February 2021

Research Review No. 95

Analysis of top and subsoil data from the

High Speed 2 (HS2) rail project

Work package 2

Leamington Spa to Crewe and Nottingham (Section B):

Soils on Red (Triassic) formations and overlying Drift

Stephen Heming[1]

[1]Reading Agricultural Consultants, Gate House, Beechwood Court, Long Toll,

Woodcote, Reading RG8 0RR

This review was produced a six month project (21140072) that started in July 2020. The work was funded by a contract for £2,700 from AHDB.

Contents

1. Executive Summary ... 4

2. Land Use and Soils ... 14

3. Sampling method and expression of nutrient levels ... 16

4. Phosphorus ... 19

  4.1 Overview of phosphorus levels ... 19

  4.2 Factors influencing phosphorus levels in topsoil ... 21

  4.3 Factors influencing phosphorus levels in subsoil ... 23

  4.4 Prediction of phosphorus in subsoil ... 28

  4.5 Agronomic Summary: phosphorus levels on red soils of the Midlands ... 30

5. Potassium ... 33

  5.1 Overview of potassium levels ... 33

  5.2 Factors influencing potassium levels in topsoil ... 34

  5.3 Factors influencing potassium levels in subsoil ... 37

  5.4 Prediction of subsoil potassium ... 43

  5.5 Agronomic conclusion: potassium levels in red soils of the Midlands ... 44

6. Magnesium ... 48

  6.1 Overview of magnesium levels ... 48

  6.2 Influence of texture on magnesium levels in topsoil ... 49

  6.3 Influence of texture on magnesium levels in subsoil ... 51

  6.4 Relationship of magnesium to parent material ... 54

  6.5 Problems of high magnesium in red soils of the Midlands ... 55

7. pH ... 57

  7.1 Overview of pH levels ... 57

  7.2 Factors influencing topsoil pH ... 58

  7.3 Factors influencing subsoil pH ... 58

  7.4 Prediction of subsoil pH ... 62

  7.5 Alkalinity in parent material? ... 64

  7.6 Agronomic conclusion: pH levels in red soils of the Midlands ... 64

8. Organic Matter ... 66

  8.1 Overview of soil organic matter levels ... 66

  8.2 Factors influencing organic matter the topsoil ... 67

  8.3 Factors influencing organic matter levels in subsoil ... 68

  8.4 Agronomic conclusion: organic matter levels in red soils of the Midlands ... 72

  8.5 Carbon stocks ... 74

9. Total Nitrogen ... 75

10. Evaluation of Accuracy of Geological and Soil Survey maps 78
11. Regression and correlation 81
11.1 Influence of topsoil parameters on subsoil P.. 81
11.2 Influence of Subsoil parameters on subsoil P 83
11.3 Effect of sampling method on topsoil P: subsoil P relationship................................ 85
11.4 Effect of Subsoil Organic Matter on topsoil: subsoil P relationship 88
11.5 Multiple correlation: factors affecting topsoil or Subsoil K....................................... 92
11.6 Arable: Subsoil Organic Matter and stone category on topsoil: subsoil K 94
11.7 Grassland: effect of Subsoil OM and stone category on topsoil: subsoil K 102
11.8 Effect of sampling method and organic matter on topsoil pH 113
11.9 Effect of topsoil pH and texture on subsoil pH.. 115
11.10 Effect of Sampling method, Stones and Texture on OM..................................... 121
11.11 Relationship of Total Nitrogen and Organic Matter... 128

1. Executive Summary

This data set comprises 796 sampling points in wide transepts from Leamington to Lichfield and thence to Nottingham or to Crewe. Half were in clusters of 2-15 points in close proximity (about 5 per ha) and the rest at a spacing of about 1 per 3 ha.

For estimation of regional averages a "balanced data" set was used which excluded 2 in 3 of the cluster data and totalled 584.

For examination of inter-relationships between topsoil and subsoil parameters the whole data was used. Measurements were made at NRM laboratory of pH, Olsen P, available K, Mg and OM (Dumas method) plus total nitrogen (Kjeldhal method) on cluster points only.

35% of the coverage was arable, 3% maize, 36% better quality grass leys, 20% other grassland and 6% woodland.

Soil Profiles

The solid geology (on BGS maps) was red (mainly Triassic) Mudstones (75%), Siltstones (9%) or Sandstones (16%). However 67% of the mudstone areas and 25% of the sandstone had superficial Drift: in 11% of cases this was Alluvium, 26% Sand & Gravel and 19% Glacial Till.

3% of topsoils hand-textured as sandy (loamy sand), 38% as light loam (sandy loam or sandy silt loam), 43% as medium - sandy clay loam, clay loam or silty clay loam with up to 26% clay - 14% as heavier loams (27-35% clay) and 3% were clay-textured.

Subsoil textures were more extreme with 13% sandy and 19% clay; in Glacial Till subsoils there could be short-range (with a few metres) variation in subsoil texture.

Over Mudstones the topsoil often contained less clay (and more sand) than the subsoil - evidence of thin Drift even where none was marked on BGS map.

Soil survey (SSEW) Association national maps were guides of soil profiles likely but each mapping unit contains a range of permitted textures. Moreover in 26% of profiles, the texture of topsoil was judged *outside* these generic descriptions (and 42% of upper subsoil texture).

Neither SSEW nor BGS maps can be relied on to predict the soil texture (nor main soil type) and sometimes there was a significant soil change within the same field, pointing to the importance of soil survey to demark management zones.

5% of topsoil colours were 2.5YR (strong red), 19% 5YR (reddish brown), 53% 7.5YR (strong brown) and 23% normal brown (10YR or lesser hue). Subsoils tended to be redder, 9%, 32, 33 and 16% respectively.

Median depth of identifiable topsoil was 30cm for arable, 28cm for leys and 25cm for extensive/permanent grassland and 25cm for woodland. Some arable topsoils were significantly deeper.

Composite samples were taken by corer 0-20/22cm and 25/30 to 50cm or by representative samples taken from Dutch auger. The former method tended to a lesser average topsoil depth in the sampling.

'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 these surveys (minimum depth of 20cm).

Phosphorus

In this summary RB209 phosphorous indices 0, 2 and 3 are shown in parentheses and divided into lower and upper halves (+/-)

Median Olsen P in topsoil was arable 23 mg/l (2+) > leys, amenity grass, woodland 17-18 mg/l (2-) >> extensive grassland 8 mg/l (0+).

24% of arable soils were below target index (2) and 14% index 4. 47% of leys and most extensive grassland were below target index. The latest 2019 (PAAG) laboratory survey gives a similar proportion of deficient arable samples (22%) but less grassland (34%) than here though based on a shallower sampling depth.

Texture was relevant: topsoil P tended to be higher on lighter land under arable or extensive grassland but on leys was even across all textures. Under woodland P was higher on sandy and peaty soils. There was no correlation of topsoil P and pH.

In subsoil medians were arable 12 mg/l (1) > amenity grass, woodland 10 mg/l (1) > leys 8 mg/l (0+) > extensive grassland 5 mg/l (0-).

38, 47, 48, 60 and 77% respectively were index 0. 10% of ley and 15% of extensive grass subsoils were below laboratory detection limit of 2.5 mg P/l.

38, 20, 30, 23 and 14 % respectively of subsoils were index 2 or above.

Subsoil P is very strongly related to topsoil phosphorous (P = 0.8) with lesser relationship with subsoil potassium (P = 0.5), subsoil texture, subsoil organic matter (OM) and sampling method **–** samples taken by corer average ~2 mg/l more P in the subsoil than auger method**.**

There was no correlation of subsoil P with subsoil pH.

The reddest soils (2.5YR hue) tended to the lowest P levels and the slightly reddened soils (7.5YR) highest, but not statistically significant.

55% of variation in subsoil P could be accounted for by topsoil P adjusted for subsoil texture and a further 10% if subsoil OM is known. Under light to medium topsoil there is a "change point" as topsoil increases above 35 mg P/l when subsoil P rises more sharply. On heavier land the rise may occur above 40 mg/l but is difficult to predict.

At topsoil 20 mg P/l the subsoil (to 50cm) is typically 12 (1) for sandy, light and medium loamy soils and 9 mg/l (0) for clay subsoils. Results vary +/- 1 mg/l depending on whether corer or auger method was used.

Each increase of 1% OM in the subsoil up to 6% correlates with an increase in subsoil P of 1.1 mg P/l on soils up to 35 mg P/l, with bigger effect on high P heavier soils.

Natural woodland and amenity soils have higher subsoil P than extensive grassland or leys, implying agriculture utilisation is leading to decline in subsoil P rather than enrichment.

Overall the higher P in *arable* than grass subsoils is linked to predominance of lighter textures. Once topsoil exceeds 35 mg/l (mid 3), subsoil will be index 2. At topsoil >45 mg P/l (4) the subsoil is likely to be index 3 on all except the heavier subsoils. Therefore it seems agronomically safe practice to curtail phosphorus inputs and utilise excess in all soils which are >35 mg P/l (mid index 3).

Assuming such soils are not subject to run-off, the environmental case is less clear in lighter undrained soils a) because downwards movement of P is not a problem, b) heavier subsoils can have underdrains but P is absorbed more strongly and subsoil rarely exceeds index 1 (and probably is less below 40cm).

Provided arable and grass soils are kept at or above mid index 2 (20 mg P/l) this should guarantee subsoil is above index 0.

Subsoil P cannot be predicted satisfactorily from topsoil P on the following: disturbed/ remade land, (layered) alluvial deposits or at very high P index over heavier subsoils. In such cases subsoil should be sampled at same time as topsoil.

Potassium in topsoil

For this report indices 0,1, 2 and 3 are divided into lower and upper halves (+/-)

A large range of potassium levels were found. Arable median topsoil K was 131 mg/l (2-), significantly higher than grass leys or extensive grass, median 87 mg K/l (mid 1). 42% of arable and 85% of grass samples were below target index, significantly more than reported in PAAG (2019), 24% and 41% respectively (though sampled somewhat shallower in both cases).
Only 27% of arable soils were above target index of which most (17%) were index 2+.

Texture of topsoil is important: under arable or grassland K tended to increase with clay content light loams < medium loams < heavier loams < clays
Typically a clay topsoil was 40 mg K/l higher than a medium topsoil (SCL/mCL)

Topsoil K strongly related to phosphorus (a management influence) and weakly with pH (1 unit rise corresponding to Δ25 mg K/l). Organic matter had weak influence and there was no effect of Average Annual Rainfall.

Potassium in subsoil

There was clear relationship of Subsoil K to Topsoil K which altered with texture. At topsoil mid index 2 subsoil K was proportionally less on sandy subsoils (due to leaching) and on heavier loams/clays (stronger adsorption).

On arable sites subsoil K was influenced by subsoil organic matter – each 1% increase in OM associated with Δ4 mg K/l in clay subsoils rising to Δ9 mg/l on light loam subsoils.

For any given topsoil K, under grass the subsoil K averaged 10 mg K/l less than arable sites and was usually unrelated to OM. Under grass there may be less deep disturbance or mixing of topsoil material than on arable land.

On sandy to medium subsoils, an increase in subsoil stones by about 10% (v/v) was associated with Δ8 mg/l increase in subsoil K, i.e. the stones may concentrate K leached from topsoil.

75% of the variation in K level in the upper subsoil could be accounted for by topsoil K adjusted for subsoil texture. Alluvial soils were unpredictable, and on some stony lighter subsoils subsoil K can be parity or higher than topsoil.

Farmers usually know their topsoil texture but not the upper subsoil: in 33% of the instances it was heavier than the topsoil and in 18% the subsoil was lighter (sandier).

The prediction of subsoil K from topsoil K alone is problematic, but some guidance is given below assuming that potash deficiency is very likely below 90 mg K/l.

- At (topsoil) K index 0 (0-60 mg/l) subsoil is also index 0 but rare on heavier soils.
- At K index 1- (61-90 mg/l) subsoil is likely 0 or 1- and thus inadequate.
- At topsoil index 1+ (90-120 mg/l) arable subsoils are likely index 1- on sandy/light loam soils but 1+ on medium and heavy soils, implying some adequacy but see note below*. Under grassland subsoil K is very unpredictable (0 to 2-).
- At topsoil index 2- (121-180 mg/l, target) subsoil is likely index 1+ on sandy to medium soils (but ranging 1- to 2-, in the former case this might cause deficiency if the topsoil dries out). Heavier subsoils are usually 1+ to 2- implying sufficiency* though index 1- was found in a fifth of cases.
- The probability of subsoil K being 90 mg/l or less is

Topsoil index 1+	65% of lighter topsoils, 44% medium to heavy.
Topsoil index 2-	38% of lighter topsoils, 21% medium to heavy
Topsoil index 2+	20% of all textures
Topsoil index 3	0%

- On heavier soils, potash levels in these Triassic clays seem better * than Carboniferous clays where the subsoils were usually index 0/1 (see NE report). Subsoils formed in Triassic mudstone tended to higher subsoil K than in heavier subsoils on Drift but were 'obviously K releasing' (see southern report).

  * A better K level in *heavier* subsoil may not be as effective as it seems because K depletion experiments show that a basal amount of the analysed K is not actually plant extractable and this 'dead K' increases with clay content. In this data intercepts (at theoretical 0 mg/l topsoil K) were light loams subsoils (0) < medium (20 mg/l) < clay (45 mg/l). It is possible that the first 50 mg K/l in heavier soils is not useable by the plant. More research is needed on this.

- Maintaining soils above target at index 2+ is likely to maintain subsoil at index 1+ to 2- (arable) or 1+ (grassland) so subsoil K should be adequate in dry seasons.

- Topsoil K index 3 corresponds to subsoil K of at least 2- and so should be quite safe to run-down despite uncertainties.

- At levels above (and at) target index it is implicit that some K is being leached from topsoil on medium soils and a substantial amount on lighter soils.

- Measurement of subsoil K should be routinely made in potash depletion (or build) experiments. It is also advisable on disturbed soils or soils on layered alluvium or stony subsoils or where there is large textural contrast e.g. medium loam over clay or heavy loam topsoil over light loam, land ploughed up from long term grassland.

Magnesium in topsoil

Mg index 2 (51-100 mg/l) is considered optimal for nearly all crops and grassland.

Only 6% of arable oils were below target, most were index 2 or 3 (median of 112 mg/l). A few (13%) were Index 5 (very high) or Index 6 (excessive)

Under grass leys Mg levels were slightly higher (median 122 mg/ l); 5% were below target and 11% index 5 to 7. Under extensive grassland values were much higher - median index 4 (219 mg/l) and 40% Index 5 to 7. Amenity grass tended to be lower. On woodland median Mg was 123 mg/l but values are widely spread with 22% index 0/1 and 33% index 5 to 8.

The PAAG (2019) survey found 12% were index 5 or more (arable and grass), which accords with the data here except on the permanent grassland.

For all land uses Mg level tended to increase with clay content :

sandy and light loams << medium topsoils (50 mg/l higher) << heavier loams (50 mg/l) << clay topsoils (usually >350 mg/l (6 or 7)).

Arable sites deficient in Mg (index 1 or 0) were mostly on lighter soils and a few on medium textures; likewise for leys. On amenity grass low Mg cases were restricted to light loams.

On extensive grass Mg was hardly ever deficient and greater across all textures, the median increasing from index 3 for lighter loams to index 5 for heavier loams. Probably higher Mg is due to lack of offtake (no cuts), predominance of grazing (Mg returned in excreta) and possibly wetness (lack of leaching).

Under woodland the differences due to texture are extreme.

Magnesium in subsoil

Under on arable land subsoil Mg averaged similar Mg to topsoil but with more extreme values - 14% index 0/1 and 19% Index 5 to 7. On grass leys there was more variation (14% low and 19% index 5 to 7) and under woodland subsoil Mg ranged from index 0-7.

Modelling of the data gives a texture matrix for predicting subsoil Mg. It is likely to be lower in the subsoil (0.8 to 0.9x topsoil Mg) if either topsoil or subsoil was sandy or light loam texture. In other cases the ratio was parity or 1.2-1.4x higher where subsoil was heavier texture than the topsoil.

Problems of low or very high magnesium

a) where the topsoil is adequate index (lower end 2) a sandy or light subsoil could be index 1 (or a topsoil index 1 may overlie index 0). This may have consequence in dry seasons. In all other textures Mg in subsoil will be equal to or higher than the topsoil.

b) RB209 states that high soil Mg may antagonise uptake of potassium. The criteria are not precisely specified but a minimum ratio of 0.5 K:Mg on a mg/l:mg/l basis is sometimes cited. High Mg might also make soil structure more unstable.

In the arable data median K:Mg ratio in topsoil was 1.3. In *16% of cases ratio was 0.5 or less.* For grass leys median K:Mg was 0.8, and *24% of cases had ratio <0.5* of which 5% were <0.25 (i.e. mg/l Mg was more than 4x the mg/l K !)

In subsoils potassium tends to be lower than topsoil while Mg can be higher, especially where heavy textured. Arable subsoil median K:Mg ratio was 0.8 and 29% of ratio less than 0.5 of (9% were < 0.25). Under leys median was 0.7 with 32% <0.5 (9% <0.25).

Very high Mg parent materials are Alluvium over Mudstone and soils directly formed on Branscombe Mudstone or Dolomitic Siltstone (index 6-7); soils formed on Gunthorpe, Sidmouth and Wilkersley Mudstones are typically index 5. Soils in Glacial Till or fluvio-glacial material over the above mudstones are slightly lower (index 4) - as expected due to dilution with foreign material. On sandstone, mixed mudstone-sandstone formations or alluvium over sandstone the subsoil is index 3 or 2.

There was no correlation between Mg and soil pH suggesting that clay mineralogy dominates rather than whether dolomite is present or not.

Magnesium: potassium antagonism could be problematic on a significant proportion of Triassic soils (though less than found in the NE region). K:Mg ratio is kept above 0.5 provided target K index (2-) is attained and Mg index does not exceed 4. At Mg index 5 topsoil K index of 2+ kept the ratio above 0.5. More agronomic trials are needed on such soils to establish what the critical ratio is for preventing potassium deficiency in crops.

pH of topsoil

34% of the arable land was at target pH (6.5-6.9), 28% at marginal pH (6-6.4) and only 12% acid (< pH 6) with almost no samples <pH 5.5. More soils were acid (19%) in the PAAG (2019) survey.

For grassland 21% of better quality leys, 38% of the extensive grassland and 50% of amenity grass was below optimum (pH 6.0+). However, of the extensive grassland only 4% was below pH 5.5 (compared to 19% in PAAG survey). 60% of woodland was < pH 6.0 or which 20% was below pH 5.

The data suggests that in this region most arable and intensive grassland farmers are regulating pH by testing and liming (though control could be improved to eliminate low pHs).

Note: normally grass is sampled at shallower depth (7.5cm or 15cm) than the 20cm+ here, and so pH may be lower in main active layer of grassland, especially on fields which are not (rotationally) ploughed..

Topsoil pH decreased in sequence arable > ley > extensive > amenity but not by a large amount (medians are 6.6, 6.4, 6.1 and 5.9 respectively).

pH is slightly influenced by topsoil texture with a median increase of 0.2 units from sandy to clay soils. pH *decreased* with topsoil OM% though it explains a poor amount of the variance.

pH of subsoil

Subsoil pH is strongly related to topsoil pH with a lesser influence of topsoil and subsoil texture. At topsoil pH 6.0 subsoil is most likely to be 6.2 on a sandy soil increasing to 6.5 on a clay; at topsoil pH 5.5 subsoil is likely to be 5.9 and 6.1 respectively. However there is considerable uncertainty (r^2 <0.6) and in some cases subsoil was more acid than the topsoil.

The general rule holds that 'if target topsoil pH is maintained the subsoil will take care of itself.' However, subsoil below 6 constitutes a risk for arable crops, and in the following instances *pH of the subsoil* (to 50cm) is worth testing as well:

a) Topsoil pH < 6.4. Light loamy or sandy soils or stony subsoils or organic soils; fields which have come out of longer term grass or been under minimal cultivation.
b) Topsoil pH < 6.0. Light loamy, sandy or stony subsoils, organic soils and all soils where cropping is sensitive to acidity e.g. barley, beans, sugar beet.
c) Topsoil pH < 5.5 all cases including intensive grassland.

Where subsoil pH is found to be below 6.0, the appropriate lime requirement can be added by over-liming the topsoil (to above 7) to accelerate leaching of bicarbonate, or "ploughing under" the extra lime or applying more lime the following autumn.

Alkaline subsoils

As topsoil pH approaches 7.0, subsoil pH tended to parity for lighter soils and was up to 0.5 higher on clays, though the latter may depend on mineralogy. About 5% of topsoils were pH 7.5 + and 6.5% of subsoils. Alkaline subsoils could be found on all Triassic Mudstones and Siltstones, on Glacial Till and (rarely) sandstones, and cannot be predicted reliably from soil or geology maps except where deposits are mapped as 'dolomitic'. Worcester association is most likely to contain calcareous layers in the (upper) subsoil. Some cases may be due to over-liming by farmer.

Organic matter assessment

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

Sampling method had no influence of OM measurement of topsoil on arable land but was 0.4-0.7% higher on grassland, reflecting inclusion of the surface layer by corer which was not always the case with samples taken off the auger. Subsoil OM was proportionately higher by corer (by an average 0.4% and 0.26% on arable and grassland) which is due to subsoil sample starting at somewhat shallower depth than auger - in the latter purer subsoil cores were selected from auger, in some cases below 35cm.

Median OM values are lower than means and a better indicator for agronomic purposes. Notwithstanding all these uncertainties, the data for region shows the following.

Organic matter in topsoil

Median was 3.2% in arable soils (moderate), very few samples below 1.5% and only 16% of samples 4.5% or higher.

Grass ley topsoils had slightly greater OM, median 3.8% OM with 31% of samples >4.5% but very few >10%. Under amenity and extensive grassland OM was higher, medians 4.3 and 4.7% OM, though including more wet sites than other land use categories and 5% were >10% OM.

Median identifiable depth of topsoil under grassland was 25cm and samples were taken to at least 20cm depth, compared to 7.5cm or 15cm RB209 recommends for permanent and temporary grass.

Under woodland OM (typically sampled to 25cm depth) was highly variable; median 5.2%.

Topsoil texture had an influence on OM levels in arable data, the median increasing from 3.2% for sandy topsoils to 4.0% on clays, but no obvious texture effect under grassland. Under woodland, organic topsoil (>10%) was common in sand and light loam textures but rare in medium or heavy soils.

Organic matter in subsoil

Was strongly related to topsoil OM%, unrelated to topsoil texture but influenced by subsoil texture - with OM levels proportionately lower on sand subsoils and higher on light loam subsoils than all other texture groups (on both arable and grassland). This could be due to a) poorer OM retention on sands b) more ready carry-down of organic matter (by earthworms) on light loams than medium or clay subsoils.

Stones might concentrate OM input from earthworms (or deeper roots) and on arable land the lighter soils each stone category (estimated 10% by volume) corresponded to an average increase of 0.18% subsoil OM. However on grassland subsoils there was a *decrease* of 0.35% OM.

Under woodland the subsoil OM% was proportionately higher in sands and light loams, and lower in medium and clay soils.

Topsoil OM% explains less than half the variation in subsoil OM% (r^2 = 0.35-0.40) in arable and grass, more under woodland. Compared to topsoil OM, subsoil OM is proportionately less in grass and woodland than arable.

Though there is considerable unexplained variation, as a generalisation, on arable soils at moderate organic matter (3-4.4%) the subsoil is likely to be low (1.5-2.9%). If the topsoil is low, the subsoil is low or very low.

For grass leys at moderate topsoil OM, the subsoil is likely to be low or very low OM. If topsoil is low OM subsoil will be very low. When topsoil OM is good (4.5-6.0%) subsoil is most likely to be low (<3.0%) and at high topsoil OM (> 6%) the subsoil OM is unpredictable, ranging from low to high.

For arable and leys a realistic target to aim for.in the upper subsoil 25-50cm is 2.5% (Dumas method). This will improve potash retention, phosphate availability and soil structure.

Carbon stocks

Stocks in soil cannot be simply derived from OM% measurements because it also depends on horizon depths, stones and bulk density. Density is higher on sandy or compact soils.

A calculation has been developed to estimate total carbon to 50cm depth which needs review but estimates average carbon in this data set to 0-50cm depth as **95 t C/ha** on arable land, **137 t C/ha** under extensive (permanent) grassland and **160** t C/ha under woodland .

However the calculation needs peer review and verification before it can be published or used to investigate whether soil texture significantly influences affects carbon stocks.

For further studies agronomic or environmental, soil is best measured to standardised sampling depths and using a corer rather than taken off augers, with standardized depths 0-25 and 25-50cm or 0-20, 20-40 and 40-50cm.

Total Nitrogen

Total N is of environmental and agronomic relevance, influencing the release of available nitrogen to crops (and grass) by mineralisation; TN > 0.23% being a threshold of importance in RB209.

About half the data set had been measured for total N, although in clusters so their representativeness to the whole region could be statistically challenged.

Hardly any arable topsoils were > 0.35% TN but 32% were >0.22%.
Median TN was 0.19%, very close to the 0.2% cited as typical in the literature.

Under grass leys, 10% of topsoils were >0.35% and 38% 0.23-0.34% TN; median was 0..22%. Under extensive (permanent) grassland and woodland, median TN was 0.26% and 0.28% respectively, though extremely variable under woodland.

In arable or grass ley *subsoils* TN averaged 0.10%; higher under extensive grass or woodland (median 0.13 and 0.4%).

Because nitrogen resides mainly in the organic matter, not surprisingly there was strong correlation (r^2 0.6-0.9) in topsoil and subsoil. OM is reported as 1.72x measured Carbon and the commonly cited C:N ratio of 10:1 is expected to give a 0.058x relationship.

Most data set fitted to a lesser slope (0.04-0.05) and with a small but significant intercept which implies that C:N ratio diminishes as the level of organic matter (and TN) increases.

Notwithstanding, C:N ratio averaged about 10 for arable and leys, albeit with significant standard deviation (about ±2). Clusters of 2-15 samples (usually taken in the same field) usually showed less variation within the cluster than between clusters. Clusters could have average C:N as low as 8:1 and as high as 12:1, implying influence of management, land use, soil type or texture. The data is investigated in more detail in the Southern report, where south and Midlands data are combined, and soil texture is shown to be highly significant.

On grassland and woodland, C:N tended to be higher (about 12:1) but again with significant difference between clusters.

C:N ratio in subsoil on average is 0.5 lower than in topsoil on arable, grass and woodland.

Dumas is a good method for measuring organic carbon because it gives C:N ratios broadly in line with expectations, unlike Carbon derived from Loss on Ignition methods which misleadingly implies C:N ratios of 12-14:1 or more.

2. Land Use and Soils

Region B: Central and West Midlands

The analysis corridor stretches from Leamington to Crewe with a branch from Lichfield to Nottingham (M1 junction 27). This whole area is characterised by red Triassic rocks..

The area comprises 35% arable land that was growing cereals, rape and occasional vegetable crops (1%), 3% was in maize. The majority was grassland: 36% was judged as well managed leys (some fields in arable-ley rotation). 20% extensively managed or 'rough' grassland with 2% under horse paddocks.

The proportion of arable land was greater in the south of the region. Average Annual Rainfall ranges from 650mm East of Birmingham to 790 mm on the Staffordshire ridge.

Table 1. Region A: Land Use

Land Use	Sample/survey points	Proportion %
Arable	207	**35**
Maize	17	**3**
Ley (managed)	209	**36**
Poorer grassland	84	**14**
Horse paddock	16	**3**
Amenity grass	15	**3**
Woodland	36	**6**
Total	584	

Balanced data base of 584 profiles (see section 2)

Geology

British Geological Society (BGS) maps [1] indicates Triassic Rocks with small occurrences of Carboniferous and Permian deposits that share similar reddening.
BGS maps are very detailed and indicate that 76% of the survey samples overlie variously named red mudstones, with smaller exposures of sandstones and siltstones (Table 2). However, much of the mudstone is covered by Drift Deposits which amount to 58% overall. These comprise Alluvium, River Terrace or Fluvioglacial Sand & Gravel and Glacial Till usually (but not wholly) derived from the red bedrocks. For full breakdown see Appendix 10.

Table 2. Region B: Geology Summary (frequency)

Parent material	**Solid Geology**	**Drift Geology**
Sandstones	16 %	none 12 %
Siltstones and mixed	9 %	none 7 %
Mudstones	75 %	none 22 %
Alluvium	any	11 %
Sand & Gravel	any	26 %
Glacial Till	any	19 %
Head or Peat	any	1 %
Disturbed	any	1 %

Soils

Topsoil and upper subsoil were hand-textured in all cases, and put into five groups according to clay content. The balanced data set in Table 3 indicates a predominance of topsoil textures in the sandy loam, sandy clay loam and medium clay loam category. Upper subsoils were more diverse with more cases of extreme textures (sands and clays). In 33% of instances the upper subsoil was heavier (i.e. contained more clay) than the topsoil and in 18% the subsoil was lighter (sandier) than topsoil. The influence of duplex (i.e. contrasting) profile texture is examined when analysing the nutrient data.

Table 3. Region B: Soil Texture Summary (frequency in balanced data)

Soil Texture		Estimated clay	**Topsoil**	**Upper Subsoil**
Very light	LS, S	<9%	3 %	13 %
Light Loam	SL, fSL, SZL	9-17%	38 %	28 %
Medium	SCL, mCL, mZCL	18-26%	43 %	28 %
Heavier	SC, hCL, hZCL	27-35%	14 %	17 %
Clay	ZC, C	>35%	2.5 %	15 %
Peaty loam or peaty sand			0.2%	0.2%

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).

