
| Arable (0) Grass (1) | 1 | | | | | | | | | |
| Time of Season | 0.32 | 1.00 | | | | | | | | |
| Annual Rainfall | 0.12 | 0.13 | 1.00 | | | | | | | |
| Topsoil Texture | 0.07 | 0.07 | 0.01 | 1.00 | | | | | | |
| Topsoil Stones | -0.03 | 0.34 | -0.18 | -0.04 | 1.00 | | | | | |
| Topsoil OM | 0.27 | 0.27 | 0.28 | 0.06 | 0.12 | 1.00 | | | | |
| Topsoil pH | -0.23 | -0.14 | -0.49 | -0.06 | 0.28 | -0.42 | 1.00 | | | |
| Topsoil P | -0.27 | -0.30 | -0.26 | -0.08 | 0.20 | 0.18 | 0.19 | 1.00 | | |
| Topsoil Mg | 0.46 | 0.21 | -0.14 | -0.04 | -0.02 | 0.16 | 0.02 | 0.07 | 1.00 | |
| Topsoil K | -0.39 | -0.22 | -0.26 | -0.01 | 0.21 | 0.09 | 0.38 | 0.63 | -0.01 | 1 |

Negative relationship with grass, annual rainfall, time of season (lower in spring)

Positive relationship with pH and stoniness and phosphorus (a farming influence)

No relationship with organic matter or magnesium

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.53 |
| R Square | 0.28 |
| Adjusted R Square | 0.19 |
| Standard Error | 81.45 |
| Observations | 48.00 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 5 | 108663.63 | 21732.73 | 3.28 | 0.01 |
| Residual | 42 | 278622.76 | 6633.88 | | |
| Total | 47 | 387286.38 | | | |

| | *Coefficients* | *tandard Erro* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 60.05 | 329.05 | 0.18 | 0.86 | -604.01 | 724.10 | -604.01 | 724.10 |
| Grass | -61.32 | 31.34 | -1.96 | 0.06 | -124.57 | 1.93 | -124.57 | 1.93 |
| TOS (wint-spring) | -38.53 | 36.68 | -1.05 | 0.30 | -112.56 | 35.50 | -112.56 | 35.50 |
| Rainfall | -0.16 | 0.36 | -0.46 | 0.65 | -0.88 | 0.55 | -0.88 | 0.55 |
| stones | 30.05 | 24.31 | 1.24 | 0.22 | -19.01 | 79.11 | -19.01 | 79.11 |
| pH | 27.68 | 21.17 | 1.31 | 0.20 | -15.04 | 70.40 | -15.04 | 70.40 |

**Effect on topsoil K**

Grass 61 mg/l reduction

Time of season 39 mg/l reduction from autumn/winter to spring

Annual rainfall no influence

Stones 30 mg/l increase per class (10% v/v) but weak P (.22)

pH 28 mg/l increase per unit but weak P (.2)

**MEDIUM and HEAVY SOILS**

| | Arable-Gras: | me of Seas | nnual Rai | op. Textur | Top Stones | Top. OM | Top. pH | Top. P | Top. Mg | Top K |
|---|---|---|---|---|---|---|---|---|---|---|
| Arable (0) Grass (1) | 1 | | | | | | | | | |
| Time of Season | 0.36 | 1.00 | | | | | | | | |
| Annual Rainfall | 0.25 | 0.31 | 1.00 | | | | | | | |
| Topsoil Texture | 0.10 | 0.15 | 0.14 | 1.00 | | | | | | |
| Topsoil Stones | -0.03 | -0.03 | -0.29 | -0.14 | 1.00 | | | | | |
| Topsoil OM | -0.28 | -0.12 | -0.35 | 0.12 | 0.20 | 1.00 | | | | |
| Topsoil pH | 0.36 | 0.14 | 0.26 | 0.25 | -0.15 | -0.23 | 1.00 | | | |
| Topsoil P | -0.37 | -0.30 | -0.27 | -0.27 | 0.09 | 0.25 | -0.16 | 1.00 | | |
| Topsoil Mg | 0.03 | -0.08 | -0.23 | 0.39 | 0.02 | 0.34 | 0.04 | -0.03 | 1.00 | |
| Topsoil K | -0.31 | -0.26 | -0.15 | -0.07 | 0.06 | 0.26 | 0.02 | 0.36 | 0.05 | 1.00 |