Most of the areas marked by BGS as Drift-free Mudstone were characterised by loamier or even sandy topsoils with red clay encountered at depths from 40 to 80cm. Conversely on areas marked as overlain by Glacial Till or Sand, the underlying Mudstone was sometimes found within 60cm.

Each point was located on the Soil Survey of England and Wales 1:250 000 maps [2]

25 associations are present, mainly as *Whimple 3* or *Clifton* but with significant inclusions of *Arrow, Wick 1* and *Bromsgrove/Brignorth* associations (Appendix 10).

General experience of surveyors was that the SSEW manual [2] was a good guide to the soil profiles and drainage. However in the SSEW guide each association contains a range of *contrasting* profiles. Furthermore, in this survey for 26% of profiles the hand texture of topsoil was judged *outside* these generic descriptions (42% for upper subsoil texture).

Clearly neither SSEW nor BGS maps are safe to rely on to deduce the soil texture (or main soil type) without field examination. For details see Appendix 10.

Redness: 5% of the topsoils were 2.5YR (strong red), 19% 5YR (reddish brown), 53% 7.5YR (strong brown) and 23% normal brown (10YR or lesser hue). Subsoils tended to be redder 9%, 32, 33 and 16% respectively. Lighter and heavy soils had similar proportions.

References

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

2 J.M.Ragg,, G.R. Beard, .H.George et al (1984) Soils and their Use in Midland and Western England. Soil Survey of England and Wales Bulletin 12

3. Sampling method and expression of nutrient levels

Region B: Central and West Midlands

Sampling grid

The data set is representative selection along the transept corridors from Leamington to Lichfield and thence to Crewe or Nottingham.

Frequency was 1 per 2-3 ha and a subset was taken at closer spacing (up to 5 per ha) in isolated clusters of 1-20 samples. The latter were measured for total N. All samples were measured for pH, available P, K, Mg and Organic Matter by Dumas method at NRM laboratory. For statistical evaluation three data sets were made:-

a) **All data –** for evaluation of topsoil : subsoil correlations of pH PKMg and OM.

b) **Close spaced data** isolated for evaluation of carbon : nitrogen relationships

c) **Balanced data –** to minimise risk of close-spaced cluster samples skewing the averages, 2 in 3 data were excluded to give a more representative data set for showing the regional values of pH PKMg OM and textural class.

Data points amount to a) 796, b) 398 and c) 584.

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 identifiable 'topsoil' and 'subsoil' are shown in Table 4

Table 4. Region B: Depth of topsoil for purposes of analysis

	mean	**median**	**10-90%**	***n***
Arable	29 cm	30 cm	25 – 32 cm	*288*
Leys	28 cm	28 cm	24 – 32cm	*286*
Extensive grass	26 cm	25 cm	20 - 30 cm	*148*
Amenity	27 cm	25 cm	25 – 32 cm	*20*
Wood	26 cm	25 cm	25 – 30 cm	*50*

Median subsoil start depth was 26cm by Corer method and 30cm by Auger.

On arable land and leys a significant proportion of the land had recognisable topsoil of 30cm or deeper, indicative of (current or former) deep cultivation. On the more extensive grassland topsoil depth was less but commonly 25cm, again indicative of cultivation in the past.

Table 5. Region B : 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 *	4.5	4.0	6.3	6.3	21.3	17.6	132	112	188	128
Dutch Auger	3.9	3.4	6.4	6.4	20.5	16.8	136	98	168	122
U. Subsoil										
Corer *	2.5	2.0	6.6	6.6	13.9	10.4	100	88	210	125
Dutch Auger	1.8	1.5	6.7	6.7	10.8	6.8	98	75	198	112

* 440 and 356 samples were taken by Corer and Auger respectively.

The Corer technique registers higher Organic Matter (OM) in topsoil and subsoil by ~0.5%. This is to be expected especially on grassland because this method includes the surface layer of topsoil.

The Corer method obtains slightly higher topsoil P and significantly higher subsoil P than the Auger method (∆3 mg/l P). The effect on correlations is checked in foregoing sections.

The Corer method obtains very slightly lower pH and very slightly higher K and Mg which is unlikely to affect the correlation analysis.

Differences in P and OM are probably because the corer method always samples the surface to 20cm and its subsoil sample can contain some transitional material (or deep topsoil) at 25-35cm whereas the auger method generally selects 'pure' subsoil. The method difference in OM and P is checked in more detail in the relevant sections.

Generally speaking this survey data is representative of upper subsoil 25-50cm. Likely nutrient gradients occur over this depth but the data shows what pH and nutrient levels roots are 'likely to encounter' as they venture deeper down.

Nutrients

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

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-

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

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. In 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 more common for Mg.

1 AHDB (2017) The Fertiliser Manual (RB209)

4. Phosphorus

Region B: Central and West Midlands

4.1 Overview of phosphorus levels

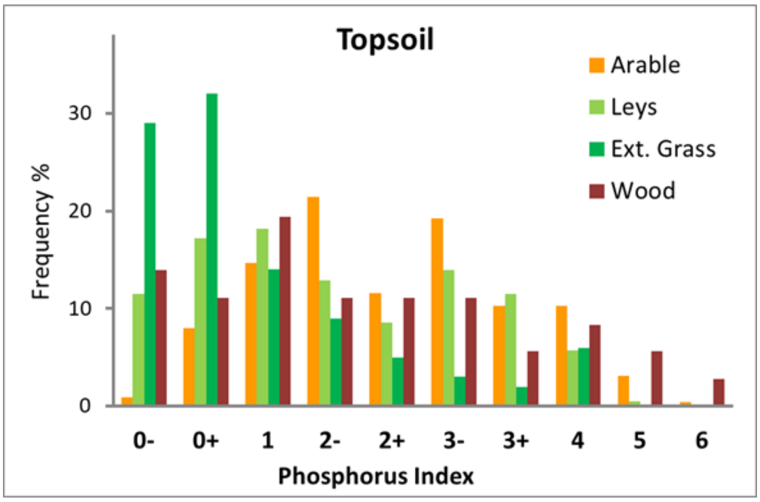


Figure 1a. Region B: available Phosphorus in topsoil (Balanced Data)

Topsoil P

Arable land: P index 2 is considered optimal. The median here is 23 mg P/l (upper 2) but distribution is bimodal with peaks in lower index 2 and lower index 3 (probably related to soil textural class). 24% of samples were below target index though almost none < 5 mg/l. 14% were excessive (index 4 or higher).

PAAG (2019) survey data gives similar proportion below target (22%) and 50% of samples of index 3 or more compared to 42% here.

Grassland: leys also have a bimodal pattern with peaks at index 1 and lower 3 and overall median of 17 mg/l (lower index 2). 47% of samples lie below target. Extensive grass has very low P levels - median 8 mg/l (index 0) and 75% below target. The PAAG (2019) survey for all grass gives a lower proportion (34%) below target but note that the results shown here are from a topsoil depth of 20cm+ compared to the top 7.5 or 15cm as normally sampled.

35% of leys and 12% of extensive grassland were index 3 or higher compared to 26% in PAAG (2019) data.

Natural: amenity grass and woodland also have highly variable P analyses but the median (lower index 2) is significantly higher than extensive grassland, suggesting that the latter soils are being depleted of phosphate, possibly by neglect of fertiliser despite some P offtake due to grazing or cutting. The more productive grass leys do not have greater P fertility than natural amenity (park) grass or land under wood.

Table 6 Region B : Typical Soil Phosphorus levels (mg/l)

	Topsoil		Upper Subsoil	
	median	**10-90%**	**median**	**10-90%**
Arable	23 (2+)	10-51	12 (1)	5-37
Leys	17 (2-)	5-39	8 (0+)	2-25
Extensive Grass	8 (0+)	4-27	5 (0-)	2-18
Amenity	17 (2-)	4-29	10 (1)	2-21
Wood	18 (2-)	5-54	10 (1)	3-46

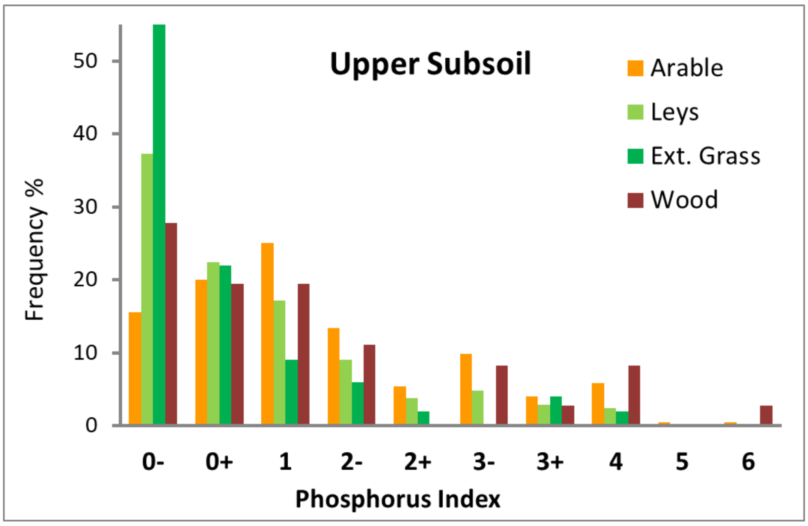


Figure 1b.   Region B: Soil available Phosphorus (Balanced Data)

Subsoil P

Arable land: the median is 12 mg P/l (index 1) though could be much higher in some cases. 36% of cases were index 0 and 38% index 2 or above.

Grassland: leys had somewhat lower subsoil P than arable land with median of 8 mg/l (upper index 0) though the mode is extremely low (lower index 0). 60% of subsoils were index 0 of which 10% were below the NRM detection limit of 2.5 mg/l (entered as 2.0 in data base). 23% of subsoils were index 2 or above.

For extensive grass, median subsoil P was extremely low (5 mg/l). 77% of subsoils were index 0 and 15% below detection limit. 14% were index 2 or above.

Natural: amenity grass and woodland had highly variable P but the median (10 mg/l, index 1) might be a considered a typical value for 'natural' subsoils. 47% of amenity grass and woodland subsoils were index 0; 20% and 30% respectively index 2 or above.

Of course the above trends in soil P levels might be related to co-factors e.g. more arable points on lighter land, so the whole data set used for more detailed analysis. Amenity and extensive grass are combined.

4.2 Factors influencing phosphorus levels in topsoil

Multiple regression analysis (Appendix 11.1) indicates topsoil P strongly correlated with topsoil potassium in all cases except woodland, implying a (historical) management influence on both arable and grassland.

There is a negative correlation of topsoil P with topsoil texture class in all cases though only significant in arable and extensive grass data sets.

There is a strong positive correlation of topsoil P with topsoil OM% on the arable set, but only weak influence on the grassland or woodland.

There is a positive trend of topsoil P with pH on the grass leys data, but this is extremely weak (see Figure 2), and very low P levels are found over the pH spectrum.

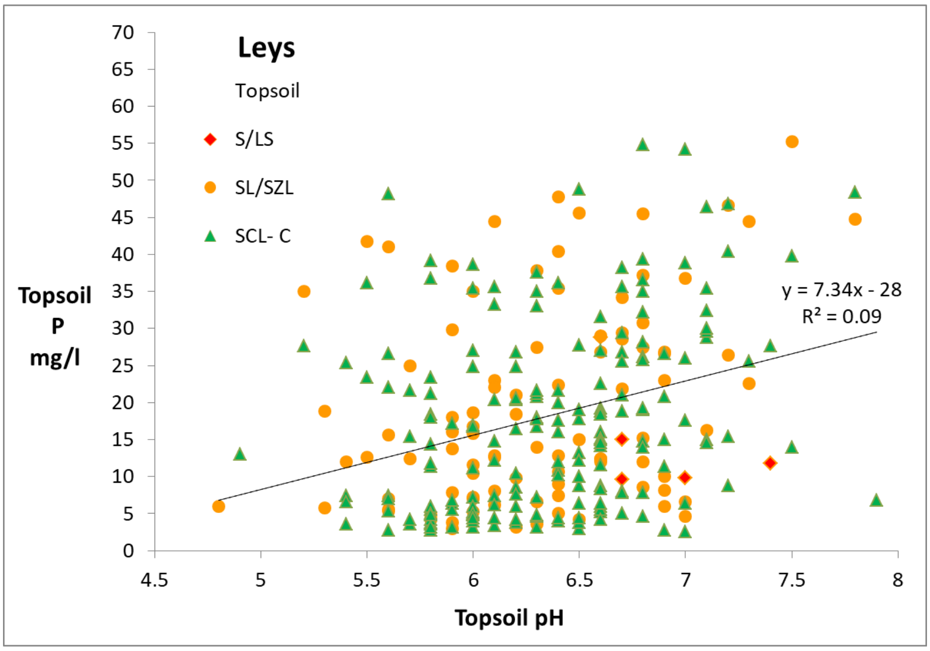


Figure 2: topsoil pH and Phosphorus. Grass leys

When topsoil redness was assessed there is no overall correlation though some evidence it is lowest on the reddest soils (5% which had 2.5YR hue, see Table 8).

Topsoil P and Topsoil texture

Tables 7a-7d show averages of all data up to P index 4. Index in parenthesis. Statistical analysis in Appendix 11.1.

Table 7a shows a major texture influence. P is higher on light loams and sandy soils. This is due to weaker P adsorption or historically more highly-fertilised crops grown on lighter land (maize and vegetables).

Table 7a Region B: Arable data Topsoil Texture and Phosphorus

Class	**Textures**	**Mean** mg P/ l	**Median** mg P/ l	**n**	n with index ≥3
0	LS,S	52	55 (4)	*10*	
1	SL, SZL	29	29 (3-)	*102*	*5*
2	SCL, mCL (mZCL)	22.1	22 (2+)	*127*	*4*
3	hCL, hZCL	21.3	20 (2-)	*35*	
4	ZC, C	17.7	17 (2-)	*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.

Highly significant difference Class 0 > 1 > 2 ($P < 0.001$). No difference 2 – 3. Possible difference 3 > 4 ($P = 0.17$).

For grass **leys** the texture effect is minimal (Table 7b) – probably a real but very small decline with clay content. This suggests intelligent management of P levels on the cut grass. Extensive grass (Table 7c) demonstrates a clearer texture influence although the median differences are half the difference in means.

Table 7b Region B: Grass Leys - Topsoil Texture and Phosphorus

Class	**Textures**	**Mean** mg P/ l	**Median** mg P/ l	**n**	n with index ≥3
0	LS,S	19.7	13 (1)	*8*	
1	SL, SZL	19.6	16 (2-)	*93*	
2	SCL, mCL (mZCL)	17.5	15 (1)	*144*	*1*
3	hCL, hZCL	15.9	14 (1)	*36*	
4	ZC, C	26.7	26 (3-)	*5*	

Possible difference: Class 1 > 2 and 3 > 4 ($P < 0.01$) but small (<2 mg P/l)

Table 7c Region B: Extensive and Amenity Grass Topsoil Texture and Phosphorus

Class	**Textures**	**Mean** mg P/ l	**Median** mg P/ l	**n**	n with index ≥3
0	LS,S	17.5	17.5 (2-)	*2*	
1	SL, SZL	15.7	9.4 (0+)	*63*	
2	SCL, mCL (mZCL)	12.0	7.6 (0+)	*66*	
3	hCL, hZCL	8.0	6.7 (0+)	*36*	
4	ZC, C	5.8	6.5 (0+)	*4*	

Highly significant : Class 1 > 2 > 3 ($P < 0.001$). Possible difference 3 > 4 ($P = 0.12$).

For **woodland –** sandy and peaty soils tend to higher P but there are small differences between other textures (Table 7d).

Table 7d Region B: Woodland Topsoil Texture and Phosphorus

Class	Textures	Mean mg P/ l	Median mg P/ l	n	n with index ≥3
0	LS,S	31	30 (3-)	*8*	
1	SL, SZL	18.7	12.0 (1)	*15*	*1*
2	SCL, mCL (mZCL)	12.7	12 (1)	*12*	*2*
3	hCL, hZCL	17.3	16 (2-)	*8*	*1*
4	ZC, C	12	12 (1)	*2*	
P	Peaty loam	24	24 (2+)	*2*	

Significant : Class 0 > 1 (*P* = 0.05). Possible Class 1 > 2 (*P* = 0.12).

4.3 Factors influencing phosphorus levels in subsoil

Multiple regression indicates that subsoil P is very strongly correlated with topsoil phosphorous (*P* = 0.8 in all cases). When data was plotted by corer and auger method there was a difference in intercept. This is typically about 2 mg/l rising to 5 mg/l on high P soils (Appendix 11.2).
There seems a consistent negative relationship of subsoil P with subsoil texture Class (overall *P* = 0.3).

There are positive relationships of subsoil P with subsoil OM% (*P* 0.1-0.4) which may be linked to sampling method.

On no data group could a meaningful correlation be found between subsoil pH and phosphorus. As Figure 3 shows, very low subsoil P can occur across the range of pH

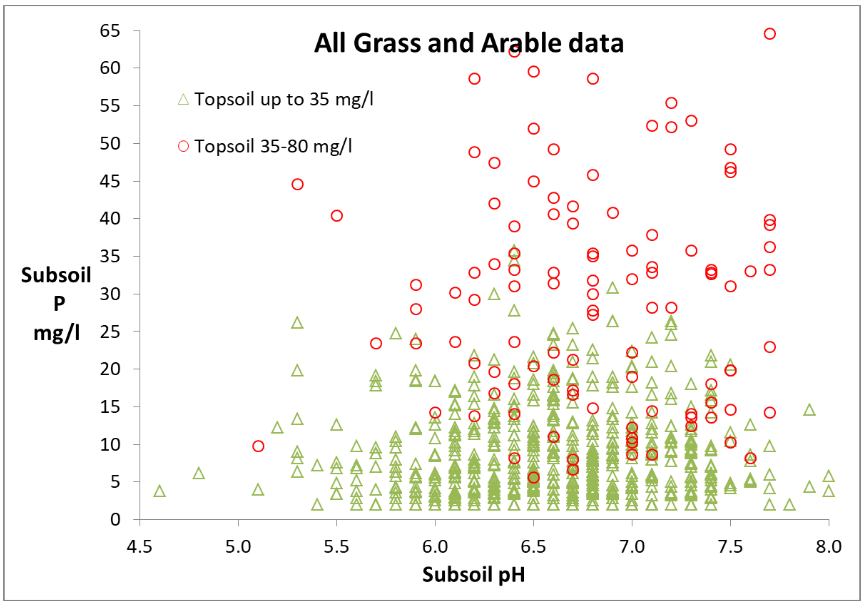


Figure 3: Region B : Subsoil pH and phosphorus

It would be expected that enhanced iron (haematite) in redder soils will absorb P more strongly. Redness is assessed in Table 8. Though there is no *overall* statistical correlation it suggests that strong and reddish brown subsoils tend to higher P levels than either non-red or the reddest soils

Table 8: Region B: Soil Colour and Phosphorus Median mg P/l values for Arable+Grass whole data.

Munsell Colours	**Topsoil** Sand-Medium	**Topsoil** Heavier	**Subsoil** Sand-Medium	**Subsoil** Heavier	***n***
0 10YR etc (brown,grey)	18.1	10.2	7.0	5.8	*138,31,91,84*
1 7.5YR (strong brown)	17.8	16.3	9.0	14.8	*327.52,143,102*
2 5YR (reddish-brown)	22.2	14.0	8.6	8.4	*115,25,122,105*
3 2.5YR (red)	5.9	7.6	5.0	7.0	*30,5,27,39*

Evaluation of influence of subsoil texture on subsoil P

This is examined in several graphs shown below on the Whole Data set (796)

The arable data of lighter topsoils (Figure 4a) exhibits a "change point" at about 35 mg P/l in topsoil (mid index 3). From 35-70 mg P/l the subsoil P rises sharply at about 80% the increase in topsoil P. Below 35 mg/l subsoil is about half topsoil P, possibly less on heavier subsoils.

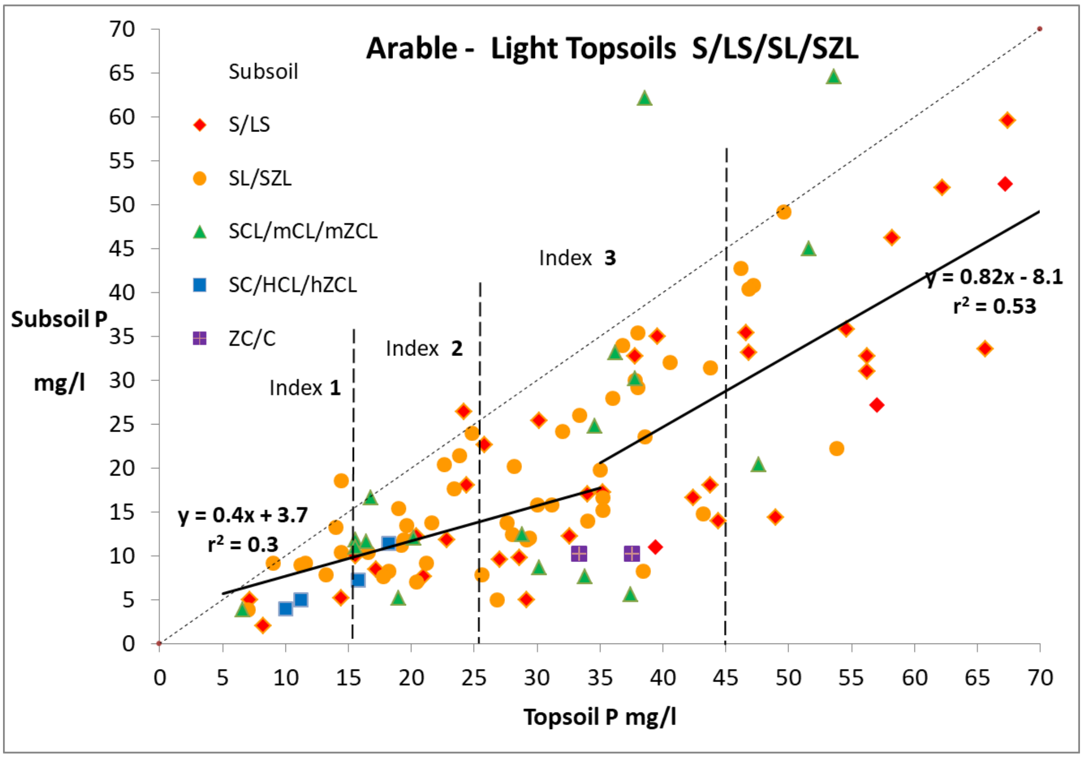


Figure 4a: Region B, Arable: P in Topsoil and Subsoil - sandy and light loam topsoils

Data for medium to heavy-textured topsoils is in Figure 4b. There are relatively few values in index 4 but the subsoil P again rises sharply above 35 mg P/l in topsoil Up to 35 mg P/l subsoil P is slightly less than half the topsoil P and slightly for heavier than medium subsoils.

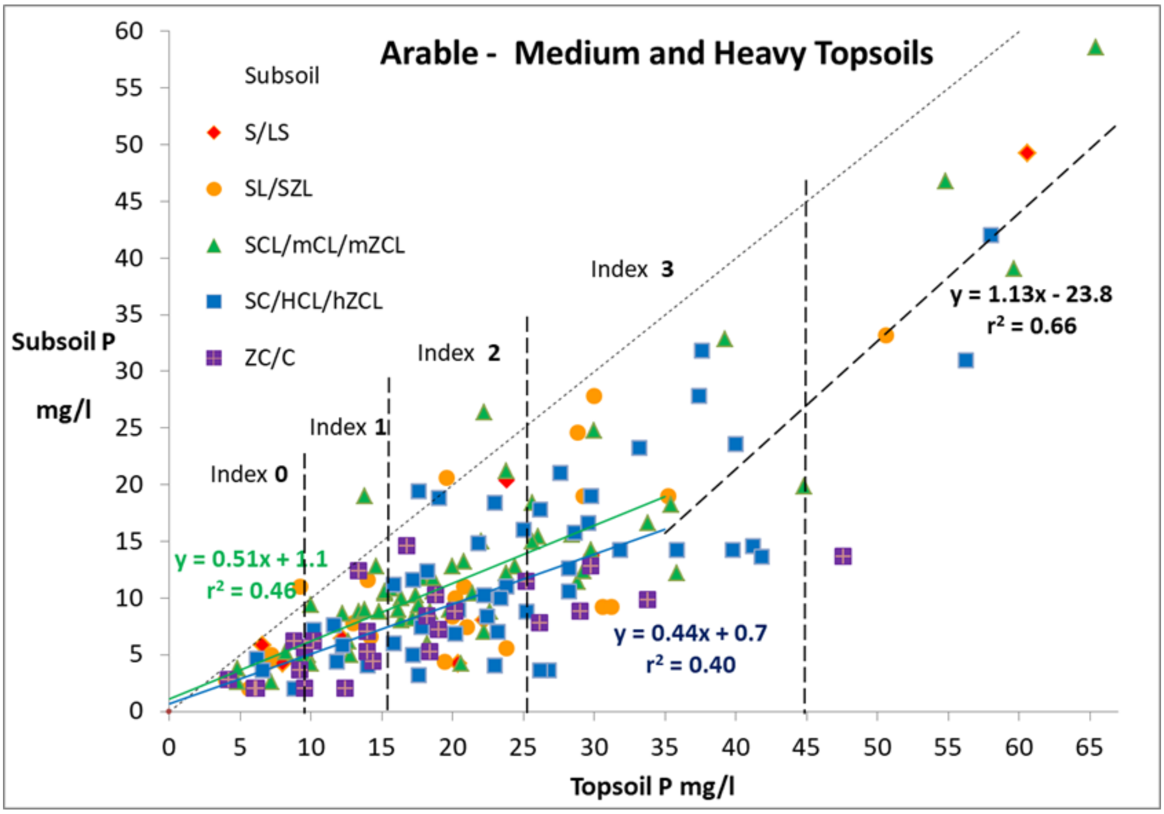


Figure 4b. Region B, Arable : P in Topsoil and Subsoil – Medium and Heavy topsoil. Green line is for subsoil textures S-mCL, blue for heavier subsoils, hCL-C.

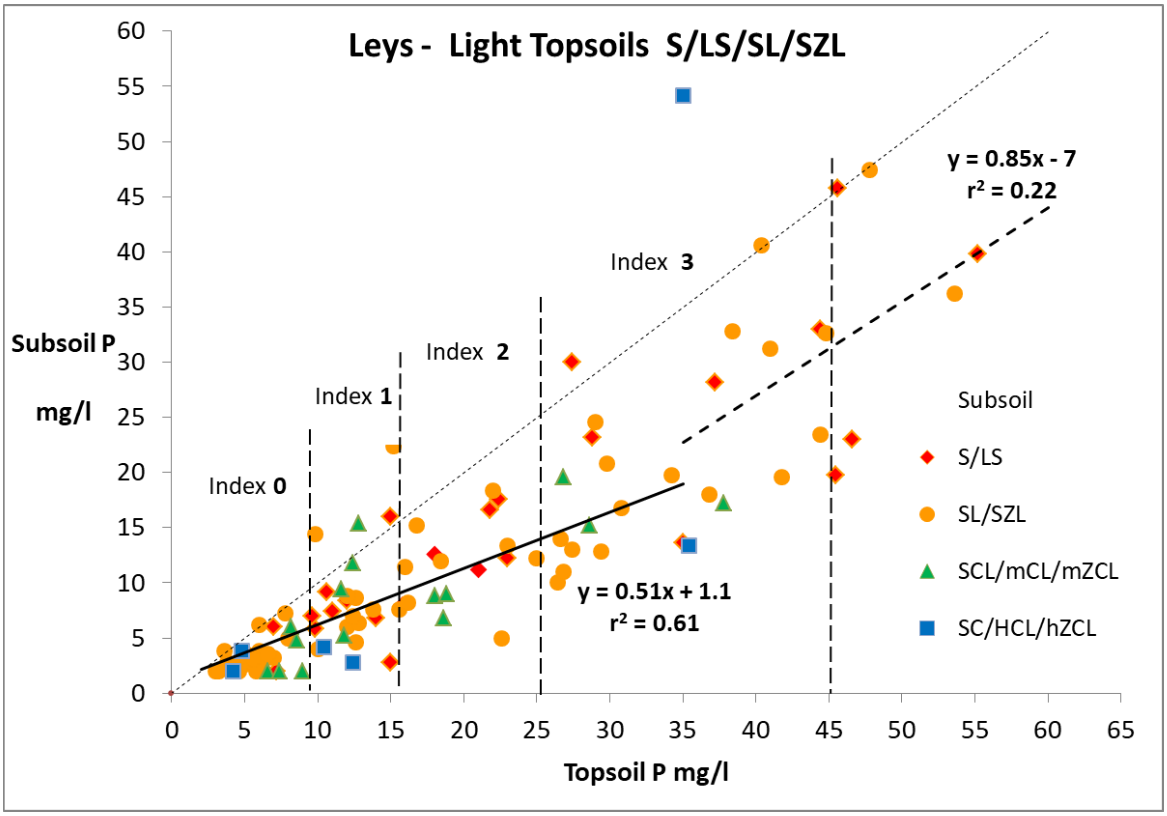


Figure 5a: Region B, Leys: P in Topsoil and Subsoil - sandy and light loam topsoils

For grass leys, lighter soils have very similar topsoil:subsoil relationships to arable data set. Though containing fewer high samples a change point at 35 mg/l P looks likely (Figure 5a).

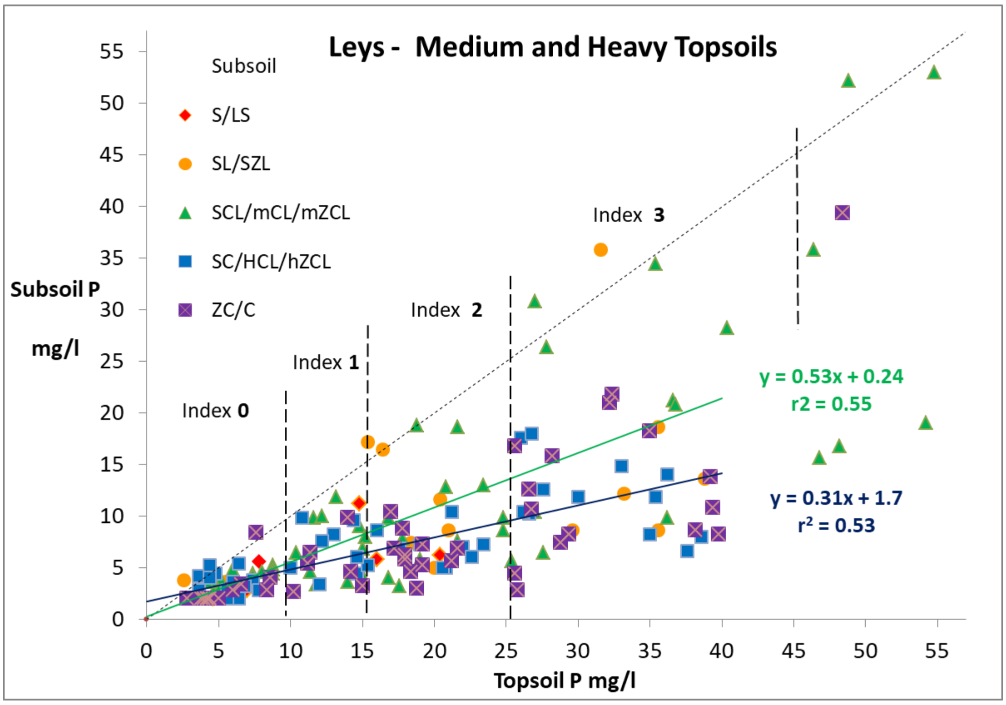


Figure 5b. Region B, Leys : P in Topsoil and Subsoil – Medium and Heavy topsoil. Green line is for subsoil textures S-mCL, blue for heavier subsoils, hCL-C.

For grass leys, medium and heavy topsoil (Figure 5b) the change point might be somewhat higher (40 mg/l. Sandy to medium subsoils give an identical plot to the arable data but stronger indication under grass that subsoil P is proportionately less in heavier subsoil.

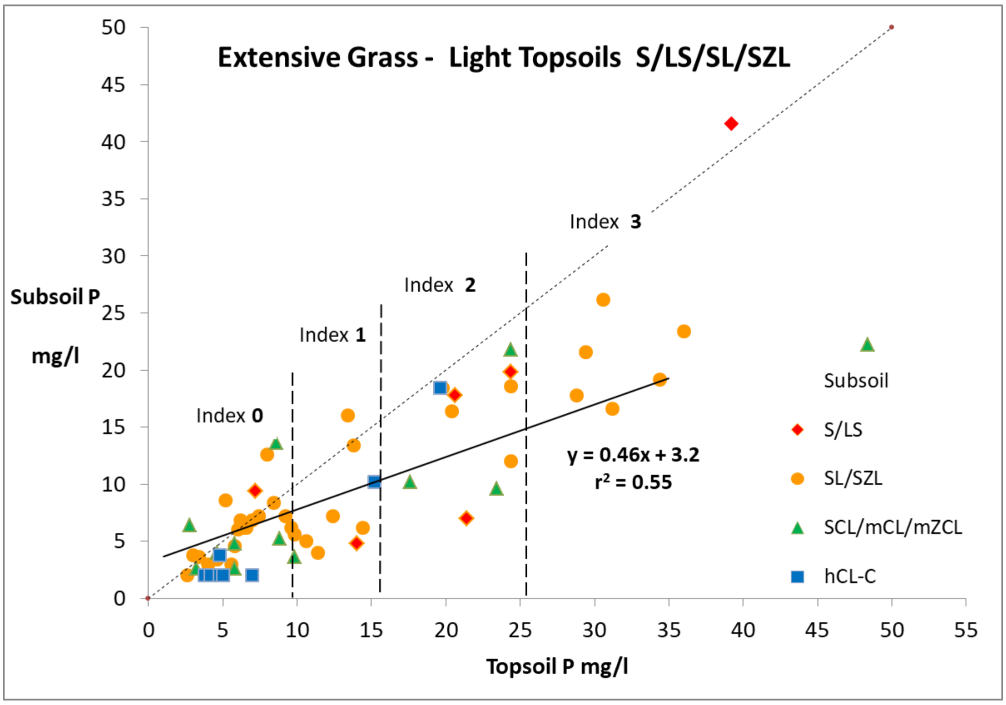


Figure 6a: Region B, Extensive and Amenity Grassland : P in Topsoil and Subsoil - sandy and light loam topsoils

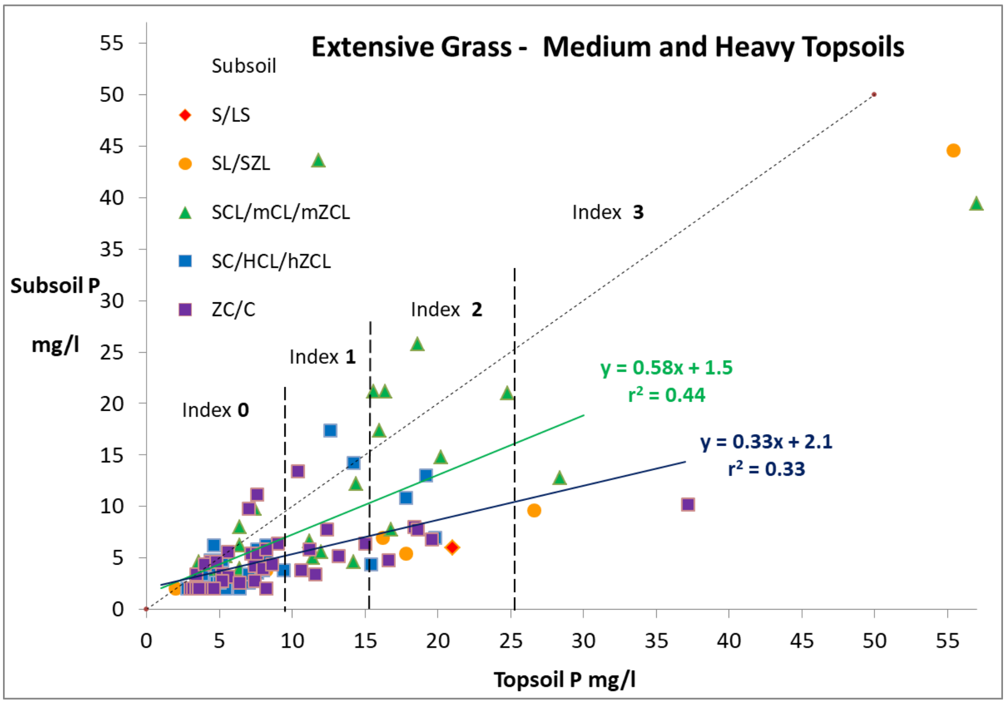


Figure 6b. Region B, Extensive and Amenity Grassland: P in Topsoil and Subsoil – medium and heavy topsoil. Green line is subsoil textures S-mCL, blue is heavier subsoils, hCL-C.

For extensive and amenity grassland, the correlations (Figures 6a and 6b) are very similar to the grass leys. r^2 is worse because of a significant minority of samples with higher P in the subsoil than topsoil.

Subsoil P > topsoil P was found in only 8 cases on arable land, 10 on leys and 20 in extensive grassland. 8 cases were disturbed profiles, 8 cases on Alluvium (layered deposit), and in 9 cases the subsoil was significantly stonier than the topsoil.

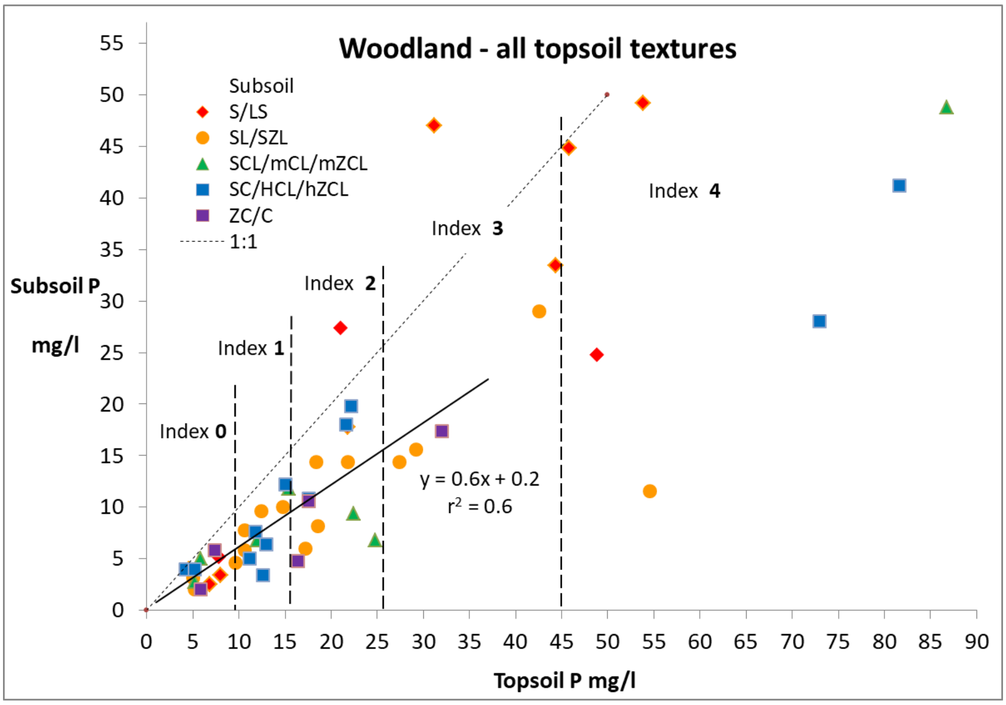


Figure 7. Region B, Woodland: Phosphorus in Topsoil and Subsoil – all topsoil textures.

The Woodland data (Figure 7) shows good correlation up to 35 mg/l P in topsoil with proportionately more P in subsoil than grass or arable data sets (factor 0.6). Some woodland can have extremely high P levels for reasons that are unclear. One point (not shown) had 206 mg P/l in topsoil and 154 mg/l in the clay subsoil beneath.

4.4 Prediction of phosphorus in subsoil

The main determinant is topsoil P and the secondarily subsoil texture class: heavy loam and clayey subsoils consistently show proportionately lower subsoil P in Figures 3 to 6. From the similarity of the fitted lines, arable versus grass does not seem to significantly affect the relationship although levels in topsoil and subsoil tend to be higher on arable fields than leys than extensive grass, and the higher soil P levels occur chiefly on sandy or light loam textured horizons.

On lighter soils there is a clear change point at about 35 mg/l above which subsoil P rises sharply with topsoil P. On medium and heavier soils the change point may be slightly greater (40 mg/l).

To produce an overall correlation data arable and grass were combined and disturbed land was excluded, giving a unified data set of 722 samples which were subdivided for topsoil P up to 35 mg/l or 36-80 mg/l. In Figure 8a the plots are identical for sandy, light loam or medium subsoil texture, but heavier subsoils fit to plots of lower slope.

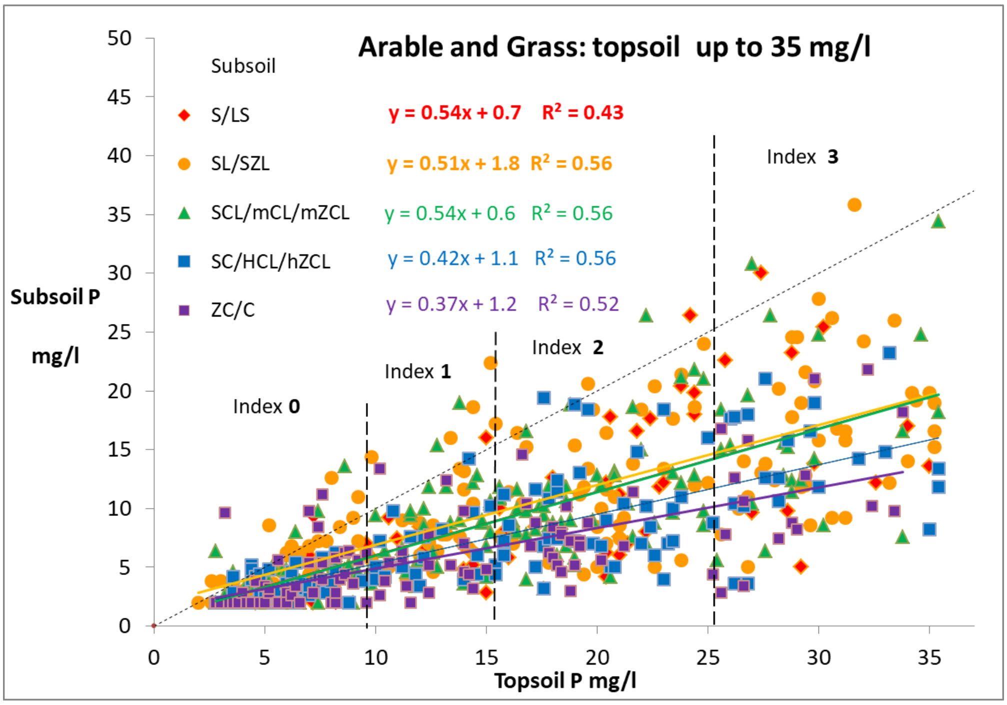


Figure 8a Region B, Combined data – arable and grass: Phosphorus in Topsoil and Subsoil.

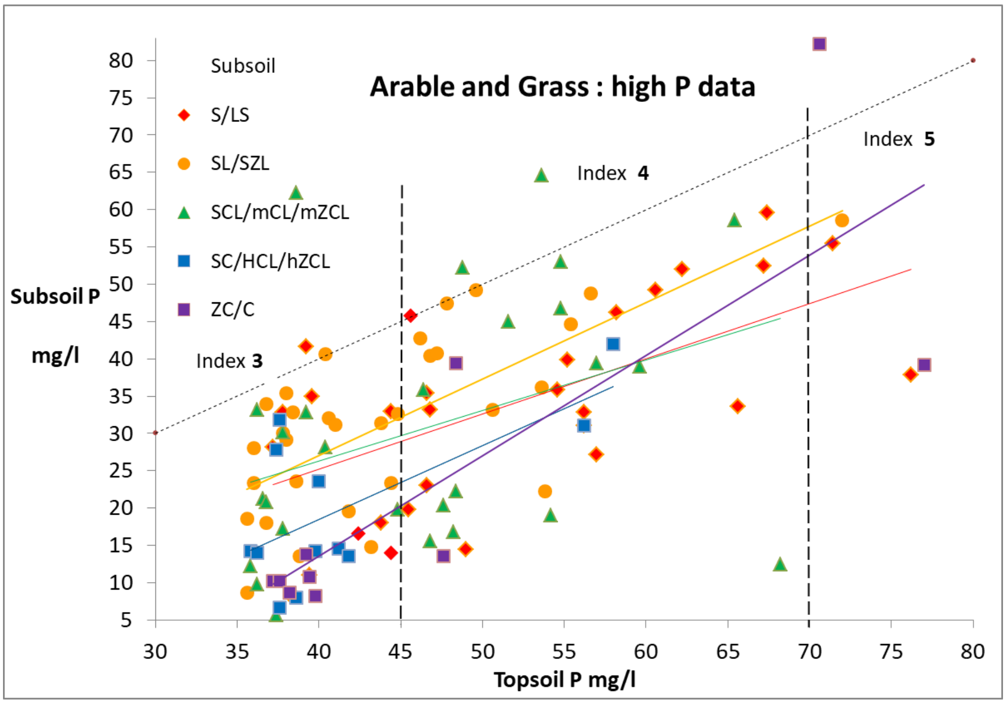


Figure 8b Region B, Combined data – arable and grass: Topsoil Phosphorus 35-80 mg/l. There a few data >80 mg/l (not shown) for which subsoil P varied from 40-110 mg/l.

The unified data for high P soils (Figure 8b) confirms there is no distinguishable difference for subsoil textures sand to medium, though for heavier loams and clays the change-point to steeper slope might be nearer 40 mg/ topsoil P.

Regression analysis confirms that over normal P range corer method averaged 2 mg P/l greater than auger method, increasing to 5-8 mg/l difference on the higher P samples (Appendix 11.3).

When subsoil OM% is included in the regression it improves r^2 in all cases. For sandy to medium soils each 1% increase in subsoil OM (up to 6%) is associated with a 1.2-1.5 mg/l increase in subsoil P.

For heavier soils the OM effect is less marked at normal topsoil P (up to 35 mg/l) but substantial at high index (up to 10 mg/l P per 1.0% increase in OM). On all textures woodland showed 1.7 mg P/l increase per 1% OM.

The above effects in part may be because subsoil OM% is affected by the sampling method where the corer can include material in transitional horizons between topsoil and 'pure' subsoil horizons (see Section 6).

A series of regression equations are produced (Appendix 11.4), summarised below.

a) is up to 35 mg P / l in topsoil (mid index 3), b) is 36-80 mg/l (up to low 5).

Sandy, light loam and medium subsoil

*a) Subsoil P = Topsoil P * 0.52 + 1.1* $r^2 = 0.54$
*b) Subsoil P = Topsoil P * 0.75 - 3.6* $r^2 = 0.28$

*a) Subsoil P = Topsoil P * 0.53 + Subsoil OM * 1.2 - 1.2* $r^2 = 0.58$

*b) Subsoil P = Topsoil P * 0.74 + Subsoil OM * 1.5 - 6.6* $r^2 = 0.30$

Heavy loam subsoils (SC, hCL, hZCL)
a) Subsoil P = Topsoil P x 0.42 + 1.1 $r^2 = 0.56$
b) Subsoil P = Topsoil P x 1..21 – 32 $r^2 = 0.60$

a) Subsoil P = Topsoil P x 0.43 + Subsoil OM x 0.7 - 0.4 $r^2 = 0.58$
b) Subsoil P = Topsoil P x 1..05 + Subsoil OM x 9.7 – 44 $r^2 = 0.85$

Clay subsoil (ZC, C)
a) Subsoil P = Topsoil P x 0.37 + 1.2 $r^2 = 0.52$
b) Subsoil P = Topsoil P x 1..21 – 32 $r^2 = 0.60$

a) Subsoil P = Topsoil P x 0.36 + Subsoil OM x 0.15 + 0.8 $r^2 = 0.54$
b) Subsoil P = Topsoil P x 1.07 + Subsoil OM x 9.7 – 44 $r^2 = 0.85$

Woodland (any texture and P level)
Subsoil P = Topsoil P x 0.60 + 0.2 $r^2 = 0.60$
Subsoil P = Topsoil P x 0.50 + Subsoil OM% x 1.74 - 2.0 $r^2 = 0.73$

Typical subsoil P that might be expected is shown in table 5. If subsoil texture is known the topsoil P can account for about 56% of the variation in subsoil P (r^2 0.56) and subsoil OM a further 20%.

However there is still significant uncertainty especially on higher P soils.

4.5 Agronomic Summary: phosphorus levels on red soils of the Midlands

Indices are in parenthesis and for this report divided in lower and upper halves (+/-).

The balanced data base shows median topsoil values for arable data of 23 mg/l (index 2+) > leys, amenity grass, woodland 17-18 mg/l (2-) >> extensive grassland 8 mg/l (0+).

However (as national surveys find) there is large range: 24% of arable soils below target index (2) and 14% index 4. 47% of leys and most extensive grassland were below target index, though based on a greater topsoil sampling depth (20cm-30cm) than is conventionally used (7.5-15cm). The latter might register higher values in cases were P inputs have been concentrated on the surface.
Topsoil P levels were significantly higher on lighter land for arable and extensive grassland though on leys were even across all textures. In woodland P levels were higher on sandy and peaty soils. There was no correlation with topsoil pH.

Subsoil medians were arable 12 mg/l (1) > amenity grass, woodland 10 mg/l (1) > leys 8 mg/l (0+) > extensive grassland 5 mg/l (0-).

38, 47, 48, 60 and 77% respectively of subsoils were index 0. 10% of ley and 15% of extensive grass subsoils were below laboratory detection limit (2.5 mg P/l).

38, 20, 30, 23 and 14 % respectively of subsoils were index 2 or above.

Multiple regression analysis indicates that subsoil P very strongly related to topsoil phosphorous (P = 0.8). There are lesser correlations with subsoil potassium (P = 0.5) , subsoil texture, subsoil organic matter and sampling method – samples taken by corer averaged ~ 2 mg/l more P in the subsoil than auger method, rising to a 5 mg/l difference on high P soils.

There is correlation of subsoil P with subsoil OM% and the latter also is greater by the corer method. There is no correlation of subsoil P with subsoil pH.

The reddest soils (2.5YR) showed a slight reduction in P levels and the slightly reddened soils (7.5YR) were highest, but the differences are not statistically significant.

56% of the difference in subsoil P can be accounted for by topsoil P adjusted for subsoil texture and a further 20% if subsoil OM is known. There is a distinction change point above 35 mg P/l on light and medium topsoil above which the subsoil P rises more quickly. A similar effect occurs on heavier land above about 40 mg/l though more unpredictable.

Table 5: Prediction of Subsoil Phosphorus (arable or grassland).
Range values correspond to subsoil OM 1.0 to 4.5%.

Class	Topsoil Texture	Regression Equation based on	at Topsoil P mg/l **10**	**20**	**30**	**45**	**70**
0-2	LS to mZCL	Topsoil P only	6	12	17	30	49
		Topsoil P and subsoil OM%	5-9	11-15	16-20	29-32	48-51
3	hCL/hZCL	Topsoil P only	5	10	14	22	53
		Topsoil P and subsoil OM%	5-7	9-11	13-16	14-48	41-75
4	C/ZC	Topsoil P only	5	9	12	22	53
		Topsoil P and subsoil OM%	5	8 – 9	12-13	14-48	41-75
0-4	All woodland	Topsoil P only	6	12	18	27	42
		Topsoil P and subsoil OM%	5-11	10 -16	12-18	22-28	35-41

[Equations are in preceding section.]

Table 5 indicates that heavy loam and clay (or medium-over-clay) upper subsoils have proportionately less P in subsoil than medium or sandy subsoils. At topsoil 20 mg P/l the subsoil (to 50cm) is typically 12 (1) for sandy, light and medium loamy soils and 9 mg/l (0+) for clay subsoils. Results by corer method are about 1 mg/l higher and auger 1mg/l lower than shown, and almost certainly there is a decline in P with depth within the upper subsoil to 50cm which gets averaged out in any sample taken.

Each increase of 1% organic matter in the subsoil up to 6% corresponds to an increase in subsoil P of 1.1 mg P/l on soils up to 35 mg P/l, with bigger effect on high P heavier soils.

Higher subsoil OM is due to carry-down of topsoil material by earthworms or deep ploughing or deep rooting. Reasons for proportionately less P in heavy subsoils include less earthworms, less rooting, less translocation of P in soluble organic and inorganic forms from topsoil and increased retention capacity so less is 'available' in the soil test. The data showed no distinction between sandy and medium subsoils (S – mCL texture).

Natural soils under woodland or amenity grassland have higher subsoil P levels than extensive grassland or the more intensively managed leys. This suggests that productive utilisation of grassland may lead to a *decline* in subsoil P rather than enrichment (as is commonly supposed).

The higher subsoil levels in arable soils are linked to predominance of lighter textures. Once topsoil exceeds 35 mg/l, subsoil will be index 2. At topsoil index 4 (>45 mg P/l) the subsoil is likely to be index 3 on all but heaviest subsoils.

There is an economic case to curtail agricultural phosphorus inputs to run-down soils which are above 35 mg P/l (mid 3). Assuming such soils are not subject to run-off, the environmental case is less clear a) because downwards movement of P in lighter undrained soils is not a problem and b) on heavier subsoils with underdrains P is absorbed more strongly and levels rarely exceed index 1 provided topsoil P is less than 35 mg/l. However in this data lighter upper subsoils could overlie heavier *lower* subsoils which may be under-drained. See section 1.

The is a case for ensuring all arable and grass soils attain target mid index 2 (20 mg P/) on the grounds that this will ensure subsoil is above P index 0 which will help deep rooting and support grass or crops during times when the top 25cm has dried out.

Subsoil P cannot be predicted satisfactorily from topsoil P on disturbed/ remade land and (layered) alluvial deposits or at very high P index over heavier subsoil. In such cases subsoil should be sampled at same time as topsoil.

5. Potassium

Region B: Central and NW Midlands

5.1 Overview of potassium levels

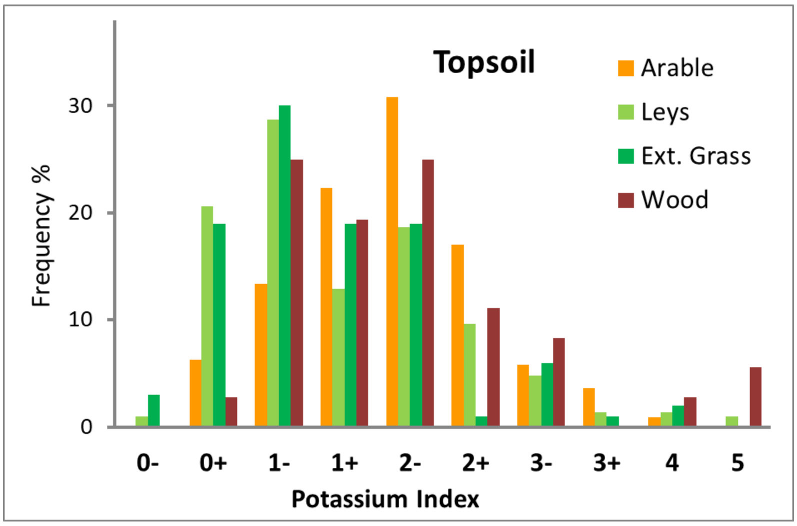


Figure 9a. Region B: Soil available Potassium in Topsoil

Topsoil K

Arable land: K index 2- is considered optimal and is the modal category here (31% of the samples) and the median value (131 mg K/l). 42% of samples are below target and 27% above target of which only 10% are index 3 or higher. The PAAG (2019) national survey showed fewer samples below target (24%).

Grassland: leys have a bimodal pattern with peaks at index 1- and 2-. The median is much lower than arable land at 89 mg/l (mid 1) and 82% of samples lie below target index. Extensive grass has marginally lower K levels (median 84 mg/l) and 90% below target.

The PAAG (2019) survey showed a lower proportion of grassland below target K index (41%) though the results shown are based on a deeper topsoil sample than normally used (0-15cm for leys and 0-7.5cm for long term grass) and some samples were taken during periods of peak growth rate.

Natural: amenity grass tends to higher K levels than other grassland as does woodland, median is 124 mg/l (2-), but with very large range. The implication is that managed grassland is being depleted of potassium in relation to "natural" soils.

Table 6. Region B : Typical Soil Potassium levels (mg/l)

	Topsoil		Upper Subsoil	
	median	**10-90%**	**median**	**10-90%**
Arable	131 (2-)	71-243	101 (1+)	59-185
Leys	89 (1-)	50-227	76 (1-)	38-174
Extensive Grass	84 (1-)	52-179	65 (1-)	43-144
Amenity Grass	98 (1+)	49-185	75 (1-)	41-114
Wood	124 (2-)	73-312	95 (1+)	43-303

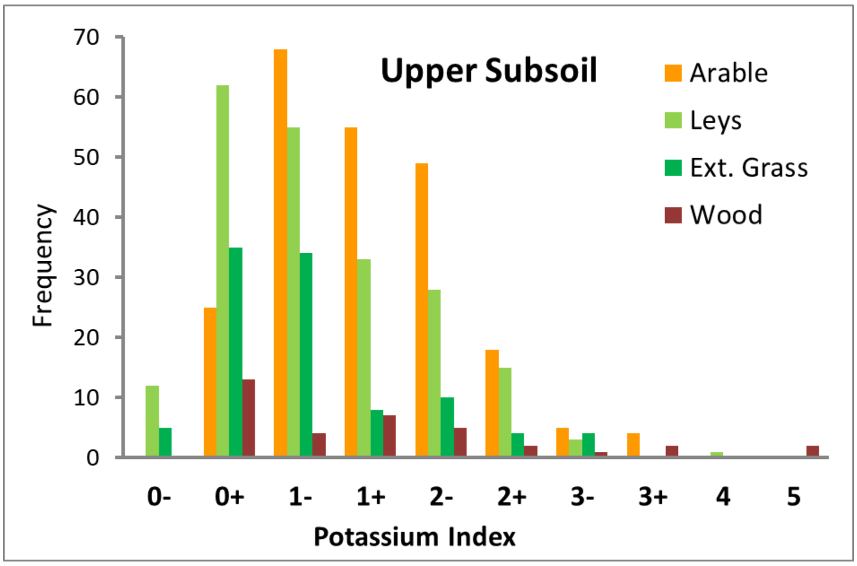


Figure 9b. Region B: Soil available Potassium in Subsoil (Balanced Data)

Subsoil K

Arable land: the median is 101 mg K/l (upper index 1). Few samples were index 0 (11%) or above index 2- (12%).

Grassland: has lower subsoil K than arable land with median of 76 mg/l (1-) for leys and 65 mg K/l for extensive grass. 40% of subsoils were index 0.

Natural: amenity grass is comparable with leys. Woodland tends to higher subsoil K (median 95 mg/l, 1+) but with a large range.

The above trends in soil K levels might be due to co-factors e.g. more arable points were on lighter land, so these are now analysed with whole data set used. Amenity and extensive grass are combined.