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.3734241 |
| R Square | 0.1394455 |
| Adjusted R Square | 0.1239865 |
| Standard Error | 56.586756 |
| Observations | 171 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 3 | 86650.758 | 28883.59 | 9.020311 | 1.43E-05 |
| Residual | 167 | 534744.18 | 3202.061 | | |
| Total | 170 | 621394.94 | | | |

| | *Coefficients* | *andard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 117.97 | 11.02 | 10.71 | 0.00 | 96.22 | 139.72 | 96.22 | 139.72 |
| Arable-Grass | -41.61 | 11.34 | -3.67 | 0.00 | -64.00 | -19.23 | -64.00 | -19.23 |
| Time of Season | -22.18 | 9.75 | -2.27 | 0.02 | -41.43 | -2.92 | -41.43 | -2.92 |
| Topsoil OM | 3.83 | 2.09 | 1.83 | 0.07 | -0.30 | 7.96 | -0.30 | 7.96 |

## 9.4 : Influence of Various parameters on subsoil Potassium

**Factors Correlating with Subsoil K in light loam and sandy topsoils**

| | Topsoil K | Sub. Textu | Sub. Stone | Sub. OM | Sub. pH | Sub. Mg | Subsoil K |
|---|---|---|---|---|---|---|---|
| Topsoil K | 1 | | | | | | |
| Sub. Texture | -0.19 | 1.00 | | | | | |
| Sub. Stones | 0.27 | -0.18 | 1.00 | | | | |
| Sub. OM | 0.06 | 0.42 | -0.08 | 1.00 | | | |
| Sub. pH | 0.20 | -0.33 | 0.28 | -0.38 | 1.00 | | |
| Sub. Mg | 0.01 | 0.48 | 0.02 | 0.17 | -0.04 | 1.00 | |
| Subsoil K | 0.87 | -0.20 | 0.27 | 0.26 | 0.18 | -0.06 | 1 |

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.91 |
| R Square | 0.82 |
| Adjusted R S | 0.80 |
| Standard Erro | 25.83 |
| Observation: | 47 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 5 | 124700.1 | 24940.02 | 37.39191 | 3.06E-14 |
| Residual | 41 | 27346.57 | 666.9896 | | |
| Total | 46 | 152046.7 | | | |

| | *Coefficient:* | *andard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -61.45 | 52.94 | -1.16 | 0.25 | -168.37 | 45.47 | -168.37 | 45.47 |
| Topsoil K | 0.50 | 0.04 | 11.14 | 0.00 | 0.41 | 0.59 | 0.41 | 0.59 |
| Subsoil Text | -9.31 | 4.94 | -1.89 | 0.07 | -19.28 | 0.66 | -19.28 | 0.66 |
| Sub Stones | 2.16 | 5.07 | 0.43 | 0.67 | -8.08 | 12.41 | -8.08 | 12.41 |
| OM | 14.21 | 3.60 | 3.95 | 0.00 | 6.94 | 21.48 | 6.94 | 21.48 |
| pH | 8.25 | 7.26 | 1.14 | 0.26 | -6.41 | 22.90 | -6.41 | 22.90 |

Stones and pH were eliminated subsequently

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.90 |
| R Square | 0.81 |
| Adjusted R S | 0.80 |
| Standard Erro | 25.75 |
| Observation: | 47.00 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *gnificance F* |
|---|---|---|---|---|---|
| Regression | 3 | 123537.7 | 41179.22 | 62.11047 | 1.13E-15 |
| Residual | 43 | 28508.99 | 662.9997 | | |
| Total | 46 | 152046.7 | | | |

| | *Coefficient:* | *andard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *ower 95.0%* | *pper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | **0.90** | 9.46 | 0.09 | 0.92 | -18.17 | 19.96 | -18.17 | 19.96 |
| Topsoil K | **0.52** | 0.04 | 12.02 | 0.00 | 0.43 | 0.60 | 0.43 | 0.60 |
| Sub Texture | **-10.41** | 4.85 | -2.15 | 0.04 | -20.19 | -0.63 | -20.19 | -0.63 |
| Sub OM | **12.84** | 3.41 | 3.77 | 0.00 | 5.97 | 19.72 | 5.97 | 19.72 |