5.2 Factors influencing potassium levels in topsoil

Multiple regression analysis (Appendix 11.5) indicates topsoil K strongly related to topsoil phosphorus ($P > 0.5$) and weakly related to topsoil pH ($P = 0.2$). Sampling method was insignificant except on extensive grassland. Topsoil organic matter and topsoil texture had weak influence on K ($P = 0.1$) and there was no relationship with Average Annual Rainfall. On average the topsoil K increases about 25 mg/l with every 1 unit rise in pH (on all texture classes) but low K could occur across the whole range of pH (Figure 10). Leys showed a similar weak trend.

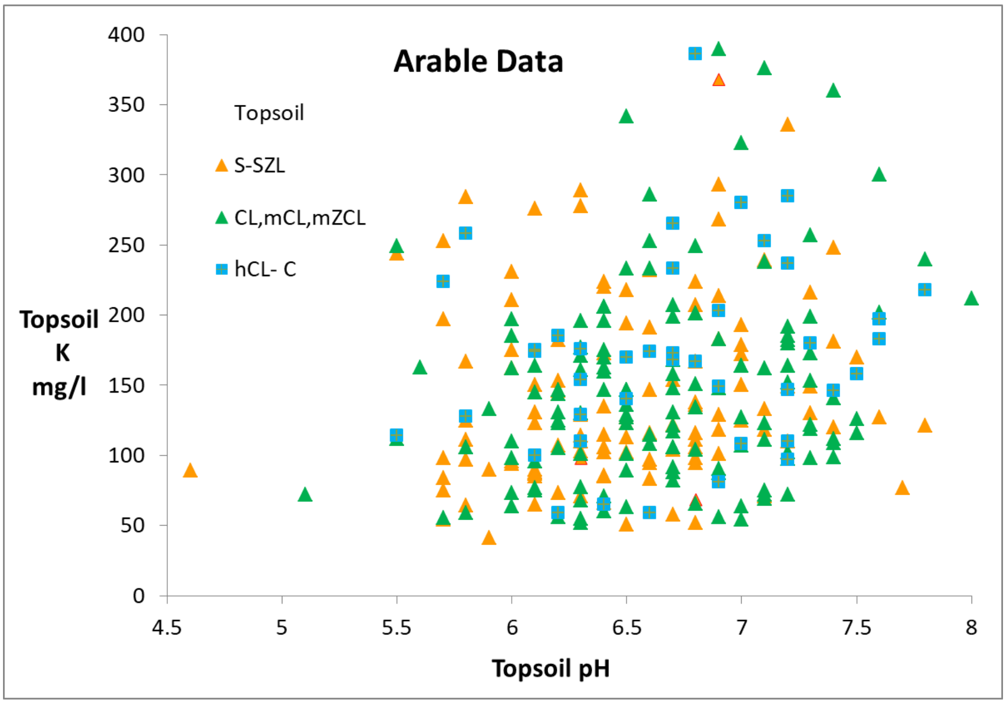


Figure 10: Region B arable data Topsoil pH and Potassium.

Topsoil K and topsoil texture

Texture influence becomes more apparent when categories are isolated

Table 7a Region B: Arable data Topsoil Texture and Potassium

Averages of all data. Index in parenthesis. Maximum value 422 mg K/l.

Class	**Textures**	**Mean** mg K/ l	**Median** mg K/ l	**n**
0	LS,S	211	181 (2+)	*10*
1	SL, SZL	139	122 (2-)	*107*
2	SCL, mCL (mZCL)	148	132 (2-)	*131*
3	hCL, hZCL	168	167 (2-)	*36*
4	ZC, C	199	183 (2+)	*5*

Class 3 > 2 ($P_{twotail}$ = 0.15) and Class 4 > 3 (*P* = 0.20), with an increase of about 25 mg K/l per texture class.

A disproportionate representation of the sandy topsoils were in maize stubble which may account for their high average K level. Otherwise there is a trend of increasing potassium with textual class, especially between medium and heavy loams and clays.

Grass leys show a significant textural influence with K increasing in order light loams medium loams and heavy loams (Table 7b). Extensive Grass, Amenity and Woodland (Tables 7c-7e) show similar trends though not significant at P < 0.2 (80% confidence).

The conclusion is that very sandy topsoils do *not* necessarily have lower K levels than other soils. But the expectation is that potassium levels will be about 10 mg/l higher in medium than light loams, a larger jump to heavier loams (30 mg K/l) with a further small 10 mg/l increase to clays, thus amounting a total texture-induced difference of about 50 mg K/l.

Table 7b Region B: Grass Leys -Topsoil Texture and Potassium

Averages of all data. Index in parenthesis. Five samples excluded 438-1600 mg K/l.

Class	Textures	Mean mg K/ l	Median mg K/ l	*n*
0	LS,S	113	112 (1+)	*8*
1	SL, fSL, SZL	102	77 (1-)	*91*
2	SCL, mCL (mZCL)	117	88 (1-)	*141*
3	hCL, hZCL (SC)	139	131 (2-)	*35*
4	ZC, C	128	130 (2-)	*4*

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.

Possible differences Class 3 > 2 ($P_{two\ tail}$ 0.14) and Class 2 > 1 (*P* 0.11). Large jumps between Class 2 to 3 or 4 (40 mg K/l).

Table 7c Region B: Extensive Grass Topsoil Texture and Potassium

Averages of all data. Index in parenthesis. Maximum value 411 mg K/l.

Class	Textures	Mean mg K/ l	Median mg K/ l	*n*
0	LS,S	109	109 (1+)	*2*
1	SL, SZL	104	78 (1-)	*51*
2	SCL, mCL (mZCL)	100	75 (1-)	*62*
3	hCL, hZCL	94	95 (1+)	*34*
4	ZC, C	110	103 (1+)	*4*

No significant differences, though medians suggest a trend of Class 4 > 3 > 2.

Table 7c Region B: Amenity Grass Topsoil Texture and Potassium

Averages of all data. Index in parenthesis. Maximum value 228 mg K/l.

Class	Textures	Mean mg K/ l	Median mg K/ l	*n*
1	SL, SZL	87	75 (1-)	*11*
2	SCL, mCL (mZCL)	104	87 (1-)	*9*
3	SC, hCL, hZCL	116	116 (1+)	*1*

Class 2 > 1 is not significant (*P* = 0.55) given the small size of data set.

Table 7d Region B: Woodland Topsoil Texture and Potassium

Averages of all data. Index in parenthesis. Three data excluded, 485-1001 mg K/l.

Class	Textures	Mean mg K/ l	Median mg K/ l	*n*
0	LS,S	111	96 (1+)	*8*
1	SL, SZL	124	107 (1+)	*16*
2	SCL, mCL (mZCL)	132	99 (1+)	*13*
3	SC, hCL, hZCL	166	125 (2-)	*9*
4	ZC, C	158	158 (2-)	*1*
P	Peaty loam	144	144 (2-)	*2*

Possible difference Class 3 > 2 (*P* = 0.3) with difference in median of 33 mg K/l.

5.3 Factors influencing potassium levels in subsoil

Multiple regression analysis (Appendix 11.5) shows that subsoil K is strongly related to topsoil K (*P* >0.75) and subsoil P (*P* > 0.45), and weakly correlated with subsoil organic matter (*P* = 0.2) and pH (*P* = 0.15). However, the Figures below show major effects of texture on the nature of the topsoil:subsoil K relationship (the slope).

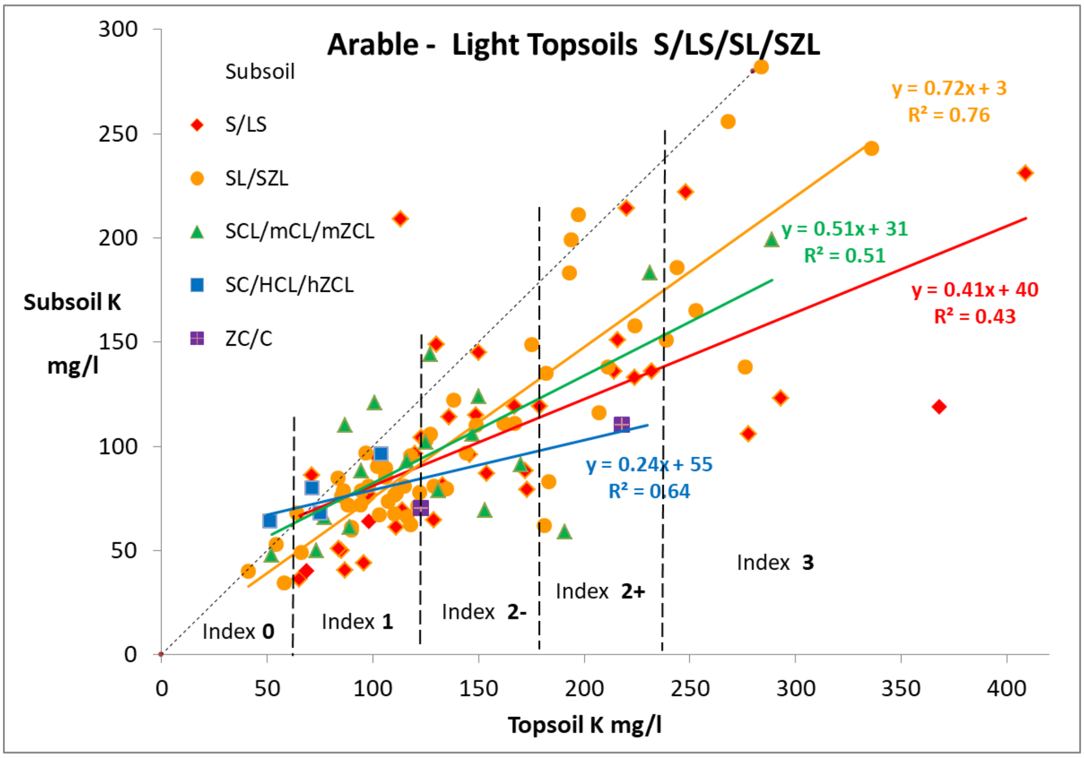


Figure 11a: Region B, Arable: K in Topsoil and Subsoil - sandy and light loam topsoils

Figure 11a isolates data with sandy or light loam topsoil. Where subsoil is light loam there is a strong linear relationship - subsoil K about 0.75x topsoil K. Where subsoil is very sandy a curve fits better (r^2 = 0.47) suggesting that above 120 mg K/l in subsoil it has more difficulty holding onto K. Medium subsoils fit a 0.5 slope with intercept (absolute minimum) of 31 mg/l subsoil K; heavy loams and clays show a diminished 0.25 slope and intercept of 55 mg K/l.

Data for medium topsoils is shown in Figure 11b. Light loam subsoils follow an identical regression line to Figure 11a. Medium subsoils have similar slope with increased intercept. Heavy loam and clay subsoils fit to same regression (combined line is shown) implying 53% slope and an intercept of 37 mg K/l in subsoil. Sandy subsoils show a similar reduced slope probably indicative of increased leachability compared to a medium-textured subsoil.

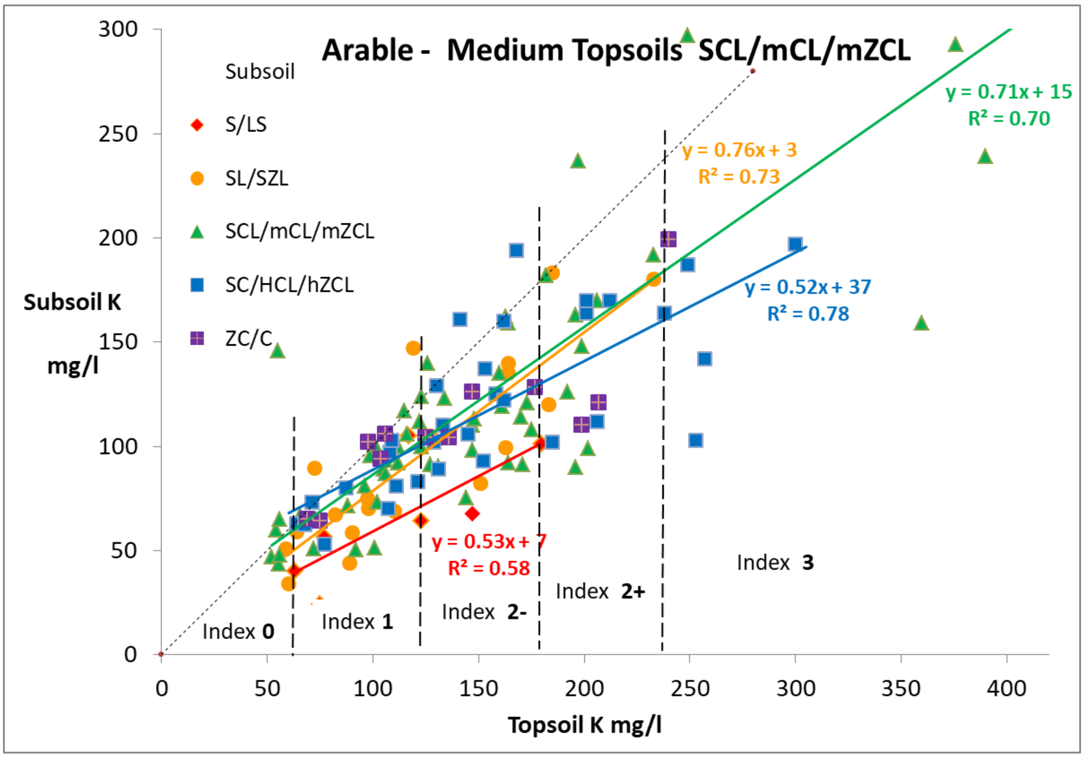


Figure 11b: Region B, Arable: K in Topsoil and Subsoil - medium topsoil (3 outlying data excluded from regressions)

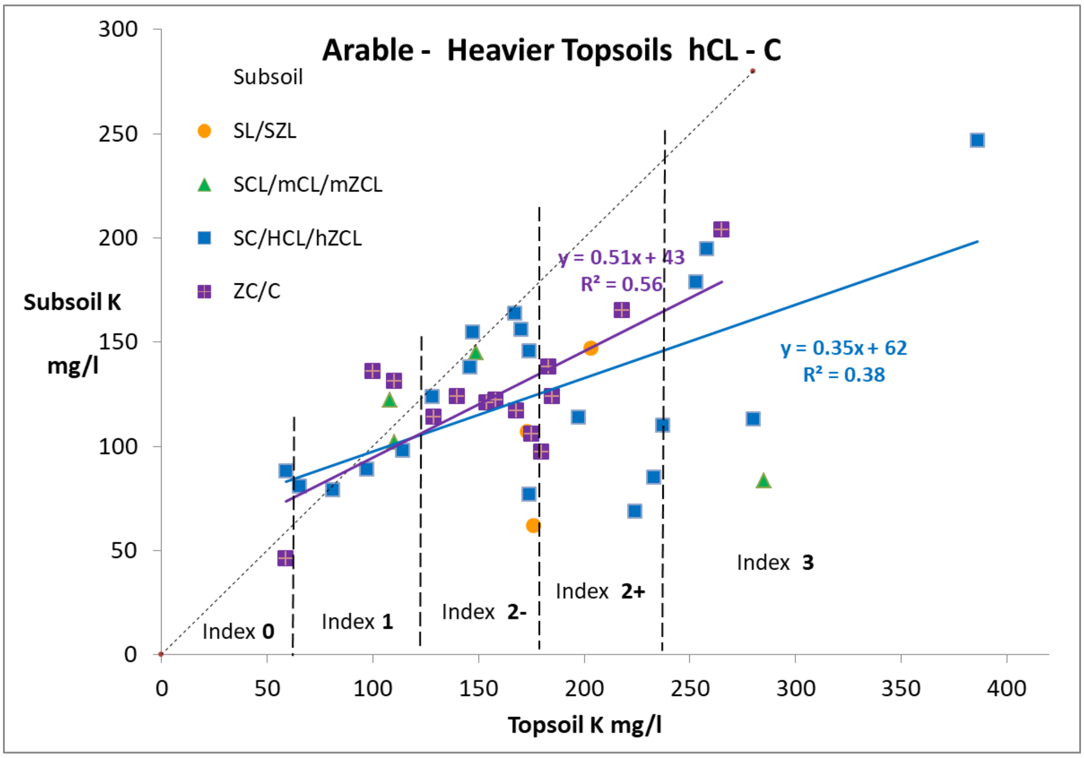


Figure 11c: Region B, Arable: K in Topsoil and Subsoil - heavy loam or clay topsoil

In Figure 11c (data with heavier topsoil) there are relatively few medium or light loam subsoils. Heavy loam and clay subsoils fit to similar plots and overall slope is 0.37 with large intercept of 60 mg/l subsoil K. Only two data were index 0.

The high correlation coefficients of Figures 11a-c indicate that on arable soils the subsoil K can be predicted from the topsoil provided textural differences are taken into account.

- For light loam subsoils subsoil is 75% of topsoil K over a wide range.
- For sand or loamy sand subsoils the subsoil K may be a lower proportion above a critical topsoil level due to high leaching losses.
- For medium subsoils proportion is reduced when topsoil is lighter than subsoil.
- Heavy loam and clay subsoils are indistinguishable but tend to result in a lower proportionate increase (25-52%) but with an intercept of 40-60 mg/l subsoil K implying that this would be present regardless of topsoil K and at 70-90 mg/l in topsoil K the subsoil K is similar.

A more precise calculation is given in next section.

A similar approach is applied to Grass leys in Figures 12a-c

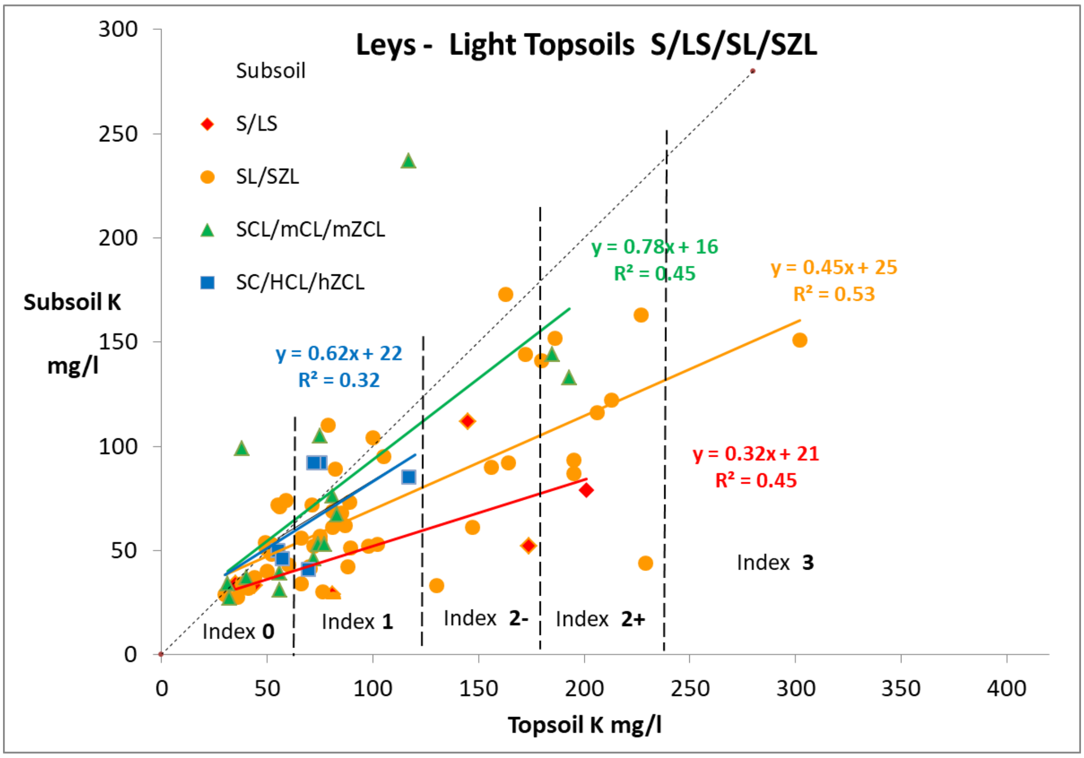


Figure 12a: Region B, Leys: K in Topsoil and Subsoil - sandy and light loam topsoil

For lighter topsoil under leys (Figure 12a) the pattern is different to arable (Figure 11a) in that slope is greatest on medium and heavy subsoils and decreases progressively on light loams and sandy subsoil. All plots have an intercept of about 20 mg K/l. Parity of subsoil K occurs at or below 50 mg/l topsoil K. The difference compared to the arable set may be due to lack of deep cultivation, reducing K transmission to subsoil (and a large number of samples at index 0 for topsoil and subsoil).

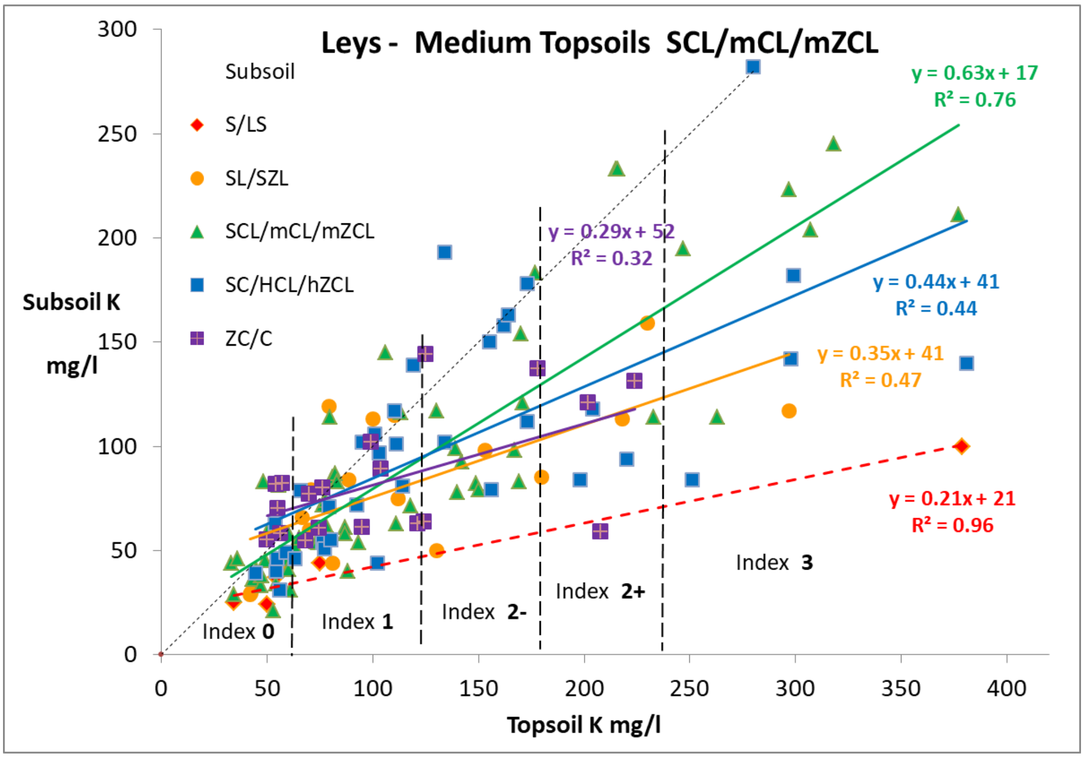


Figure 12b: Leys: K in Topsoil and Subsoil - Medium topsoil. (3 very high points omitted).

Leys with medium topsoil (Figure 12b) give similar plots to lighter data (Figure 12a); subsoil K tends to be lowest on light loam and sandy textures.

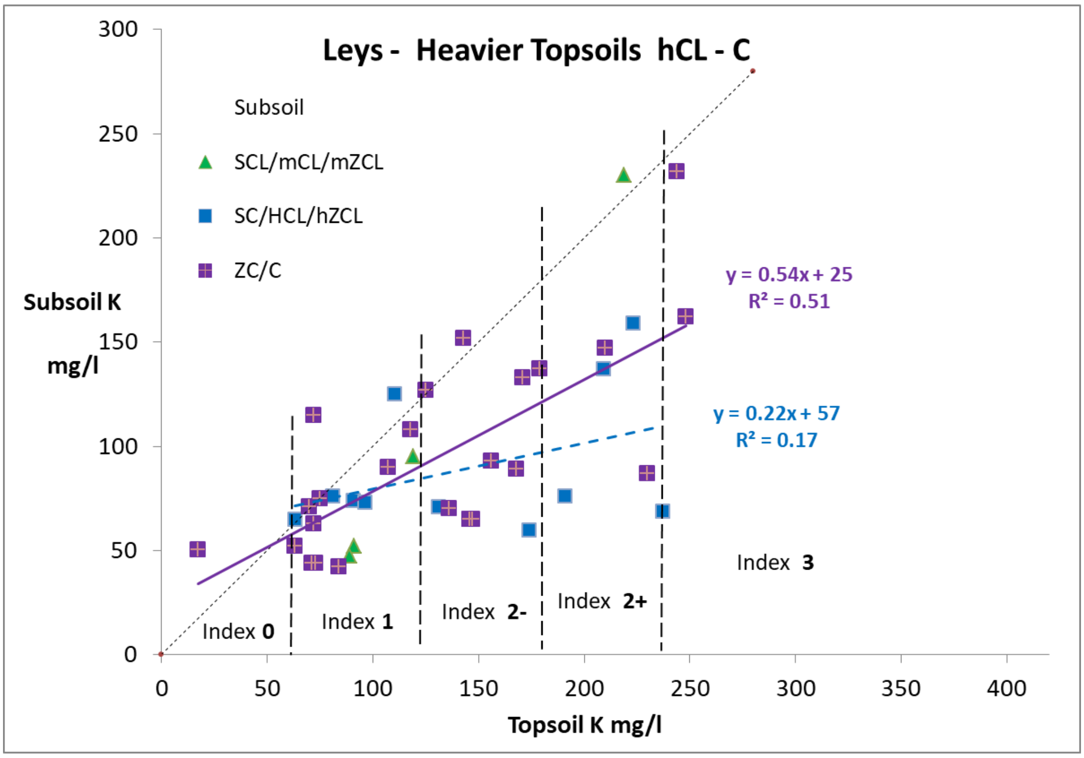


Figure 12c: Region B, Leys: K in Topsoil and Subsoil - Heavier topsoil.

In Figure 12c the heavy loam subsoils have a poor correlation. When combined with clay subsoils the overall slope is 0.43 (similar to arable Figure 11c) but with a lower intercept of 35 mg/l subsoil K (r^2 = 0.39). Only one topsoil was index 0 (on alluvium).

It seems leys behave differently to arable soils especially lighter textures.

Plots are also compared for extensive grass below.

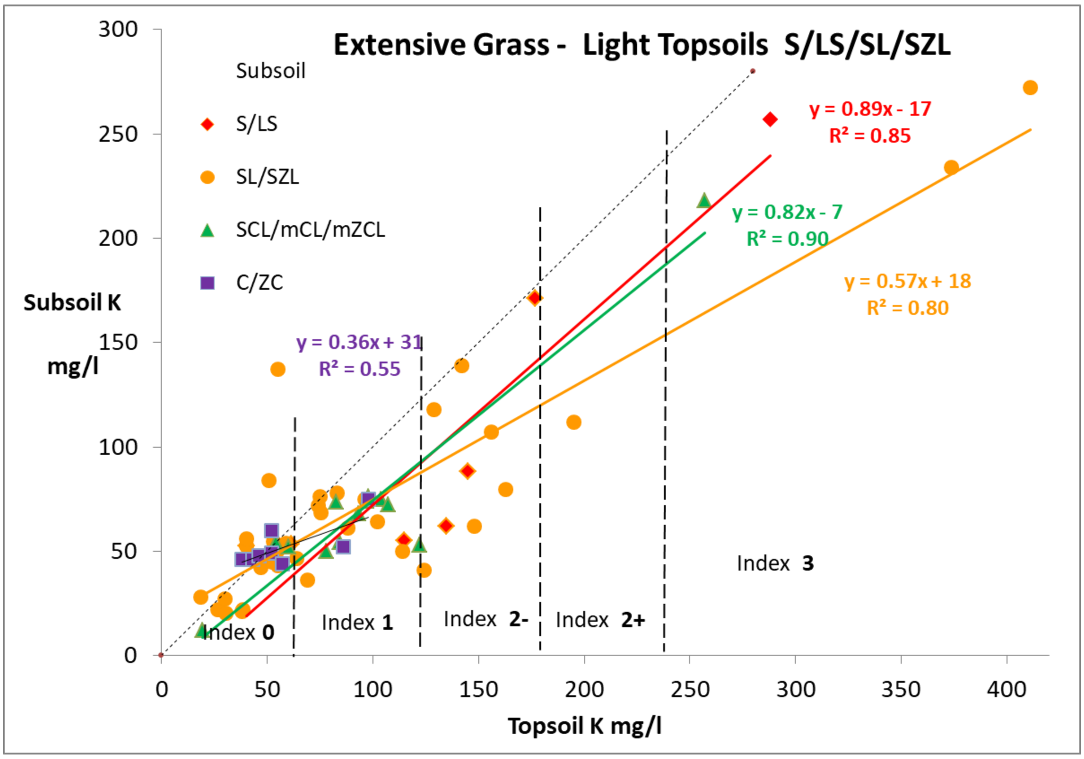


Figure 13a: Region B, Extensive and Amenity Grassland: K in Topsoil and Subsoil - sandy or light loam topsoil.

Under extensive grass on lighter topsoils, the slope of line decreased from light loam to medium to heavy subsoils, similar to plots for leys (Figure 12a) whereas sandy subsoils show a steeper line.

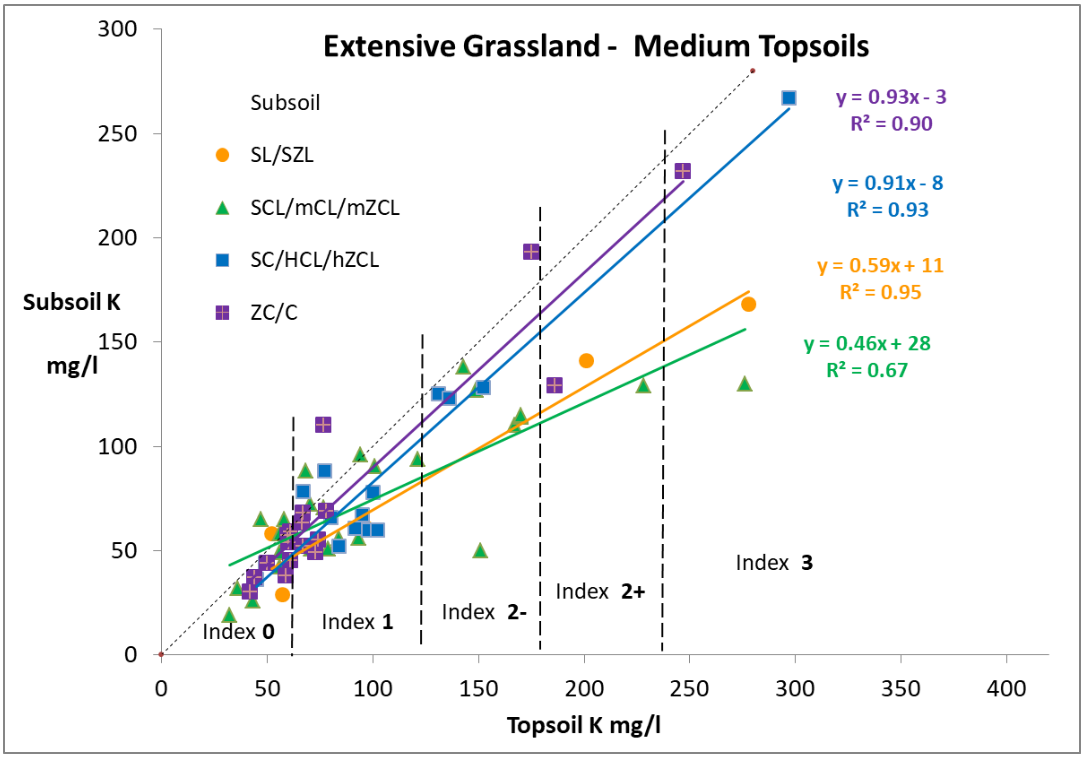


Figure 13b: Extensive and Amenity Grassland: K in Topsoil and Subsoil – medium topsoil.

In Figure 13b the unusual almost 1:1 relationship on heavy loam subsoils may be due to inclusion of samples with high organic matter or stony subsoil. And the majority of clay subsoils here were alluvial soils.

Medium and light loam subsoils are not too different to leys (Figure 12b).

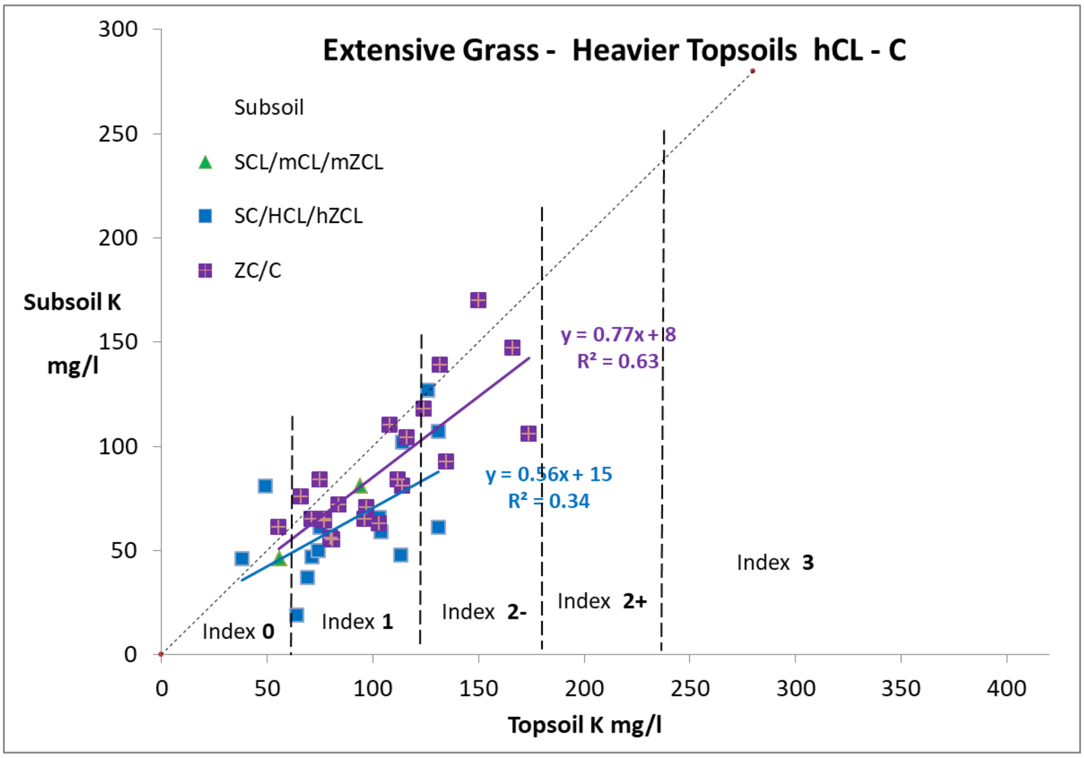
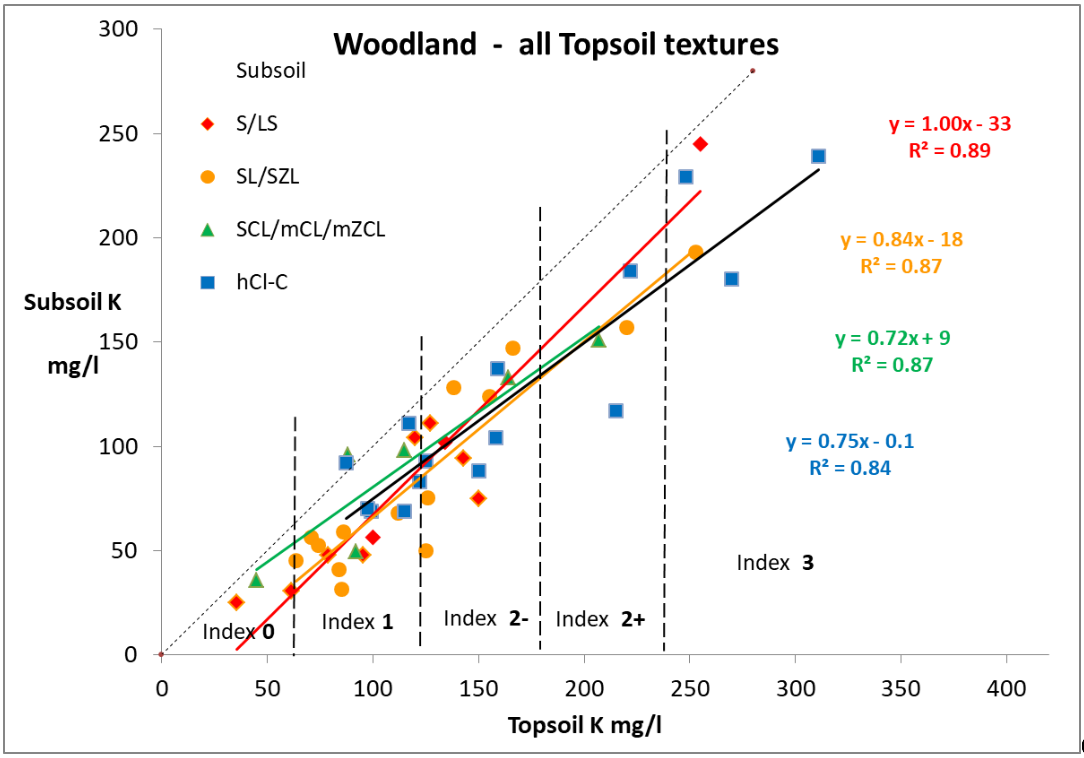


Figure 13c: Extensive and Amenity Grass: K in Topsoil and Subsoil - Heavier topsoil.

Figure 13c also contains a high representation of alluvial soils and disturbed soils, implying closer correspondence of subsoil and topsoil K.



d.

Figure 14: Region B, Woodland: K in Topsoil and Subsoil. 3 data omitted (485-1001mg/l)

Under woodland there is very strong relationship and about 0.8 the topsoil K is registered in subsoil over the range of textures. This suggests greater equilibration has occurred than under arable or grassland where potassium inputs to the topsoil in fertiliser and manures and offtakes in crops and grass can cause relatively rapid changes in the topsoil K.

5.4 Prediction of subsoil potassium

The graphs beforehand suggest a difference between arable and grassland sites, and different relationship according to subsoil texture. Topsoil texture is of minor importance and is discounted for modeelling purposes.

In the arable data points above topsoil K of 300 mg/l (240 for sandy subsoils) are excluded to avoid disproportionate weighting of the correlation by higher points. (And they represent cases where deficiency of K in subsoil is extremely unlikely and not of agronomic concern).

For grassland, leys, extensive grassland and amenity were combined. Soils on alluvium were excluded and all data with topsoil K exceeding 240 mg K/l.

Co-factors

Regression analysis indicated that sampling method could have an influence with a small (~9 mg/l) increase in subsoil K by corer data compared to auger for arable and 5 mg/l increase under grass.

Inclusion of measured subsoil OM% improved the correlation on arable land, especially on lighter soils, but on grassland it had a weak influence which turned negative on the heavier subsoil textures.

On arable data for sandy to medium subsoils an increase of one stone category (about 10% by volume) was associated with a 9 mg/l increase in subsoil K (or 7.5 mg/l per stone class plus 7 mg/l per 1% subsoil OM). However, on heavier subsoils and alluvium light to medium textures increased subsoil stoniness corresponded with a reduction in subsoil K.

A series of regression equations are produced for arable (A) and grassland (G) in Appendix 11.6 and 11.7 and are summarised below and used to give predicted values in Table 8.

Sand or loamy sand upper subsoil
A. Subsoil K = Topsoil K x 0.64 + 9 $r^2 = 0.48$
A. Subsoil K = Topsoil K x 0.57 + Subsoil OM% x 9.1 + 1 $r^2 = 0.52$
A. Subsoil K = Topsoil K x 0.65 + Subsoil stone class x 10.5 - 3 $r^2 = 0.52$
G. Subsoil K = Topsoil K x 0.58 + 8 $r^2 = 0.65$

Light loam upper subsoil
A. Subsoil K = Topsoil K x 0.71 + 4 $r^2 = 0.70$
A. Subsoil K = Topsoil K x 0.71 + Subsoil OM% x 7.9 - 9 $r^2 = 0.72$
A. Subsoil K = Topsoil K x 0.71 + Subsoil stone class x 8.9 - 5 $r^2 = 0.72$
G. Subsoil K = Topsoil K x 0.48 + 23 $r^2 = 0.53$

Medium upper subsoil
A. Subsoil K = Topsoil K x 0.69 + 15 $r^2 = 0.54$
A. Subsoil K = Topsoil K x 0.69 + Subsoil OM% x 6.1 + 4 $r^2 = 0.54$
A. Subsoil K = Topsoil K x 0.69 + Subsoil stone class x 8.5 + 7 $r^2 = 0.55$
G. Subsoil K = Topsoil K x 0.67 + 12 $r^2 = 0.67$

Heavy loam or clay upper subsoil
A. Subsoil K = Topsoil K x 0.43 + 50 $r^2 = 0.47$
A. Subsoil K = Topsoil K x 0.43 + Subsoil OM% x 4.3 + 42 $r^2 = 0.48$
A. Subsoil K = Topsoil K x 0.43 - Subsoil stone class x 6.2 + 54 $r^2 = 0.48$
G. Subsoil K = Topsoil K x 0.47 + 32 (heavy loam) $r^2 = 0.40$
G. Subsoil K = Topsoil K x 0.37 + 47 (clay) $r^2 = 0.35$
G. Alluvium *Subsoil K = Topsoil K x 0.43 + Subsoil OM% x 4.1 + 14* $r^2 = 0.57$

Light and medium subsoils on Alluvium
G. *Subsoil K = Topsoil K x 0.88 + Subsoil OM% x 2.9 - 5* $r^2 = 0.42$

Woodland (any texture)
Subsoil K = Topsoil K x 0.82 - 12 $r^2 = 0.86$
Subsoil K = Topsoil K x 0.81 + Subsoil OM% x 2.0 - 17 $r^2 = 0.86$

5.5 Agronomic conclusion: potassium levels in red soils of the Midlands

In this region a large range of potassium levels were found, with arable topsoils tending to higher K (median 131 mg K/l) than grass (87 mg K/l) though in both cases sampling depth was somewhat deeper than normally used (0-15cm, less on long-term grass).

Under both arable and grassland the K in topsoil tended to increase with clay content
light loams < medium loams < heavier loams < clays

Typically clay topsoils were 40 mg K/l higher than medium topsoil (SCL/mCL/mZCL)

Topsoil K strongly correlates strongly with topsoil phosphorus (a management influence) and weakly with pH where a 1 unit rise corresponded to ∆25 mg K/l. Topsoil organic matter had weak influence and there was no effect of Average Annual Rainfall.

Table 8: Prediction of Potassium levels in upper subsoil
Ranges of values corresponds to subsoil OM of 1.0 and 4.5%.

Class	Subsoil Texture	Equation based on	at Topsoil K mg/l **60**	**120**	**180**	**240**	**300**
0	S, LS	Topsoil K only	47	86	124	163	>150
		Topsoil K & subsoil OM%	44-76	79-111	113-144	147-178	
		Grass	43	78	112	147	
1	SL, SZL	Topsoil K only	47	89	132	174	217
		Topsoil K & subsoil OM%	42-69	84-112	126-154	169-197	
		Grass	52	81	109	138	
2	SCL,mCL	Topsoil K only	56	98	139	180	222
		Topsoil K & subsoil OM%	52-73	93-115	134-157	176-197	
		Grass	52	92	133	173	
3,4	hCL to C	Topsoil K only	76	102	127	153	179
		Topsoil K & subsoil OM%	72-87	97-113	122-139	148-164	
3	hCL/ZCL	Grass	60	88	117	145	
4	C,ZC	Grass	69	91	114	136	
3,4		Grass on Alluvium	44-58	71-85	96-110	121-136	

S = sand, LS = loamy sand, SL = 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.

Subsoil K correlates significantly with the topsoil K but this relationship alters with subsoil texture and on arable sites is influenced by subsoil organic matter – each 1% increase in SOM (capped at 6%) was associated with increase ranging from ∆4 mg K/l on clay subsoils to ∆9 mg/l on light loam subsoils. Some of this may be due to history of deep cultivation or earthworms moving topsoil into the subsoil.

For the same topsoil K, the subsoil K under grass tends to be approximately 10 mg K/l less than arable sites and is unrelated to OM content. Under grass there may be less deep disturbance or mixing of topsoil material than on arable land.

On sandy and medium soils, an increase in subsoil stones by one category (about 10% by volume) is associated with ∆8 mg/l increase in subsoil K, which is likely due to a concentration by the stones. However, because the amount of soil is reduced the net amount of K available to roots is unchanged. In some cases K measured in stonier subsoils was greater than topsoil. This of course implies that movement by leaching is occurring.

Overall, 50-75% of the variation in K level in the upper subsoil was accounted for by topsoil K adjusted for subsoil texture. However, alluvial soils are unpredictable - in lighter subsoils subsoil K can be parity or higher than topsoil whereas on heavy subsoils can be lower than found than on other clays, but affected positively by organic matter content unlike on geological clays where organic matter is associated with a marginal *decrease* in subsoil K.

If subsoil texture is unknown predictability is worse as illustrated in Table 9. Farmers may know their topsoil texture but have little awareness of the upper subsoil: in 33% of the instances the upper subsoil was heavier than the topsoil and in 18% the subsoil was lighter (sandier).

Table 9: Matrix of Topsoil and Subsoil K (number of data in each category)

Sandy and Light loam topsoil (arable)

		Subsoil K			
Topsoil K	Index 0	Index 1-	Index 1+	Index 2-	Index 2+/3
Index 0	4	1			
Index 1-	8	11	1		
Index 1+	1	20	6	1	1
Index 2-(L)		8	10	5	
Index 2-(H)		4	5	1	
Index 2+	1	2	2	8	5
Index 3			2	4	5

Sandy and Light loam topsoil (leys)

		Subsoil K			
Topsoil K	Index 0	Index 1-	Index 1+	Index 2-	Index 2+/3
Index 0	25	4	1		
Index 1-	17	11	4		
Index 1+	2	1	3	1	1
Index 2-(L)	1	2	2	1	
Index 2-(H)	1	1	1	3	
Index 2+	1	2	3	5	1
Index 3				2	2

Medium topsoil (arable)

		Subsoil K			
Topsoil K	Index 0	Index 1-	Index 1+	Index 2-	Index 2+/3
Index 0	6	1		1	
Index 1-	8	12			
Index 1+	2	9	13	1	
Index 2-(L)		6	12	6	1
Index 2-(H)		1	8	11	1
Index 2+	1	5	11	4	
Index 3			1	2	8

Medium topsoil (leys)

		Subsoil K			
Topsoil K	Index 0	Index 1-	Index 1+	Index 2-	Index 2+/3
Index 0	31	6			
Index 1-	16	16	2		
Index 1+	2	7	9	2	
Index 2-(L)	1	5	4	1	1
Index 2-(H)		3	3	7	1
Index 2+	1	1	4	3	2
Index 3		1	3	4	5

Heavy loam or clay topsoil (arable)

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

Heavy loam or clay topsoil (leys)

		Subsoil K			
Topsoil K	Index 0	Index 1-	Index 1+	Index 2-	Index 2+/3
Index 0	1				
Index 1-	5	5	1		
Index 1+	2	3	2	1	
Index 2-(L)		2	3	2	
Index 2-(H)	1	1	1	2	
Index 2+		3		3	1
Index 3				2	2

In table 9 grey indicates adequacy - topsoil (2-) and upper subsoil (1+ or more). Orange indicates adequate topsoil (2- or 1+) but inadequate subsoil K, 1- or 0 (pink). Boxes with only 1 data are not shaded.

- At (topsoil) K index 0 (0-60 mg/l) subsoil is also index 0 but rare on heavier soils.
- At K index 1- (61-90 mg/l) subsoil is likely index 0 or 1- and inadequate.
- At topsoil index 1+ (90-120 mg/l) subsoil is likely index 1- on sandy/light loam soils but 1+ on medium and heavy soils, implying some adequacy but see note below*. However under grassland subsoil is unpredictable ranging from 0 to 2-
- At topsoil index 2- (121-180 mg/l, target) subsoil is likely index 1+ on sandy to medium soils but with range 1- to 2-. In the lower case this might pose deficiency if

the topsoil dries out. On heavier soils subsoil is usually 1+ to 2- implying sufficiency* however 1- was found in a fifth of cases.

- In summary the probably of finding a subsoil K of 1- or less (<90 mg/l) in this region
  Topsoil index 1+ 65% of light soils, 44% medium to heavy.
  Topsoil index 2- 38% of light soils, 21% medium to heavy
  Topsoil index 2+ 20% of all textures
  Topsoil index 3 0%

- On heavier soils, potash levels in these Triassic heavier soils are better * than Carboniferous clays where the subsoils were usually index 0/1 (see NE report).

  * We cannot be sure that the better K level in heavier subsoils is as effective as it seems because K depletion experiments show that a basal amount of the K extracted by conventional ammonium nitrate method is not actually plant available. This 'dead' K increases with clay content (and possibly mineralogy). In this data intercepts (at theoretical 0 mg/l topsoil K) increase in order light loams subsoils (0) < medium (20 mg/l) < clay (45 mg/l). So perhaps the first 0-50 mg K/l measured in heavier soils is not useful to the plant. *More research is needed on this.*

- Maintaining soils above target at index 2+ (180-240 mg/l) is likely to maintain subsoil at 1+ to 2- (arable) or 1+ (grassland). So subsoil K should be adequate in seasons where the topsoil dries out.

- Topsoil levels of index 3 correspond to subsoil K of at least index 2- and so should be safe to run-down though it may be inferred that those cases with proportionately less subsoil K may run-down faster than those with higher subsoil K. At levels above (and at) target index it is implicit that some K is being leached from topsoil on medium soils and a substantial amount on lighter soils.

- Measurement of subsoil K should be routinely made in potash depletion (or build) experiments. It is also advisable on disturbed soils or soils on layered alluvium or those with stony subsoils and where there is known to be a significant textural contrast e.g. heavy loam topsoil over light loam or sandy subsoil.

6. Magnesium

Region B: Central and North West Midlands

6.1 Overview of magnesium levels

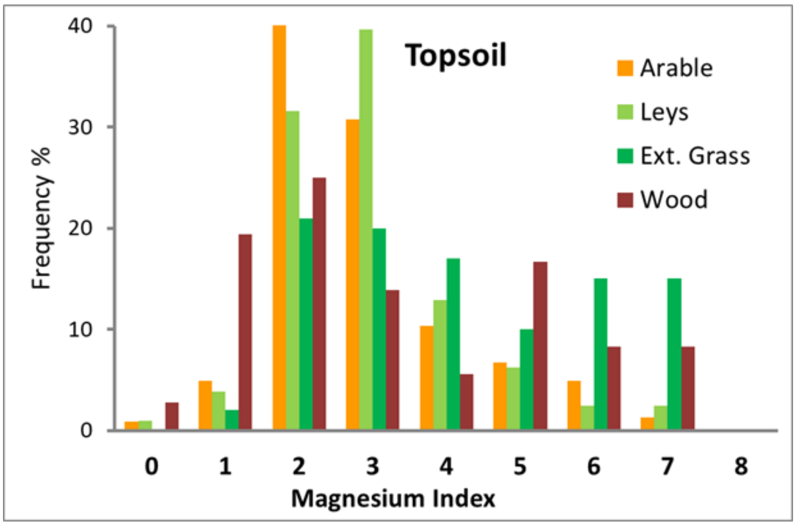


Figure 15a. Region B: Available Magnesium in Topsoil (balanced data)

Topsoil

Arable land: Mg index 2 is considered adequate for nearly all crops, with index 3 for some specialised fruit and vegetable crops. Only 6% of samples were below target, most were index 2 or 3 with a median of 112 mg/ l. Relatively few (13%) were Index 5 (very high) or Index 6 (excessive)

Grassland leys; values were slightly higher than arable samples (median 122 mg/ l) with 5% below target and 11% at index 5 – 7. On extensive grassland values were considerably higher - median index 4 (219 mg/l) and 40% were Index 5 to 7.

Amenity grass tended to lower Mg perhaps indicative of absence of returns in animal excreta or manures. On woodland median Mg was 123 mg/l but values were widely spread with 22% deficient and 33% index 5 to 8.

The PAAG (2019) national survey found 12% of all samples had index 5 or higher.

Table 10. Region B : Typical Soil Magnesium levels (mg/l)

	Topsoil		Upper Subsoil	
	median	**mean**	**median**	**mean**
Arable	113 (3)	144	102 (3)	113
Leys	120 (3)	156	110 (3)	152
Extensive Grass	210 (4)	288	243 (4)	361
Amenity Grass	95 (2)	133	60 (2)	126
Wood	133 (3)	199	126 (3)	224

Subsoil

Arable land: average Mg in subsoil similar to topsoil (Table 10) though with greater spread (14% index 0/1 and 19% Index 5-7).

Grassland leys; again similar average values to topsoil but with more variation 14% below target and 16% very high (one sample was index 8).

Under extensive grassland subsoil Mg was higher than topsoil with 50% at index 5-8. On woodland: as in the topsoil the subsoil gave a large range of values from index 0-7.

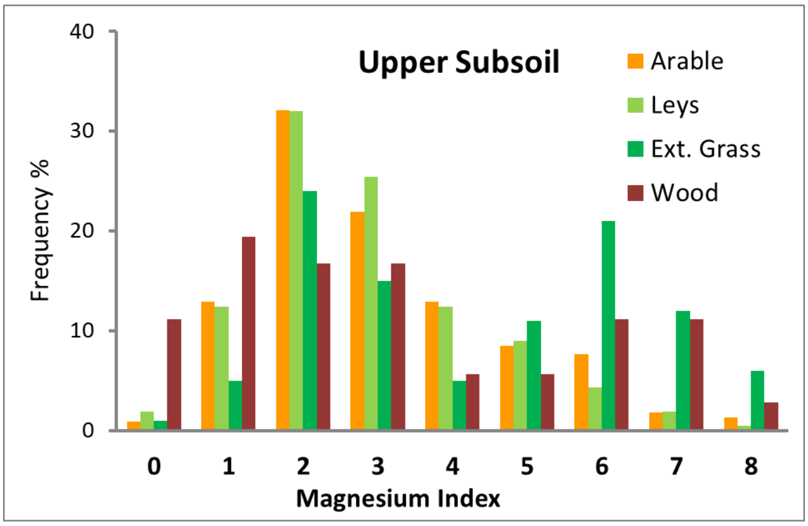


Figure 15b. Region B: Available Magnesium in Subsoil (balanced data)

6.2 Influence of texture on magnesium levels in topsoil

In Tables 11a-e the topsoil Mg data is partitioned according to topsoil hand-texture class.

Across all land uses there is a trend of Mg level increasing with clay content category.

Light loam textures have marginally higher Mg than sand topsoils, but medium topsoils are about 50 mg/l (approx.one index) higher, heavy loams a further 50 mg/l and for clay topsoil the index typically shoots up to 6 or 7.

Arable sites deficient in Mg (index 1 or 0) were few - 14 instances were light loam topsoil, 5 medium and none were heavier soils; on leys 3 were sandy, 10 light loams, 5 medium and no heavier topsoils. On amenity grass all cases of low Mg cases were on light loams.

Table 11a Region B: Arable data Topsoil Texture and Magnesium

Averages of all data. Index in parenthesis.

Class	**Textures**	**Mean** mg Mg/ l	**Median** mg Mg/ l	**n**
0	LS,S	80	80 (2)	*10*
1	SL, fSL, SZL	89	80 (2)	*107*
2	SCL, mCL (mZCL)	160	143 (3)	*131*
3	hCL, hZCL	222	155 (3)	*36*
4	ZC, C	476	541 (6)	*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.

Class 4 >> 3 > 2 > 1, 0.

Much higher Mg on extensive grass than leys or arable occurs across the texture range and the medians increase from index 3 for lighter loams to index 5 for heavier loams. We conjecture this high Mg is caused by lack of offtake (few or no cuts), predominance of grazing (Mg returned in excreta) and sometimes wetness (lack of leaching). Alluvium is evaluated later.

Under woodland the differences due to texture are exacerbated.

Table 11b Region B: Grass Leys -Topsoil Texture and Magnesium

Class	**Textures**	**Mean** mg Mg/ l	**Median** mg Mg/ l	***n***
0	LS,S	57	56 (2)	*8*
1	SL, fSL, SZL	116	98 (2)	*91*
2	SCL, mCL (mZCL)	155	120 (3)	*141*
3	hCL, hZCL	236	167 (3)	*35*
4	ZC, C	524	589 (6)	*4*

Clear trend: Class 4 >> 3 > 2 > 1 > 0

Table 11c Region B: Extensive Grass Topsoil Texture and Magnesium

Class	**Textures**	**Mean** mg Mg/ l	**Median** mg Mg/ l	***n***
0	LS,S	[178]	[178]	*2*
1	SL, fSL, SZL	185	133 (3)	*51*
2	SCL, mCL (mZCL)	280	221 (4)	*62*
3	hCL, hZCL	423	284 (5)	*34*
4	ZC, C	638	656 (7)	*4*

Clear trend: Class 4 >> 3 > 2 >> 1. Much higher Mg than for grass leys of same texture.

Table 11d Region B: Amenity Grass Topsoil Texture and Magnesium

.Class	**Textures**	**Mean** mg Mg/ l	**Median** mg Mg/ l	***n***
1	SL, fSL, SZL	78	71 (2)	*11*
2	SCL, mCL (mZCL)	146	124 (3)	*9*
3	hCL, hZCL	635	[635]	*1*

Clear trend Class 2 > 1 and less than leys or arable land of same texture class.

Table 11e Region B: Woodland Topsoil Texture and Magnesium

Class	**Textures**	**Mean** mg Mg/ l	**Median** mg Mg/ l	***n***
0	LS,S	78	65 (2)	*8*
1	SL, fSL, SZL	116	69 (2)	*16*
2	SCL, mCL (mZCL)	250	222 (4)	*13*
3	hCL, hZCL	309	297 (5)	*9*
4	ZC, C	793	793 (7)	*2*
P	Peaty loam	95	95 (2)	*2*

Clear trend Class 4 >> 3 > 2 >> 1, 0. Compared to arable land on lighter woodland soils Mg levels are marginally lower and on medium and heavy land is much higher

6.3 Influence of texture on magnesium levels in subsoil

For regression analysis arable and leys were combined; samples >250 mg/l Mg were excluded because of their disproportionate influence on the fitted lines.