Subsoil K = Topsoil K x 0.52 - Subsoil Texture Class x 10.4 + Subsoil OM % x 12.8 + 0.9

This is the simplest combination that gives the highest r2

Lighter subsoil class increases the K presumably because of less adsorption

Subsoil organic matter may be indicative of deepened topsoil

Maximum of 6% applied to the data

**Factors correlating with subsoil K**

**MEDIUM and HEAVY TOPSOILS**

| | *Topsoil K* | *Topsoil Tex* | *Sub. Textur* | *Sub. Stones* | *Sub. OM* | *Sub. pH* | *Sub. Mg* | *Subsoil K* |
|---|---|---|---|---|---|---|---|---|
| Topsoil K | 1 | | | | | | | |
| Top.Texture | -0.07 | 1.00 | | | | | | |
| Sub. Texture | -0.02 | 0.57 | 1.00 | | | | | |
| Sub. Stones | -0.11 | -0.07 | -0.24 | 1.00 | | | | |
| Sub. OM | 0.05 | 0.10 | 0.10 | 0.01 | 1.00 | | | |
| Sub. pH | 0.05 | 0.03 | 0.01 | 0.04 | -0.29 | 1.00 | | |
| Sub. Mg | 0.01 | 0.45 | 0.38 | -0.02 | -0.01 | 0.09 | 1.00 | |
| Subsoil K | 0.71 | -0.01 | -0.01 | -0.19 | 0.23 | 0.04 | 0.04 | 1.00 |

Surprising lack of correlation with subsoil texture

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.73 |
| R Square | 0.54 |
| Adjusted R S | 0.53 |
| Standard Err | 24.33 |
| Observation | 170.00 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 115953.7 | 57976.86 | 97.95601 | 7.14E-29 |
| Residual | 167 | 98841.66 | 591.8662 | | |
| Total | 169 | 214795.4 | | | |

| | *Coefficients* | *Standard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | **16.30** | 5.19 | 3.14 | 0.00 | 6.07 | 26.54 | 6.07 | 26.54 |
| Topsoil K | **0.41** | 0.03 | 13.32 | 0.00 | 0.35 | 0.47 | 0.35 | 0.47 |
| Subsoil OM | **4.29** | 1.18 | 3.63 | 0.00 | 1.96 | 6.63 | 1.96 | 6.63 |

OM correction up to 6%

**Subsoil K = Topsoil K x 0.41 + Subsoil OM x 4.3 + 16 r2 = 0.54**

Correlation is improved a little (0.56) by making a negative stone correction but difficult to justify this

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.71 |
| R Square | 0.50 |
| Adjusted R S | 0.50 |
| Standard Err | 25.19 |
| Observation | 170.00 |

| | *Coefficients* | *Standard Err* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | **27.63** | 4.29 | 6.44 | 0.00 | 19.16 | 36.10 | 19.16 | 36.10 |
| Topsoil K | 0.42 | 0.03 | 13.05 | 0.00 | 0.35 | 0.48 | 0.35 | 0.48 |

**Subsoil K = Topsoil K x 0.42 + 28 r2 = 0.50**

Not so good but does not require subsoil measurements

## 9.5 : Influence of Various parameters on topsoil Magnesium

| Magnesium in Topsoil (all data) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Grass?* | *me of sam* | *nnual Rai* | *Top Texture* | *op. Stone* | *Top pH* | *Top OM* | *Top. Mg* |
| Grass Arable | 1 | | | | | | | |
| Time of Seaso | 0.36 | 1.00 | | | | | | |
| Annual Rain | 0.23 | 0.31 | 1.00 | | | | | |
| Top. Texture | 0.08 | 0.21 | 0.26 | 1.00 | | | | |
| Top. stones | -0.04 | 0.00 | -0.31 | -0.26 | 1.00 | | | |
| Topsoil pH | -0.28 | -0.13 | -0.38 | 0.02 | 0.22 | 1.00 | | |
| Topsoil OM | 0.34 | 0.19 | 0.30 | 0.36 | -0.17 | -0.26 | 1.00 | |
| Topsoil Mg | 0.08 | 0.00 | -0.13 | 0.46 | -0.05 | 0.25 | 0.13 | 1.00 |

The only significant factors appear to be Texture and pH
Annual rain has a very small negative affect and organic matter positive