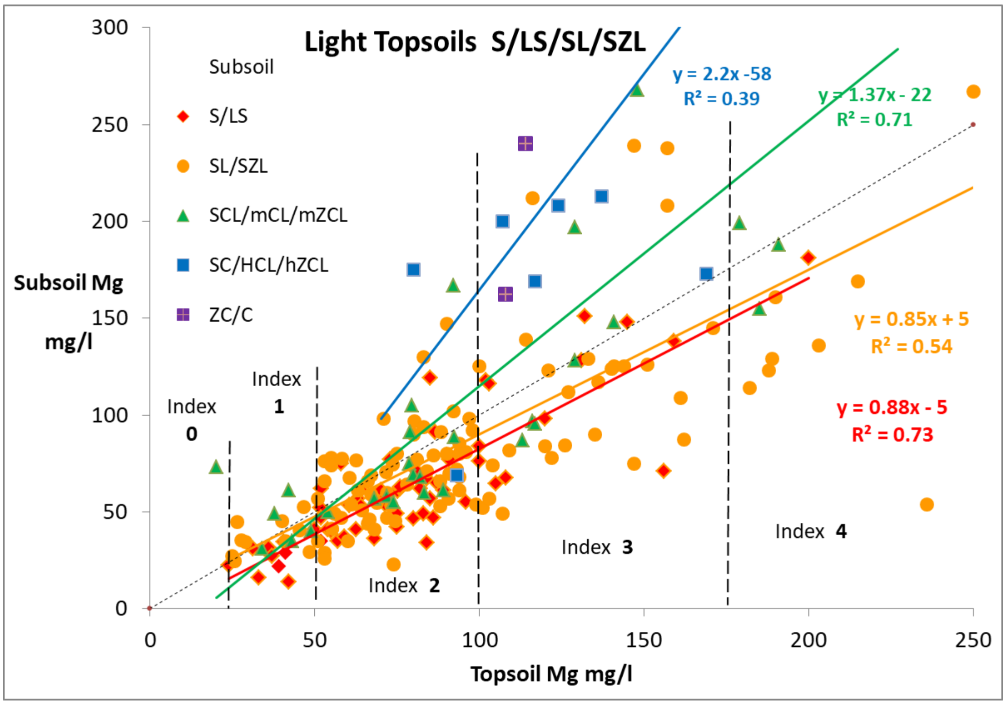


Figure 16a. Region B: Magnesium in topsoil and subsoil – Light loam topsoil. 5 samples are not shown (Mg 251 to 330 mg/l).

Under lighter topsoil the subsoil Mg was slightly less than topsoil (about 0.86x) for light loam or sandy subsoils. Index 1 in topsoil corresponds to index 1 in subsoil except where sandy it it is likely to be index 0 (reflecting accelerated leaching).

At medium subsoil texture subsoil Mg was about 1.2x topsoil ie *greater* and much higher in heavy loam subsoil - indicative of resistance to leaching or more release from clay.

Unsurprisingly, when subsoil and topsoil are both medium textured (Figure 16b) Mg levels are similar (1.06x) however if subsoil is light loam subsoil Mg is less about 0.9 or 0.65 (35% less) if sandy texture. At topsoil index 2 the subsoil could be index 1 but never 0.

Heavier loam subsoils tend to 1.2x higher Mg and clays 1.45x.

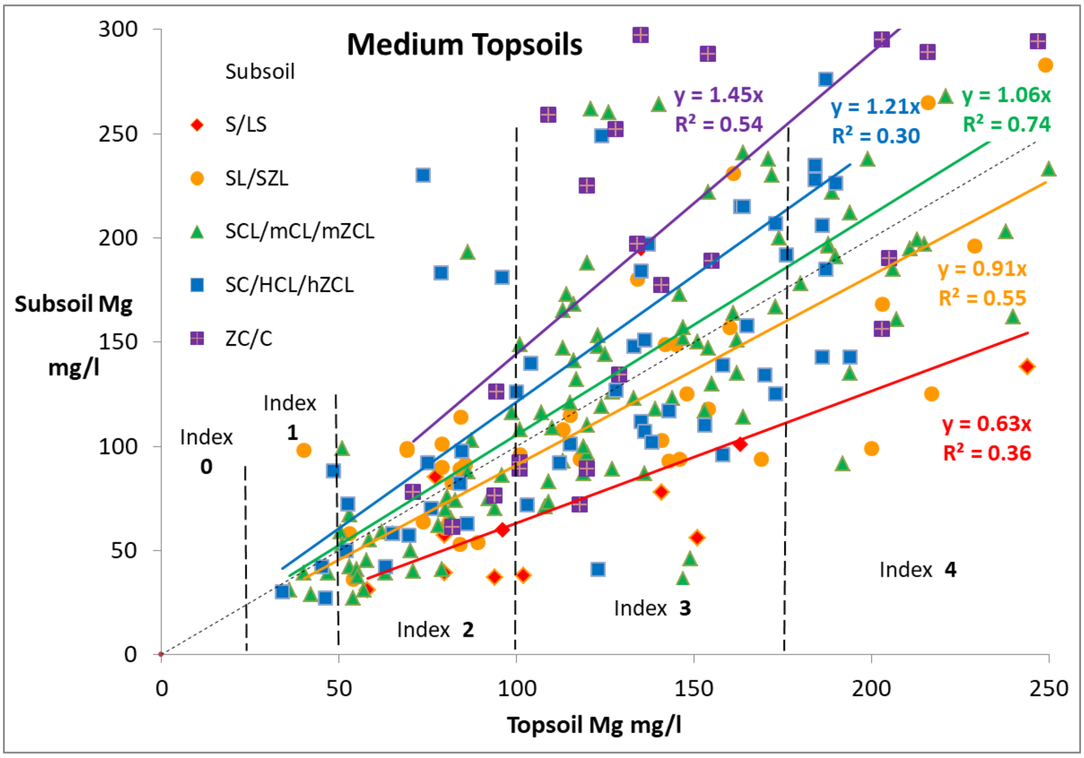


Figure 16b. Region B: Magnesium in topsoil and subsoil – Medium topsoil up to 250 mg/l. For clarity all fitted lines are forced through origin (with no reduction in r^2).

Under heavier topsoil (Figure 16c), the subsoil Mg tends to be higher than topsoil if medium or heavy subsoil. The data shows a constant increase (of about 40 mg/l) rather than a proportionate increase in subsoil Mg but the correlation is quite poor so inclusive.

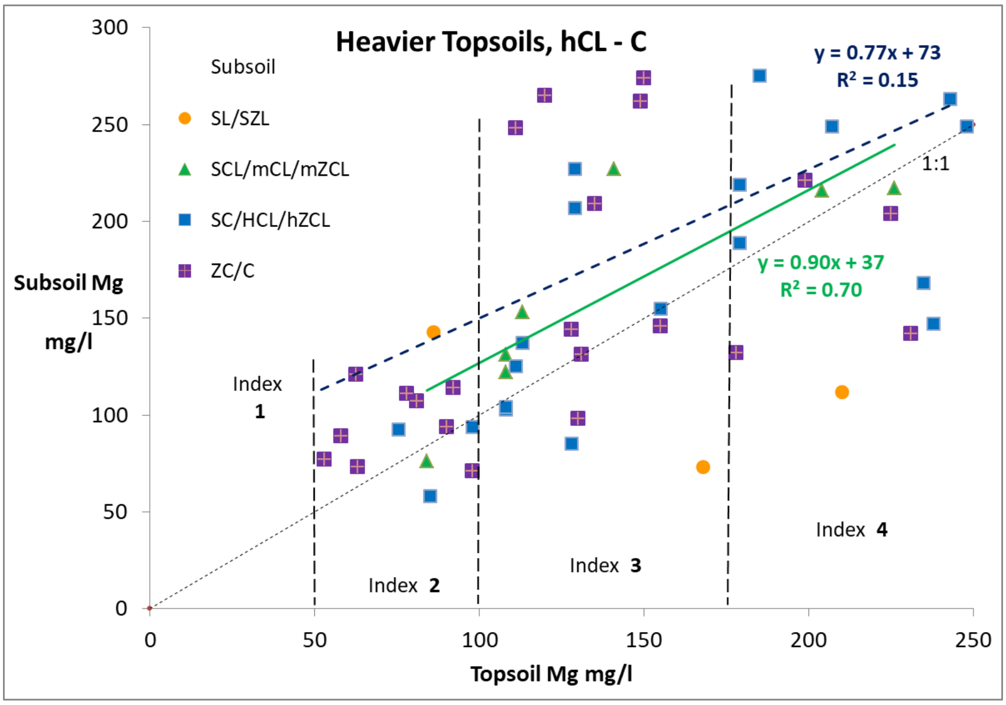


Figure 16c. Region B: Magnesium in topsoil and subsoil – heavier topsoil up to 250 mg/l.

Extensive grassland data is summarised on Figure 17 extended up to 350 mg/l Mg in topsoil. There are no examples of low index. All topsoil textures are combined. Data for heavier and clay subsoils has been forced through origin with no loss of r^2.

It shows the same pattern as arable-ley data in Figure 16a-c: subsoil Mg is parity with topsoil where subsoil is medium textured, below parity where light loamy and much lower where sandy. On heavy loam subsoil the subsoil Mg is higher than topsoil (1.25x) and >1.5x in clay subsoils though with considerable variation.

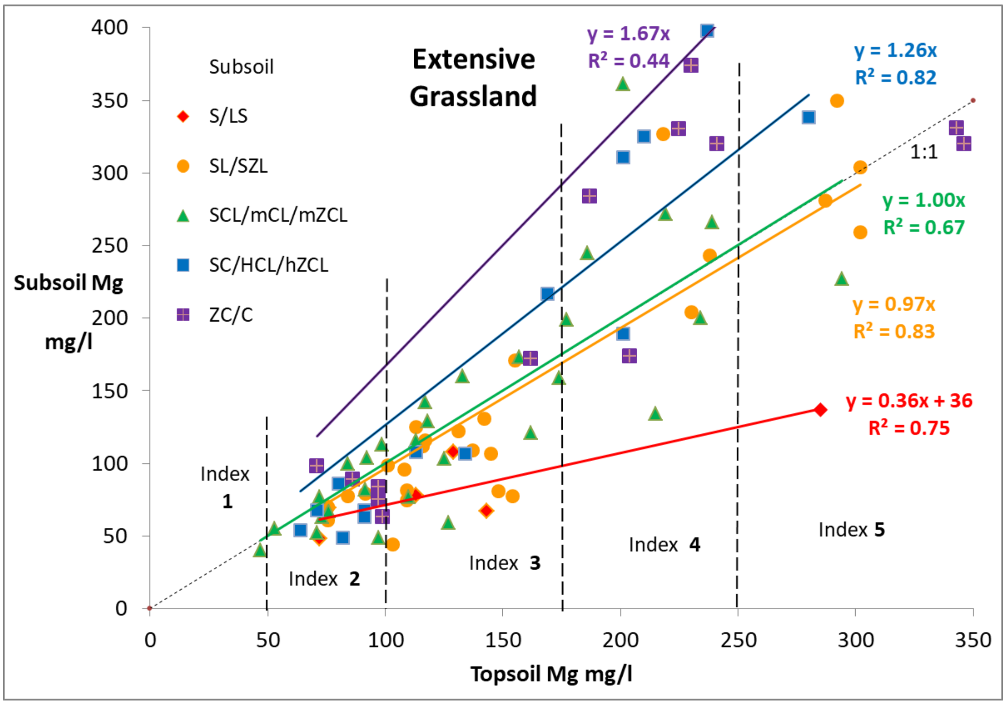


Figure 17. Region B: Magnesium in topsoil and subsoil **– Extensive Grassland**

Figures 16-17 are simplified (intercept forced through zero) to produce Table 12.

Table 12: Prediction of subsoil magnesium where topsoil ≤ 250 mg/l Mg (Index 0-4)

Subsoil Mg = Topsoil Mg x coefficient in table

Class	Topsoil Texture	Subsoil Texture 0	1	2	3	4
0	LS,S	0.80	0.90	1.20	1.45	
1	SL,SZL	0.80	0.90	1.20	1.45	1.45
2	SCL, mCL ,mZCL	0.65	0.90	1.05	1.25	1.45
3	SC, hCL, hZCL		0.70	1.00	1.15	1.25
4	ZC,C			1.00	1.10	1.20

S = sand, LS = loamy sand, SL = 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.

When the same approach was applied to Carboniferous soils (NE region) similar coefficients were derived of 0.8,1.0,1.0,1.17 and 1.29 respectively for the five subsoil classes (any topsoil texture).

The main area of agronomic interest is where the coefficient is less than 1 due to a sandy or light subsoil, where an adequate topsoil Mg (lower end of index 2) could overlie a subsoil that is index 1 (or index 1 overlying index 0). In other situations the subsoil Mg is equal to or higher than the topsoil.

6.4 Relationship of magnesium to parent material

There is no obvious relationship of Mg to pH in topsoil (Figure 18) nor in subsoil.

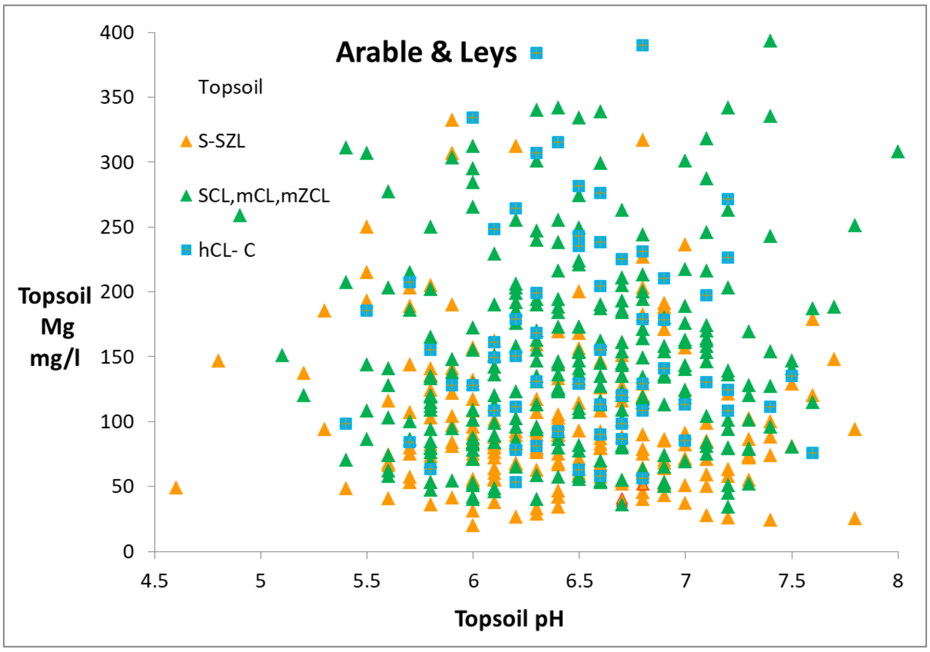


Figure 18. Region B: Magnesium versus pH in topsoil and subsoil

To investigate the relationship of soil Mg levels with geology, the data was isolated which had heavy loam or clay subsoils and shown in Table 13. Woodland was excluded. Total data in each category is shown (n) with extensive grass in parentheses. Medians are cited and 25-75% percentiles.

Table 13: Magnesium in relation to Geological formation

.Geological Grouping (BGS maps)	Top mg/l	**Subsoil Mg** mg/l	25-75%	Subsoil pH	25-75%	Subsoil K mg/l	K:Mg	*n*
Alluvium over Bransombe Mudston	418	**741**	381-1201	6.5	6.4-6.8	52	0.07	*19(17)*
Dolomitic Siltstone*(Sidmouth/Gun)	441	**572**	457-785	7.9	7.6-8.1	126	0.22	*10 (8)*
Alluvium over Gunthorpe Mudstone	452	**530**	373-615	6.9	6.3-7.2	99	0.19	*8 (4)*
Alluvium over Sidmouth Mudstone	436	**530**	253-866	6.5	6.0-6.7	72	0.14	*8 (4)*
Branscombe Mudstone	172	**515**	268-886	6.5	6.3-6.8	71	0.14	*10 (1)*
Alluvium over Mercia Mudstone	491	**481**	363-604	6.9	6.7-7.0	63	0.13	*8 (7)*
River Terrace over Mudstones	307	**445**	372-396	6.8	6.0-7.0	104	0.23	*9 (2)*
Mercia Mudstone & Halite	270	**312**	156-430	7.0	6.6-7.4	121	0.39	*41(2)*
Tarporley Siltstone	243	**276**	270-284	7.1	6.9-7.7	106	0.38	*3 (0)*
Gunthorpe Mudstone	170	**262**	113-371	6.6	6.3-7.2	123	0.47	*8 (0)*
Sidmouth Mudstone	139	**242**	227-259	7.2	6.8-7.4	125	0.52	*10 (0)*
Glacial Drift over Mercia Mudstone	151	**223**	208-331	6.8	6.5-7.1	131	0.59	*6 (0)*
Glacial Drift over Mudstone & Halite	158	**217**	178-318	7.0	6.2-7.3	77	0.35	*15 (2)*
Mercia Mudstone	174	**196**	117-282	7.1	6.7-7.3	99	0.51	*10 (2)*

Glacial Drift over Sidmouth Mudstn	154	**192**	146-279	7.0	6.5-7.3	76	0.40	*26 (2)*
Glacial Drift over Halesowen & Chester formations	189	**145**	130-194	6.8	6.6-6.9	63	0.43	*12 (0)*
Oadby Glacial Till (not red)	98	**137**	102-145	6.2	6.2-6.7	75	0.55	*7 (0)*
Glacial Drift over Salop Formations	128	**104**	89-107	6.9	6.3-7.0	71	0.68	*5 (0)*
Ashow Mudstone & Sandstone	91	**98**	56-160	6.4	6.0-6.8	74	0.76	*4 (0)*
Salop Mudstone	100	**91**	73-111	6.2	5.9-7.0	87	0.96	*18 (1)*
Alluvium over Wildmoor Sandstone	86	**72**	64-88	6.6	6.1-6.8	42	0.58	*10 10)*

* one sample in Arden Sandstone (a siltstone noted for its green calcareous layers) had 689 and 1190 mg/l Mg though pH did not exceed 7.0.

Table 13 indicates significant ranges within each geological class, so exact statistical analysis is difficult (mean values are substantially greater than medians cited above). However, reasonable conclusions are as follows:-

a) the highest subsoil Mg levels occur in Alluvium over red Mudstone and on soils directly formed on *Branscombe Mudstone* or Dolomitic Siltstones. These are index 6 or 7 in subsoil. A disproportionate number of the alluvial soils are on extensive grassland, and this may have some influence as mentioned previously.

b) heavier subsoils formed on *Gunthorpe, Sidmouth and Wilkersley* Mudstones or 'Mudstone with halite', are typically Mg index 5.

c) heavier subsoils in Glacial Till or fluvio-glacial material on the above mudstones are slightly lower (index 4), as might be expected due to dilution with "foreign" material.

d) the lowest subsoil magnesium (index 3 or 2) occurs on red mudstone+sandstone formations; also alluvium over Sandstone where (despite heavy subsoil) Mg is not high

Average topsoil Mg levels are somewhat less than subsoil Mg because the topsoils are sandier/loamier than the subsoil. Note that only heavier subsoils are included in Table 13.

6.5 Problems of high magnesium in red soils of the Midlands

1) RB209 states that high soil Mg can antagonise uptake of potassium by crops. This is often noted by agronomists. Criteria are not precisely known but a minimum K:Mg ratio of 0.5 (mg/l:mg/l) 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.

Median potassium values in subsoil are also shown in Table 13. K tends to be slightly higher on most red mudstones than in soils influenced by Drift, nevertheless the mg/l Mg typically exceeds the mg/l K by 2-3 times and by over 4 times in the very high Mg soils.

Over all the arable data median K:Mg ratio in topsoil was 1.3 and in *16% of cases ratio was 0.5 or lower.* For grass leys: median K:Mg was less than arable, 0.8, and *24% of cases had ratio <0.5* of which 5% were <0.25 (i.e. mg/l Mg was greater than 4x the mg/l K).

Compared to topsoil, subsoil potassium tends to be lower while Mg is higher if heavier textured. The arable subsoil median K:Mg ratio was 0.8 and 29% had ratio <0.5 (9% were < 0.25). Under leys median was 0.7 with 32% <0.5 (9% <0.25).

Therefore issue of potential magnesium: potassium antagonism applies to a significant proportion of the Triassic soils reviewed here as well as the Carboniferous soils in NE report (these had an even lower K:Mg in topsoil (median 0.55).

On the data for Triassic soils shows K:Mg ratio is commonly less than one, but it is kept above 0.5 if target K index (2-) is attained and Mg index does not exceed 4. At Mg index 5 the ratio is above 0.5 if the topsoil K is kept at index 2+. More agronomic research is needed to establish the ratio in soil solution below which roots are impeded in taking up potassium and whether this relates simply to the K:Mg ratio reported from soil analysis.

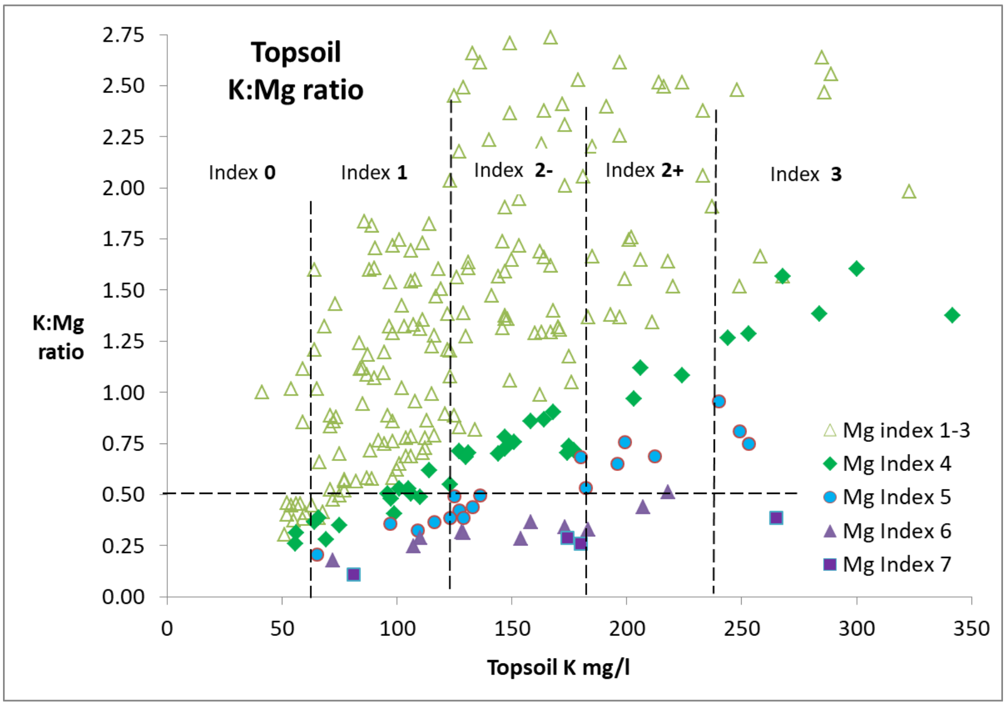


Figure 19: Region B, Arable data: potassium levels and K:Mg ratio (mg:mg).

7. pH

Region B: Central and North West Midlands

7.1 Overview of pH levels

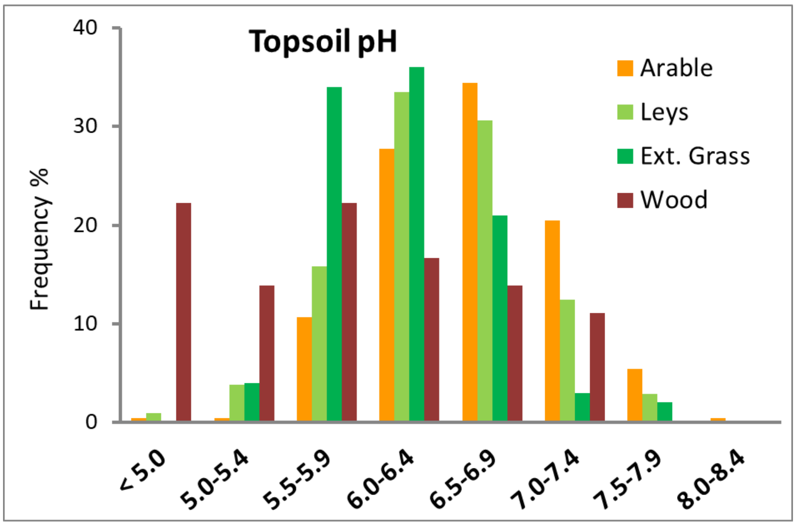


Figure 20a. Region B: pH in Topsoil (balanced data)

For arable land 6.5-6.9 is considered optimal (RB209). 34% of samples were at target pH (modal) and 28% at pH 6-6.4 which is satisfactory for some crops but not all e.g. barley and legumes. Only 12% were acid (< pH 6), a lower proportion than the PAAG (2019) data (19%), with almost no samples < pH 5.5. Median pH was 6.6. 20% of samples were very slightly alkaline (7-7.4) and 6% too alkaline (pH 7.5+).

pH 6.0-6.4 is optimal for grassland. Only 21% of leys were below pH 6.0 and 38% of extensive grassland but only 4% of the latter was below 5.5 (which would warrant liming). This is a much lower proportion than 19% reported in PAAG (2019), however grass is sampled at shallower depth (7.5cm or 15cm) than the 20cm+ here, and it is quite likely that pH where the most roots reside was somewhat lower pH than Figure 20a implies. 4% of grassland was pH 7.5+.

pHs tended to be slightly lower in *amenity* grassland and woodland, the latter showing wide variation with 25% of samples extremely acid (pH < 5.0).

Table 14. Region B : Typical Soil pH (balanced data)

	Topsoil		**Upper Subsoil**		***n***
	median	**10-90%**	**median**	**10-90%**	
Arable	6.6	5.8 - 7.3	6.8	6.1 - 7.4	*225*
Leys	6.4	5.7 - 7.1	6.7	5.9 - 7.4	*209*
Extensive Grass	6.1	5.6 - 6.7	6.5	5.8 - 7.2	*100*
Amenity Grass	5.9	5.3 - 6.1	6.2	5.6 - 7.0	*15*
Wood	5.9	4.4 - 7.0	6.0	4.6 - 7.0	*36*

Subsoil pH tends to be higher than topsoil though not by a large amount. In the arable data 17% of subsoils were marginally acid and 8% below pH 6.0 of which only 1.3% were <5.5. Under grass leys 11% of subsoils were below pH 6.0 of which 3% were below 5.5.

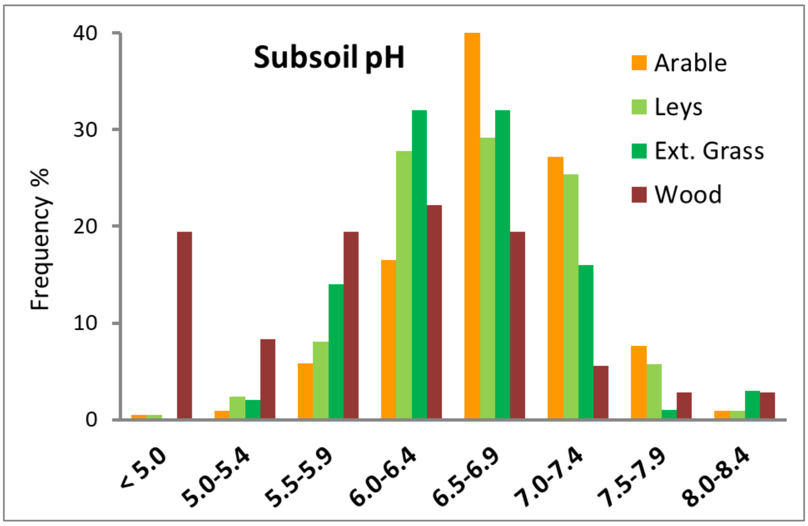


Figure 20b. Region B: pH in Subsoil (balanced data)

7.2 Factors influencing topsoil pH

Regression analysis of all the data shows that topsoil pH is unaffected by sampling method on arable data while there is a small effect on grassland (0.07 units less by corer, P = 0.17). This might be expected in that the latter method always includes surface soil whereas auger method takes a typical sample from auger (topsoil can be deeper than 20cm).

Topsoil pH shows a negative relationship with organic matter with a drop of 0.05 pH with each % OM up to 10% but this explains a minor part of the total variance (Appendix 11.9).

There is a trend of both topsoil and subsoil pH increasing with texture category (increasing clay content) but the differences are very small as shown in Table 15, and there is wide variation, half the samples lying outside the ranges shown.

Table 15. Region B : Texture and pH (all data, arable and leys, *n* = 624)

Texture of horizon	**Topsoil**		**Upper Subsoil**	
	median	**25-75%**	**median**	**25-75%**
Sandy, light loam	6.4	6.0 - 6.8	6.6	6.2 - 6.9
Medium	6.5	6.1 - 6.8	6.8	6.4 - 7.1
Heavy loam, clay	6.6	6.2 - 6.9	6.9	6.7 - 7.4

7.3 Factors influencing subsoil pH

Subsoil is expected to be higher pH than topsoil because leaching occurs of calcium, magnesium and bicarbonate from topsoil to subsoil. The dominant influence on subsoil pH is topsoil pH with a smaller effect of texture

As for magnesium, all arable and ley data was combined and subdivided firstly by topsoil texture category and secondarily by subsoil texture, displayed in the Figures below.

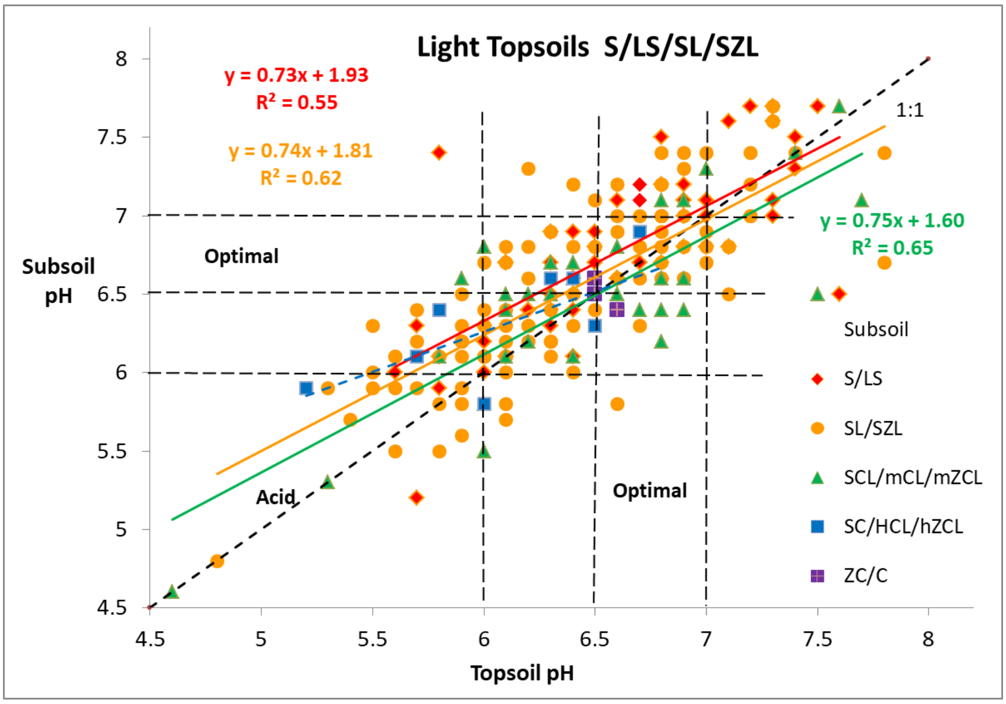


Figure 21a. Region B: pH in topsoil and subsoil – Light loam topsoil (arable and leys)

For **lighter topsoil** data for all subsoil textures fits lines of r^2 about 0.6. As topsoil pH declines below pH 7.0 the subsoil tends to a higher pH than topsoil.

When the topsoil is optimal pH (6.5-6.9) the subsoil is very likely optimal or slightly alkaline.

At suboptimal pH (6.0-6.4) the subsoil is similar or optimal and very unlikely to be below pH 6.0. When topsoil is acid (pH < 6.0), subsoil is suboptimal or acid, and can be more acid than topsoil in some instances.

For **medium topsoil** (Figure 21b), at pH 6.5 the different subsoil textures fit similar lines with subsoil pH slightly higher than topsoil. At pH 7.0 heavier subsoils are likely to be more alkaline than medium or lighter soils.

When the topsoil is optimal pH (6.5-6.9) the subsoil was rarely less than 6.5.

At suboptimal pH (6.0-6.4) the subsoil pH varies from similar to slightly alkaline. When topsoil is acid (pH < 6.0), subsoil pH is rarely lower and typically 0.1 to 0.6 units higher.

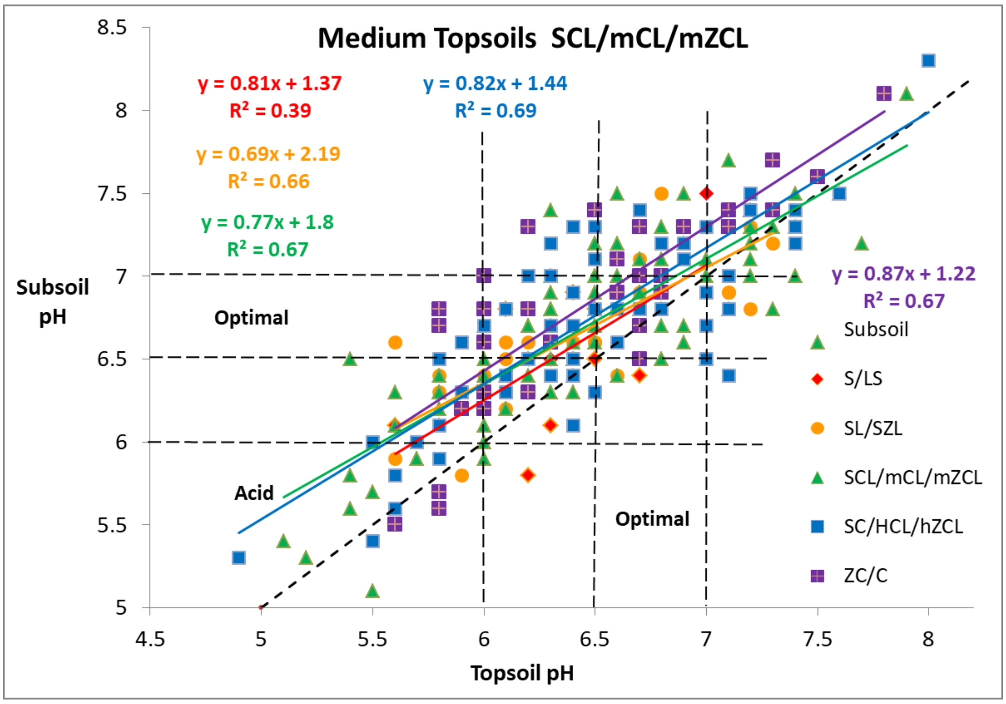


Figure 22b. Region B: pH in topsoil and subsoil – Medium topsoil (arable and leys)

For **heavier topsoil** (Figure 21c), the different subsoil textures fit to lines that are not obviously different. Subsoil pH tends to be higher than topsoil though the difference diminishes above pH 7.0.

When the topsoil is optimal pH (6.5-6.9) the subsoil was less than 6.5 in only 3 instances. There were few cases where topsoil is acid (pH < 6.0).

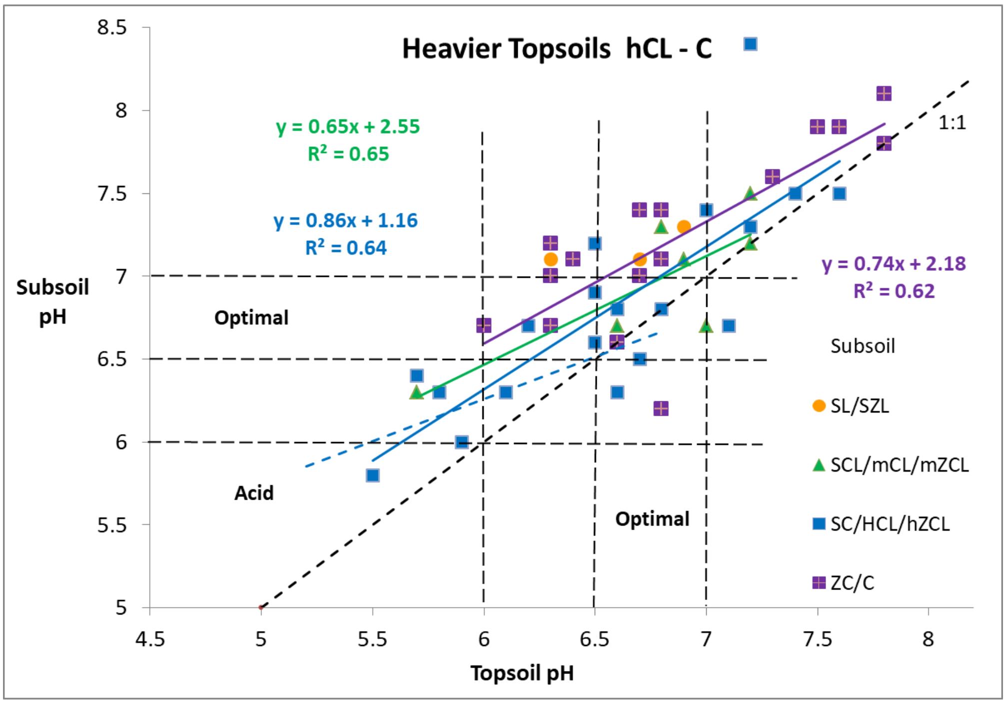


Figure 22c. Region B: pH in topsoil and subsoil – Heavier topsoil (arable and leys)

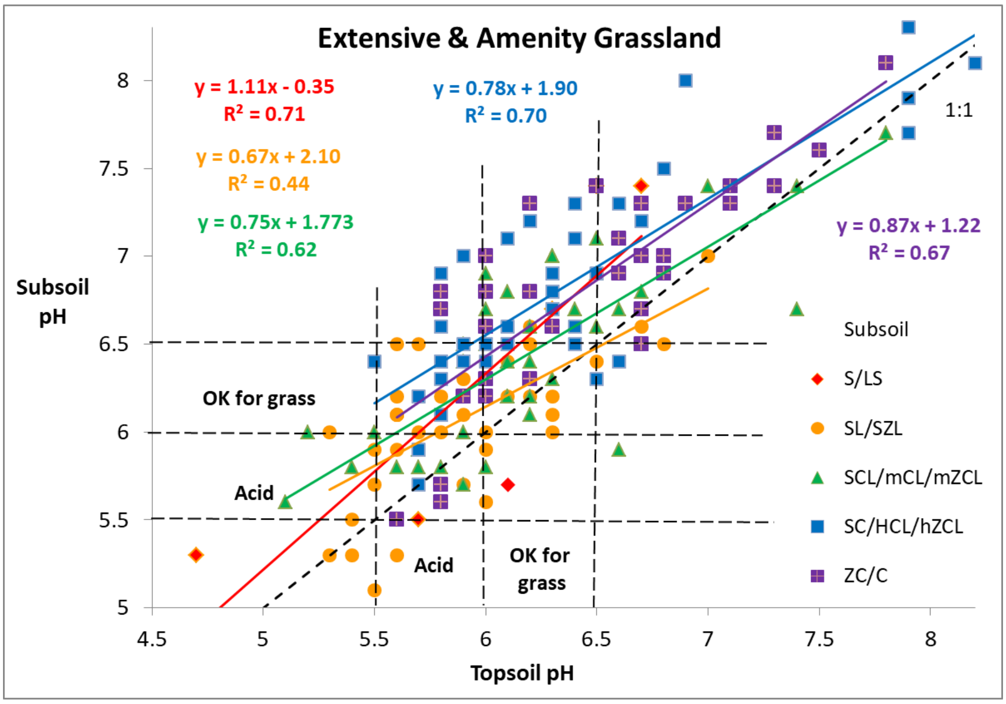


Figure 23a. Region B: pH in topsoil and subsoil – Extensive and Amenity Grassland

Extensive and Amenity Grass ('permanent grass') data is in Figure 23 for all topsoil textures. As in Figure 22a-c subsoil pH tends to be slightly above topsoil pH over most of the range.

Assuming that pH 6-6.4 is acceptable for grass then if topsoil is OK the subsoil is also. Where the topsoil is below 6.0 there is a range of possibility in subsoil from < 5.5 to above pH 6.5. Below 5.5 in topsoil, the subsoil is typically 0.5 higher but can be parity

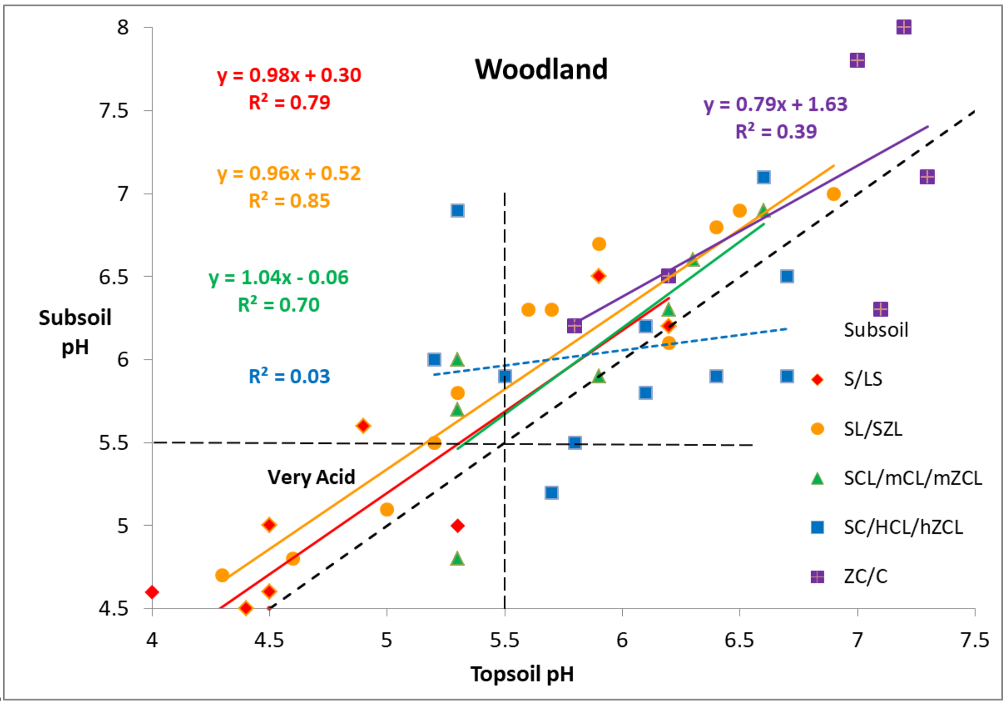


Figure 23b. Region B: pH in topsoil and subsoil – Woodland

Data for woodland (Figure 23b) shows for sandy to medium soils a parallel linear correlation of subsoil pH about 0.3 higher than subsoil pH from extremely acid to neutral. For heavier soils data is scattered, but with no instances of topsoil or subsoil pH below 5.5.

7.4 Prediction of subsoil pH

In the above Figures it is evident that soil texture has a less significant influence on pH than on phosphorus, potassium or magnesium levels.

Table 15 indicates that for arable/ley fields the pH tends to be marginally higher on heavier topsoil compared to lighter loams but only a 0.2 difference. On sandy soils about 25% were acid (below 6.0), with the % reducing slightly on medium and heavy soils.

To fit regression equations all data was included apart from woodland. Samples above topsoil pH 7.0 were isolated to improve precision over the agronomically significant range.

Sandy to medium topsoils and heavy loam / clay topsoils were analysed separately.

For sandy to medium loams topsoil pH was by far the most important influence on subsoil pH, explaining over half the variance ($r^2 = 0.56$).

- Sampling method had a significant but small influence, the corer method giving pH 0.06 lower than auger method.
- Topsoil texture had a significant influence increasing the pH 0.2 between sandy and medium topsoils. Subsoil texture had a smaller influence (0.05 per texture class).
- Subsoil OM% (capped at 6%) had a negative influence on pH with a decrease of 0.2 units between 1 and 4.5% OM. This may reflect more topsoil-derived material in the subsoil which is more acid than the in situ subsoil.

For heavy loam and clay topsoils, topsoil pH was again dominant though there was greater variance ($r^2 = 0.45$). Sampling method or subsoil OM% had no influence.

- Heavy loam versus clay *topsoil* increased subsoil pH by 0.08 though of dubious significance.
- Heavy loam versus clay subsoil increased subsoil pH by 0.07 (significant).

The regression equations in Appendix 11.9 are summarised below. The use of topsoil texture rather than subsoil texture gives better correlation here (and easier to use).

Sand topsoil
Subsoil pH = Topsoil pH x 0.82 + 1.23 $r^2 = 0.58$

Light loam topsoil
Subsoil pH = Topsoil pH x 0.82 + 1.33 $r^2 = 0.58$

Medium topsoil
Subsoil pH = Topsoil pH x 0.82 + 1.43 $r^2 = 0.58$

Heavy loam topsoil
Subsoil pH = Topsoil pH x 0.84 + 1.39 $r^2 = 0.45$

Clay topsoil

Subsoil pH = *Topsoil pH x 0.84 + 1.47* $r^2 = 0.45$

For topsoil pH of 7.1+ equations are *Topsoil pH x 0.75 + 1.6, 1.75 or 1.9* $r^2 = 0.20$
and for heavier textures *Topsoil pH x 0.85 + 1.30 or 1.45* $r^2 = 0.30$

Although of poor r^2 they extend smoothly the equations above and are used in table 16.

Woodland all textures (up to pH 7.0)
Subsoil pH = *Topsoil pH x 0.89 + 0.79* $r^2 = 0.73$

Table 16: predictions of subsoil pH from topsoil pH and topsoil texture

Class	Topsoil Texture		at Topsoil pH				
		5.0	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**
0	S, LS	*5.4*	5.9	6.2	6.6	7.0	*7.2*
1	SL, fSL, SZL, ZL	*5.5*	6.0	6.3	6.7	7.1	*7.4*
2	SCL, mCL, mZCL		6.1	6.4	6.8	7.2	*7.5*
3	hCL, hZCL		6.0	6.4	6.8	7.2	*7.6*
4	C, ZC		6.1	6.5	6.9	7.3	*7.8*
any	Woodland	5.2	5.7	6.1	6.6	7.0	

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

When is subsoil acidity likely?

a) At topsoil pH 6.0 subsoil pH is about 0.2, 0.4 or 0.5 units higher on sandy, medium and clay soils respectively. When topsoil is pH 5.5 subsoil is likely to be 5.9-6.1 on all textures (though such acidity was rare on heavier soils).
b) At topsoil pH 7.0 subsoil pH is likely to be similar on sandy soils and 0.3 higher on clay soils.
c) Where the topsoil is alkaline, medium or heavy subsoils are likely to be significantly more alkaline. In some instances this is due to dolomitic layers in the parent material siltstone or clay (see previous section).
d) The assumption 'take care of the topsoil pH the subsoil will take care of itself' is examined in Table 17. It indicates 85% probability of subsoil pH equalling or exceeding the topsoil pH and only a 5% probability that the subsoil is at least 0.3 *lower* than the topsoil (3% for samples of topsoil pH 6.0 or less).

Table 17 : Subsoil pH minus Topsoil pH (all data)

pH difference	**Topsoil ≤ 6.7**	**Topsoil ≤ 6.0**	***n***	***n***
> +1.0	1.5 %	1.0 %	*8*	*3*
+0.6 to +1.0	20.8%	21.9 %	*111*	*46*
+0.3 to +0.5	35.6 %	40.0 %	*190*	*84*
0.0 to +0.2	27.9 %	23.8 %	*149*	*50*
-0.2 to 0.0	9.4 %	9.0 %	*50*	*19*
-0.3 to -0.5	**4.1 %**	**3.3 %**	*22*	*7*
-0.6 to -1.0	**0.7 %**		*4*	

The 26 cases where the subsoil pH was at least 0.3 less than the topsoil and below 6.7 were examined more closely :

- 19 were grass, only 7 were arable (39% of all data was arable).
- in 6 cases the topsoil (and subsoil) were high in organic matter.
- only 2 cases were on heavy loam or clay topsoil.
- In 18 cases topsoil texture was loamy sand or sandy loam (17 cases of subsoil texture)
- 19 cases had slightly or moderately stony subsoils and in 9 cases the subsoil was stonier than topsoil. The predominant geology was Sand & Gravel (13) or Sandstone (4).

It is possible that in some light/stony subsoils acidification rate could exceed acidification of topsoil. However it is possible the field had been limed within past 2 years with a delay in leaching of bicarbonates to maintain or raise the subsoil pH.

Generally speaking, this data indicates that if topsoil pH is greater than 6.0 there is no need to measure subsoil pH *apart from light loamy or sandy soils or stony subsoils or organic soils, where the fields have come out of longer term grass or been under minimal cultivation.* In such cases subsoil pH is worth checking.

If topsoil pH is 5.5, subsoil pH is probably higher but probably less than 6.0. So for arable or horticultural crops this raises the question of whether subsoil pH should be also checked, especially on lighter/stonier soils.

At topsoil pH below 5.5 the subsoil is very likely to be acid but with considerable uncertainty in degree of acidity, and therefore *subsoil pH should always be checked*.

7.5 Alkalinity in parent material?

In whole data 52 cases (6.5%) had subsoil pH >7.5, though only 8 registered as calcareous by dilute HCl test in the field. In some cases this failed due to slow reaction of dolomitised material. 10 cases were designated by BGS as Sand & Gravel and 6 as Sandstones (Mg index 3 or less) but most alkaline subsoils (70%) were spread evenly across the various Mudstones though those classed as 'Dolomitic' or 'Siltstones' were always alkaline, sometimes due to green 'skerries' in the parent material.

Alkaline subsoils were most likely in Worcester Association (431) (50%, 6 samples), followed by 11 samples in Whimple 3 Ass. (572f, loam over red mudstone), 7 + 7 in Clifton and Salop Associations (711n/m, Till), 8 in the light loamy groundwater-affected associations (Everingham and Wigton Moor Ass., 821b/831c) and (surprisingly) 7 cases in Brignorth Ass. association (551a, sandy over sandstone).

Clearly the extent of calcareous soils on Triassic-derived strata cannot be predicted from SSEW or BGS maps. The topsoil is usually of lower pH (due to inclusion of Drift or decalcification).

7.6 Agronomic conclusion: pH levels in red soils of the Midlands

In this region of central and north west Midlands, 34% of the arable land was at target pH, 28% marginal pH (6-6.4) and only 12% acid (< pH 6) with almost no samples <pH 5.5.

For grassland 21% of better quality leys, 38% of the extensive grassland and 50% of amenity grass was below optimum (pH 6.0+). However, of the extensive grassland only 4% was below pH 5.5. 60% of woodland was < pH 6.0 or which 20% was below pH 5.

The data implies that most arable and intensive grassland farmers in the region are regulating pH by testing and liming, however control could be improved to reduce the number of samples below optimum.

Note that normally grass is sampled at shallower depth (7.5cm or 15cm) than the 20cm+ here, and so pH may be lower in main active layer of grassland, especially on fields which are not (rotationally) ploughed..

Topsoil pH tends to decrease in sequence arable > ley > extensive > amenity but not by a large amount (medians 6.6, 6.4, 6.1 and 5.9 respectively).

Topsoil pH is slightly influenced by topsoil texture with a median increase of 0.2 units from sandy to clay soils.

Topsoil pH *decreases* with topsoil OM% though it explains a poor amount of the variance.

Subsoil pH is strongly related to topsoil pH with a lesser influence of topsoil or subsoil texture. The regressions predict that at topsoil pH 6.0 subsoil pH is most likely to be 6.2 on a sandy soil increasing to 6.5 on a clay; at topsoil pH 5.5 subsoil is likely to be 5.9 and 6.1 respectively. However there is considerable uncertainty and in some cases subsoil is more acid than the topsoil.

The general rule holds that 'if topsoil pH is maintained adequate the subsoil will take care of itself.' However cases where subsoil is below 6 may constitute a risk for arable crops, and the following instances *pH of the subsoil* (to 50cm) is worth testing :-.

d) Topsoil pH < 6.4. Light loamy or sandy soils or stony subsoils or organic soils, where the fields have come out of longer term grass or been under minimal cultivation.
e) Topsoil pH < 6.0. Light loamy, sandy or stony subsoils, organic soils and all soils where cropping is sensitive to acidity e.g. barley, beans, sugar beet.
f) Topsoil pH < 5.5 all cases including intensive grassland.

If subsoil pH is below 6.0, the appropriate lime requirement can be added by over-liming the topsoil (to above 7) to accelerate leaching of bicarbonate, or "ploughing under" the extra lime or applying more lime the following autumn.

Neutral and alkaline soils: as topsoil pH approaches 7.0, the subsoil tends to parity for lighter soils and up to 0.5 higher on clays, though the latter may depends on the mineralogy. About 5% of topsoils were pH 7.5 or more and 6.5% of subsoils. Such moderately alkaline subsoils could be found within all the Triassic Mudstones and Siltstones, Glacial Till and (rarely) sandstones. Alkalinity cannot be predicted reliably from soil or geology maps except where the rocks are mapped as 'dolomitic'; Worcester association is most likely to contain calcareous layers in the (upper) subsoil.

8. Organic Matter

Region B: Central and NW Midlands

8.1 Overview of soil organic matter levels

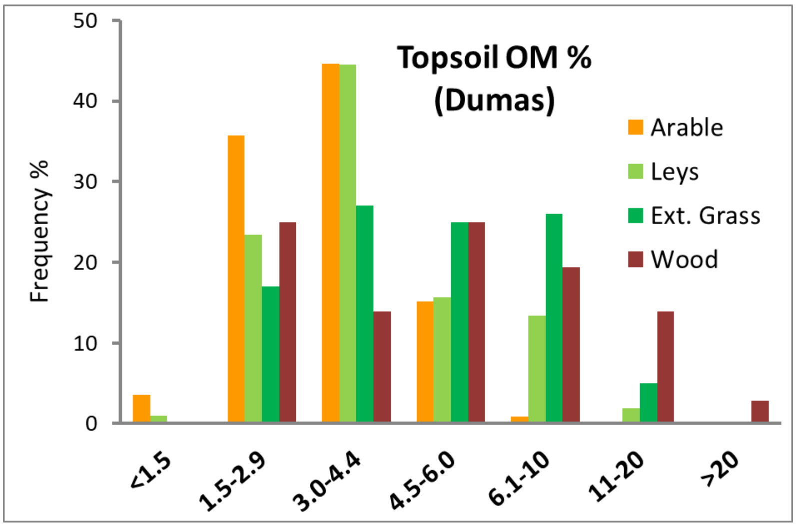


Figure 24a. Region B: Organic Matter content of Topsoil (balanced data)
The categories are as specified in Soil Survey of England and Wales manual with 3-4.4% designated moderate and > 6% OM as very high (here termed 'high' and the intermediate 4.5-6% range termed 'good').

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

Topsoil Organic Matter

Arable land: the median (3.2%) and modal category is 'moderate'. Few samples are very low. 16% of samples are Good or greater (4.5%+).

Grass leys tend to slightly higher topsoil OM than arable samples (median 3.8%) with 31% of samples 'good' or greater but very few 'organic'.

In extensive (presumably permanent) **grassland**, median topsoil OM is higher (4.7%). 31% of samples were > 6.0% (high) of which 5% are organic. NB This is to a sample depth of usually 20cm so in the surface layer OM% could be quite high. Amenity grass is similar.

Woodland has the highest average OM though on too small a sample size to be definitive.

It is evident from Table 18 that a few samples with very high organic matter can distort the means which is why medians are more useful for agronomic purposes.

Notwithstanding, the data implies that under "natural scenarios" (woodland, extensive and amenity grassland) the topsoil organic matter is about 1.0% greater than in leys and 1.5% higher than in arable land. Environmental issues (carbon stocks) are mentioned at the end.

Table 18. Region B : Typical Soil Organic Matter % (balanced data)

	Topsoil			Upper Subsoil			
	mean	**median**	**10-90%**	**mean**	**median**	**10-90%**	
Arable	3.3	**3.2**	2.0-4.8	1.9	**1.7**	0.9-3.0	*225*
Leys	4.3	**3.8**	2.5-6.8	2.3	**1.7**	0.9-3.4	*209*
Extensive Grass	5.3	**4.7**	2.8-9.2	2.8	**2.2**	1.3-4.6	*100*
Amenity Grass	4.3	**4.3**	2.9-6.4	2.1	**1.9**	1.1-3.1	*15*
Wood	6.2	**5.2**	2.3-11.8	2.9	**2.3**	1.0-5.1	*36*

Subsoil Organic Matter

Arable land: median is 1.7% (low). 40% of samples were very low; only 11% exceeded 3.0% and almost none exceeded 4.5%.

Under **grass leys** the subsoil OM is not greater than under arable crops. 32% of samples were very low and only 14% exceeded 3.0%.

Under **extensive Grassland and Woodland** the median OM% is about 0.5% greater but still categorised as low (<3%) though covering a wide distribution form very low to organic (>10% OM). The tail of samples with high OM might be due to the greater frequency of wet soils in these categories.

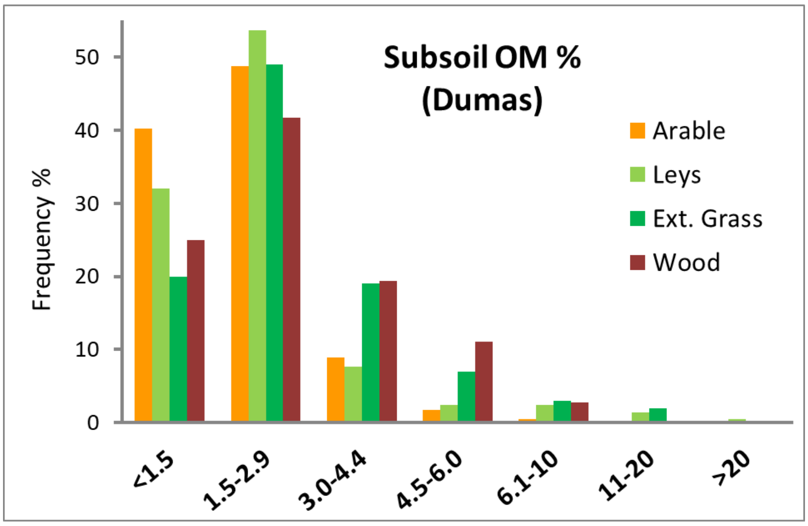


Figure 24b. Region B: Organic Matter in Subsoil (balanced data)

8.2 Factors influencing organic matter the topsoil

As shown earlier (Table 5) there is an influence of sampling method. Closer analysis (appendix 11.10) shows no difference on arable fields but on leys the corer method averages 0.7% OM higher than auger and 0.4% higher on the extensive/amenity grassland. This is almost certainly because the corer always includes the surface layer whereas samples taken from the auger may not. Since both methods were used throughout the data set the overall trends remain valid.

For arable and ley data there is a small effect of texture class - a 0.2% increase between sand and medium texture, but a larger jump (0.5%) to heavy loam or clay topsoils. The proportion of arable to ley is similar in all texture categories so land use is not the reason.

For extensive and amenity grass there is no consistent trend with texture (Table 19b). In this region there are a lot of dark sandy loams in less well drained sand and gravel deposits.

Table 19a Region B: Topsoil Texture and organic matter, All Arable and ley data

Class	**Textures**	**Mean** OM %	**Median** OM %	***n*** arable	***n*** leys
0	LS,S	3.24	**3.2**	*10*	*8*
1	SL, fSL, SZL	3.40	**3.4**	*107*	*92*
2	SCL, mCL (mZCL)	3.66	**3.4**	*131*	*144*
3,4	hCL – C	4.35	**4.0**	*40*	*41*

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.

8.3 Factors influencing organic matter levels in subsoil

Table 19b Region B: Topsoil Texture and OM, Extensive & Amenity Grass

Class	**Textures**	**Mean** OM %	**Median** OM %	***n***
(0) 1	LS, SL, SZL	5.2	**4.7**	*64*
2	SCL, mCL (mZCL)	4.4	**3.9**	*66*
3,4	hCL – C	6.7	**5.2**	*40*

Averages in subsoil textural groups are shown in Table 20 and examined in Figures 25-27.

Table 20a Region B: Subsoil Texture and organic matter, All Arable and ley data

Class	**Textures**	**Arable** mean	**Arable** median	**Ley** mean	**Ley** median
0	LS,S	1.87	**1.6**	*1.86*	***1.5***
1	SL, SZL	1.80	**1.6**	*2.14*	***1.8***
2	SCL, mCL (mZCL)	1.91	**1.8**	*2.07*	***1.7***
3,4	hCL – C	1.76	**1.7**	*2.14*	***1.7***

Table 20b Region B: Subsoil Texture and OM, Extensive & Amenity Grass

Class	**Textures**	**Mean** OM %	**Median** OM %	***n***
0	LS	1.89	**1.6**	*7*
1	SL,SZL	2.79	**2.2**	*42*
2	SCL, mCL (mZCL)	2.35	**1.9**	*42*
3	SC, hCL, hZCL	2.46	**1.8**	*32*
4	C, ZC	2.59	**2.5**	*46*

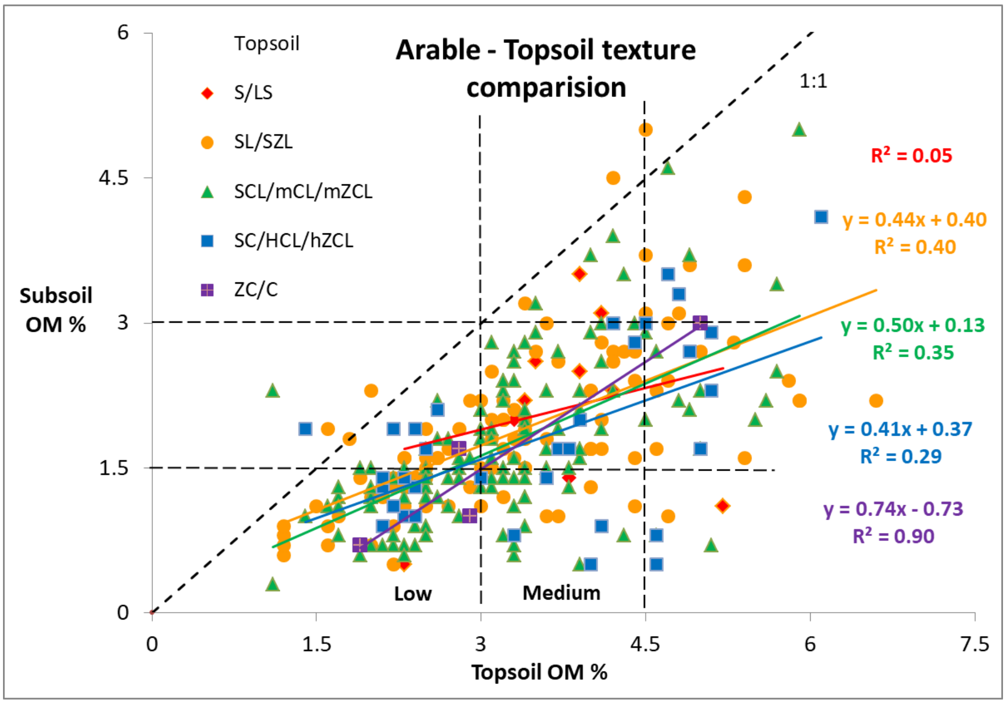


Figure 25a. Region B: Organic Matter in Topsoil and Subsoil - Topsoil Texture influence

Arable data: topsoil versus subsoil organic matter is plotted in Figure 25a.

The plots do not differ significantly for any of the *topsoil texture* categories. When topsoil OM% is moderate the subsoil is most likely to be low but can be very low (<1.5%); when topsoil is low (<3%), subsoil is most likely to be very low, but with considerable uncertainty.

Figure 25b suggests that as topsoil OM% increases the *proportionate* increase in subsoil OM% is least on heavy subsoils, increasing in order of subsoil texture:
clay < heavy loams < medium < light loams

When subsoil texture category is factored in and sand subsoils excluded, the overall r^2 is improved (0.41) and fits Δ0.14% OM between categories. Inclusion of subsoil stoniness gives a further improvement, with 0.18% OM increase associated with each stone category in subsoil (about 10% by volume).

The subsoil data for sands may fit a lower line but r^2 is very poor (0.24) however Tables 20a,b suggest that sandy textures may retain less organic matter. If stone category is included r^2 improves for sandy subsoils and gives the same increase with stone class as sandy loams (Δ0.19% OM) so it can be tentatively concluded that lighter stony subsoils may concentrate the organic matter that gets taken down.

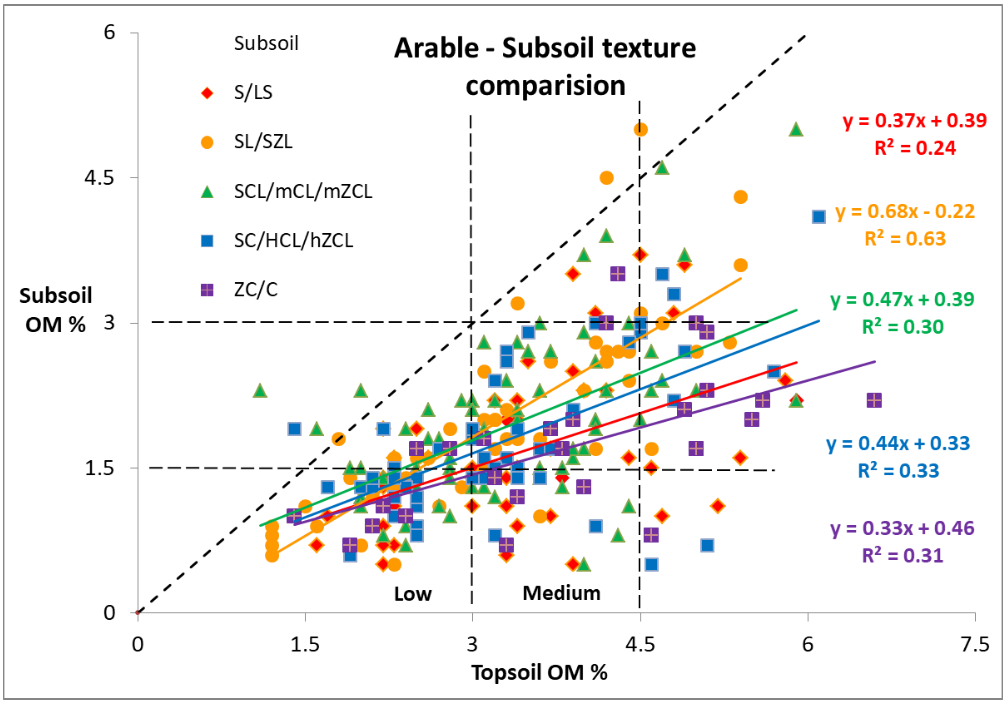


Figure 25b. Region B: Organic Matter in Topsoil and Subsoil - Subsoil Texture influence

Topsoil OM% is by far the biggest determinant of subsoil OM% but only explains 35% of the variation on the arable plots.

Relationship is Subsoil OM% = Topsoil OM% x 0.46 + 0.28 $r^2 = 0.35$

Separation of the corer and auger data shows identical intercept but the corer data has steeper slope than the auger (0.51 versus 0.36) and much better r^2 (0.53 versus 0.21). On average subsoil OM is 0.4% higher by corer method (Appendix 11.10)

The difference may be because with the corer, sampling the subsoil tends to start at a lesser depth than with the auger.

Grass data: leys, extensive and amenity grassland are combined (Figure 26). Data (10) with topsoil OM >10% are excluded to prevent undue influence. For clarity all the lines have been forced through origin with little loss of r^2.

Subsoil texture does not affect the fitted line except for sandy loams where subsoil OM is proportionately higher, as found on the arable data (Figure 25b) and therefore probably genuine.

Under grass when topsoil OM (to 20cm+) depth is moderate, subsoil will be low or very low OM%. When topsoil OM is good (4.5-6.0%) subsoil is most likely to be low (<3.0%).

At higher topsoil OM (> 6%) subsoil OM is highly unpredictable, ranging from low to high.

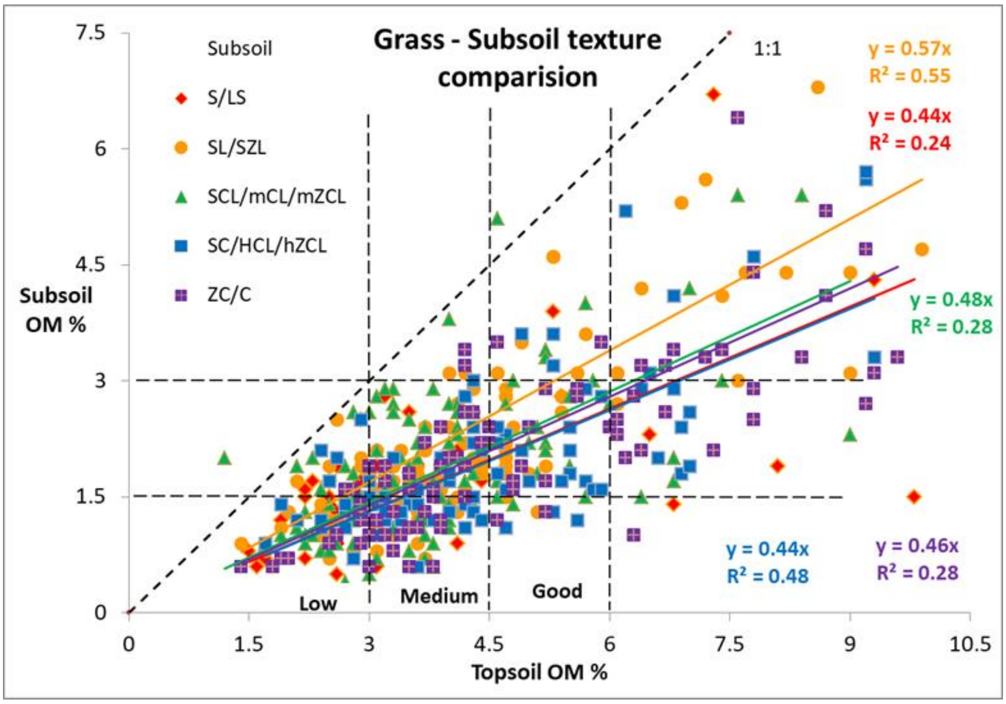


Figure 26: Region B: Organic Matter in Topsoil and Subsoil - Subsoil Texture influence

Regression analysis confirms that under grass the topsoil OM% is the biggest determinant of subsoil OM%. Relationship is

Subsoil OM% = Topsoil OM% x 0.47 + 0.1 $r^2 = 0.38$

The slope is identical to arable data but intercept appears somewhat lower.

Subsoil stoniness has a *negative* influence reducing subsoil OM by 0.35% per stone class and opposite to arable.

Separation of the corer and auger data shows very similar intercept but the corer data has steeper slope than the auger (0.50 versus 0.40) and much better r^2 (0.49 versus 0.25). On average subsoil OM was 0.26% higher by corer method (Appendix 11.10).

As with arable data the difference is probably because with the corer sampling of subsoil tends to start at a lesser depth than with the auger.

Woodland data is shown in Figure 27: examples in the organic range (>10%) are included, but rare on medium and heavy textures. Light loam subsoils fit a steeper line (the gradient is unchanged if very high point is excluded). For the other subsoil textures there is a significant intercept (>1.0%) and lower slope than found on arable and grass data, suggesting that in woodland OM accumulated in the topsoil does not penetrate so far down in medium and heavy subsoils.

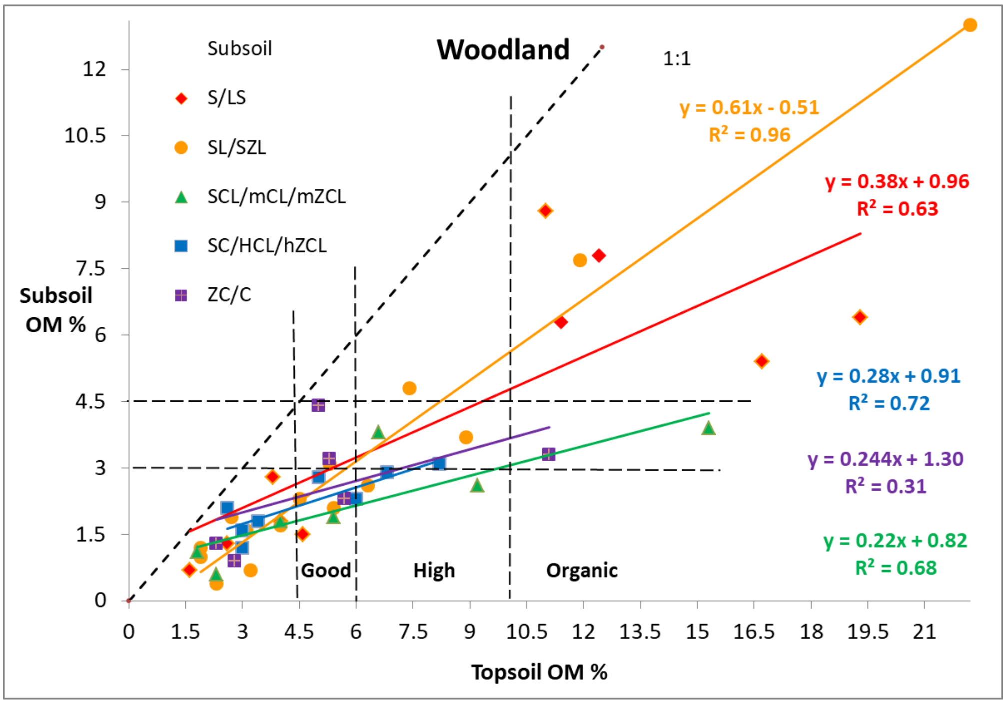


Figure 27: Region B: OM in Woodland Topsoil and Subsoil - Subsoil Texture influence

Regressions for woodland are

Sand to light loam	Subsoil OM% = Topsoil OM% x 0.50 + 0.1	$r^2 = 0.81$
Medium to clay	Subsoil OM% = Topsoil OM% x 0.21 + 1.32	$r^2 = 0.38$

There was no influence of sampling method.

8.4 Agronomic conclusion: organic matter levels in red soils of the Midlands

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

Sampling method had no influence of OM measurement of topsoil on arable land but was 0.4-0.7% higher on grassland, reflecting inclusion of the surface layer by corer which was not always case with samples taken from auger. Subsoil OM was proportionately higher by corer (by an average 0.4% and 0.26% on arable and grassland) which is partly due to subsoil sample starting at somewhat shallower depth than auger - in the latter purer subsoil cores were selected, frequently starting below 35cm.

Median OM values are lower than mean values and probably a more reliable indicator for agronomic purposes. Notwithstanding these uncertainties, the data for the Central and NW Midlands shows :

Arable topsoils had median OM of 3.2% (moderate). Very few samples were below 1.5% and only 16% of samples considered Good or higher (4.5%+).

Grass ley topsoils were slightly higher - median 3.8% OM with 31% of samples >4.5% but very few >10% ('organic'). Under **amenity and extensive grassland** OM was significantly higher, medians 4.3 and 4.7% OM, though including more wet sites than other cropping categories. 5% of topsoils were >10% OM. Note that the median identifiable depth of topsoil under grassland was 25cm and samples were taken to at least 20cm depth, compared to 7.5cm or 15cm RB209 recommends for permanent and grass leys up to 5 years old.

Woodland topsoil OM was highly variable but median was 5.2%. This data suggests that under more "natural scenarios" - woodland, extensive and amenity grassland - the topsoil organic matter is about 1.0% greater than grass leys and 1.5% than arable land (though the latter has greater average sample depth (30cm versus 25cm in grass).

For arable data, topsoil texture had some influence on topsoil OM levels, median increasing from 3.2% for sandy topsoil to 4.0% on clays. There was no texture effect under grassland.

In woodland organic topsoils (>10%) were common in sand and light loam textures but rare in medium or heavy soils. The sample size (50) was small compared to other groups.

Subsoil organic matter

Subsoil OM% was strongly related to topsoil OM%, unrelated to topsoil texture but influenced by subsoil texture - with OM levels proportionately lower on sand subsoils and higher on light loam subsoils. This was found on both arable and grassland, and may be due to a) poorer OM retention on sands b) more ready carry-down of organic matter (by earthworms) on light loams than medium or clay subsoils.

Stones may concentrate any OM input from earthworms (or deeper roots). On the lighter soils there was an influence of subsoil stoniness, with each stone category (estimated 10% by volume) corresponding to +∆0.18% subsoil OM on arable land but a decrease of 0.35% on grassland.

Under woodland, subsoil OM% was proportionately higher in sands and light loams, and lower in medium and clay soils.

Topsoil OM% alone explains under half the variation in subsoil OM% (r^2 = 0.35-0.40) in arable and grass, more under woodland. Proportionately less OM is found in subsoil under grass and woodland than arable.

Table 21 indicates typical values but the indifferent r^2 (and sampling method influence) implies considerable range around these averages cited.

As a generalisation, on arable soils at moderate organic matter (3-4.4%) the subsoil is likely to be low (1.5-2.9%). If the topsoil is low, the subsoil is low or very low.

For grass leys at moderate topsoil OM, the subsoil is likely to be low or very low OM. If topsoil is low OM subsoil will be very low. When topsoil OM is good (4.5-6.0%) subsoil is most likely to be low (<3.0%) and at high topsoil OM (> 6%) the subsoil OM is highly unpredictable, ranging from low to high.

Table 21: Prediction of subsoil Organic Matter

Text Class	Topsoil	Equation Subsoil OM % =	at Topsoil OM% 2.0	3.0	4.5	6.0	10
see *	Arable	0.46 x Topsoil OM + 0.28	1.2	1.7	2.4	3.0	4.9
see *	Grassland	0.47 x Topsoil OM + 0.1	1.0	1.5	2.2	2.9	4.8
0,1	Woodland	0.50 x Topsoil OM + 0.1	-	1.6	2.4	3.1	5.1
2-4	Woodland	0.21 x Topsoil OM + 1.32	1.1	2.0	2.3	2.6	-

* subsoil OM somewhat more than prediction in light loam subsoils and less in sands.

As topsoil organic matter increases, some gets carried down by (historically) deep cultivation and/or earthworms or other soil forna and, this results in significant increases in OM below the normal cultivated layers. Under arable use especially clay subsoils are more resistant because a) are (historically) less likely to have been deep ploughed and b) higher packing density limits lateral rooting and earthworms are less able (or unable) to carry topsoil material downwards into the subsoil.

For arable and leys a realistic target to aim for.in the upper subsoil in Triassic soils 25-50cm depth is 2.5% (Dumas method). This will improve potash retention, phosphate availability and soil structure.

8.5 Carbon stocks

Carbon held in soil profile is not simply proportional to measured OM% because it also depends on horizon depths, stones and bulk density. Density is higher on sandy or compact soils.

A calculation has been devised to convert this data to total carbon to 50cm depth, adjusting for sampling depth and standardising at 0-25cm and 25-50cm. On this data it eliminated the sampling method difference for arable data, although on grassland the corer method still tends to higher estimation of carbon in the top 25cm.

Mean calculated carbon 0-50cm depth was **95 t C/ha** on arable land increasing to **137 t C/ha** under extensive (permanent) grassland and 160 t C/ha under woodland. These averages are lower than calculated for the north east region Carboniferous soils - 125 t/ha on arable land and 170 t/ha under grass, though the latter region had a lesser representation of lighter soils.

The calculation needs peer review and verification before any data can be published. Soil texture may be critically important, especially under woodland.

For environmental studies, subsoil OM and carbon might be approximated from topsoil measurement using Table 21 but both topsoil and (ideally) subsoil needs to be measured to standardised sampling depths using a corer method.

9. Total Nitrogen

Region B: Central and NW Midlands

Total N measurement is of environmental and agronomic relevance. It influences the release of available nitrogen to crops (and grass) by mineralisation. The AHDB winter wheat guide (2012) stated these limits and organic matter measurement might be used as a surrogate.

Increase soil N supplies to allow for mineralisation, according to Table 9.

Table 9. Estimate additional mineralisable N on organic soils

Topsoil organic matter	Topsoil total N	Additional SNS England & Wales	Additional SNS Scotland & N Ireland
<6%	under 0.35%	Insignificant	Insignificant
6-10%	0.35 to 0.6%	+ 40kg/ha N	Insignificant
11-15%	0.6 to 0.9%	+ 100kg/ha N	+ 20kg/ha N
16-20%	1.0 to 1.2%	+ 150kg/ha N	+ 60kg/ha N
>20%	over 1.2%	+>150kg/ha N	+>100kg/ha N

While these estimates of mineralisable N are not quoted in *The Fertiliser Manual* or *SAC Technical Note 625*, they are derived from these N recommendations.

RB209 (2017) Arable p16 states *"As a guide, where measurement is not done, for every 1% organic matter above 4%, a topsoil may release an additional 10 kg N/ha to crops"* (equivalent to a fertiliser-substitute 15 kg N/ha if fertiliser is 65% efficient).

This report uses the above total N ranges to rank values in the data set. 0.23% total N corresponds to the 4% OM implied above.
Not all samples were measured for total N and these data are in clusters so may not be as representative averages as the PKMg pH or OM graphs derived from the 'balanced' data set.

Total N in topsoil

Arable: Figure 28a shows that hardly any topsoils were in the 0.35%+ category, although 32% were >0.22% TN and therefore eligible for a small mineralisation adjustment to the nitrogen recommendations. Median TN was 0.19% (Table 23), very close to the 0.2% figure often cited as typical.

Grass: the number of samples >0.35% and 0.23-0.34% TN rose to 10 and 38% of the data. It is uncertain whether such raised total N will persist once these soils revert to arable use.

Total N levels tend to be higher under extensive (permanent) grassland and highly variable under woodland.

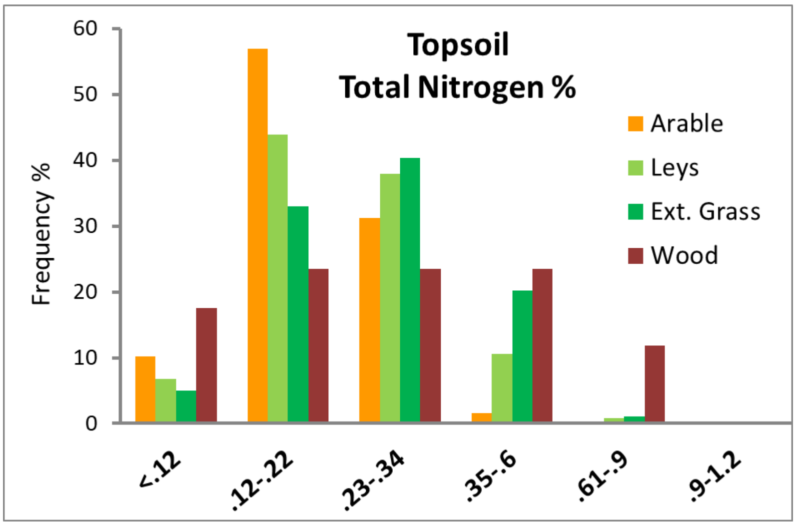


Figure 28a. Region B: Total Nitrogen content of Topsoil (where measured)

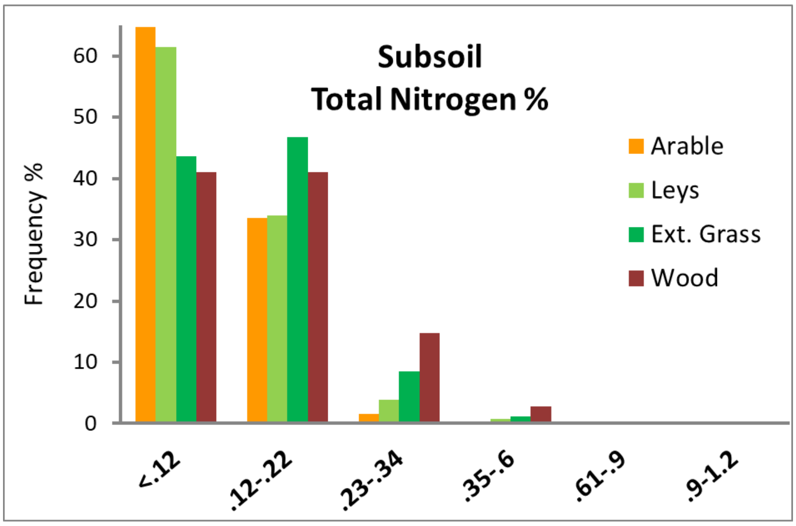


Figure 28b. Region B: Total Nitrogen content of Subsoil (where measured)

Topsoil N in subsoil

Arable and ley subsoils averaged 0.1% TN, somewhat higher under extensive grass and woodland.

Table 22 Region B : Typical Soil Total Nitrogen % (where measured)

	Topsoil			Upper Subsoil			
	mean	**median**	**10-90%**	**mean**	**median**	**10-90%**	***n***
Arable	0.19	**0.19**	0.11-0.27	0.11	**0.10**	0.06-0.16	*128*
Leys	0.24	**0.22**	0.12-0.35	0.11	**0.10**	0.06-0.17	*132*
Extensive Grass	0.26	**0.26**	0.12-0.38	0.14	**0.13**	0.06-0.21	*94*
Amenity Grass	0.20	**0.21**	9.12-0.27	0.11	**0.08**	0.05-0.17	*9*
Wood	0.30	**0.28**		0.15	**0.14**	0.05-0.27	*34*

Factors affecting total Nitrogen levels

Nitrogen resides mainly in the organic matter and not surprisingly shows a strong correlation with measured OM. Statistical analysis is summarised in Table 23. OM is reported as 1.72x Carbon; the commonly cited C:N ratio of 10:1 should give a coefficient of 0.058 OM.

In fact, all but one data sets have slope <0.058 and significant intercept ($P < 0.01$, see Appendix 11.11) which implies that C:N ratio diminishes as the level of organic matter (and TN) increases.

Notwithstanding the C:N ratio averaged about 10 for arable and leys, although the standard deviation is quite wide. The samples were taken in clusters of 2 to 15 samples, usually in the same field, and analysis indicates that variation within a cluster is often lower than the variation between clusters. Some clusters averaged as low as 8:1 and some as high as 12:1.

C:N seems to be higher on extensive grassland and woodland, and clusters in some woods gave significantly different average values than in other woods.

C:N ratio in subsoil on average is 0.5 less than in topsoil for arable, grass and woodland.

Table 23 Region B : Predicting Soil Total Nitrogen from Organic Matter measured by Dumas Method (OM = OC x 1.72)

		Equation	r^2	C:N mean	C:N std dev
Arable	Topsoil	TN = OM x 0.045 + 0.04	0.66	10.5	2.0
	Subsoil	TN = OM x 0.041 + 0.03	0.60	10.1	2.8
Leys	Topsoil	TN = OM x 0.047 + 0.05	0.63	10.1	2.5
	Subsoil	TN = OM x 0.038 + 0.04	0.71	9.7	2.6
Extensive Grassland	Topsoil	TN = OM x 0.053 + 0.01	0.86	12.1	1.9
	Subsoil	TN = OM x 0.047 + 0.02	0.77	11.0	3.1
Woodland	Topsoil	TN = OM x 0.035 + 0.06	0.82	12.6	3.4
	Subsoil	TN = OM x 0.036 + 0.03	0.87	12.1	2.9

The data suggests that C:N ratio is affected by management factors, and possibly soil texture/type. Direct measurement of total N to estimate nitrogen mineralisation is better than carbon measurement unless the causes of variable C:N ratio can be quantified. This will be examined in more detail combining with data from the southern region.

Dumas is a good method for measuring organic carbon inasmuch as it gives C:N ratios broadly in line with expectations. However, when carbon is calculated from organic matter measured by Loss on Ignition commonly gives C:N ratios 12-14:1 which are misleading.

10. Evaluation of Accuracy of Geological and Soil Survey maps

BGS Geology maps

British Geological Society (BGS) maps [1] are very detailed and a full breakdown is given in table 24 below.

Trends of hand-texture

a) on the Sandstones, and Sand & Gravel deposits main texture is sandy loam but could vary from sand to medium loam (Class 2, 18-27% clay) or heavier.

b) on mudstones, Glacial Till and Alluvium median texture is medium but varies from sandy loam to clay in topsoil or upper subsoil (to 50cm). Very few samples marked as directly on Mudstone had clay topsoils and relatively few had clay subsoil 30-50cm. This is indicative of widespread 'thin loamy drift' not mapped by BGS.

Profiles in Glacial Till could exhibit short range variation of sandy (LS) and clayey (SC) layers, and areas mapped as Sand & Gravel could contain heavier loam layers. Frequently the underlying stoneless red clay (Solid Mudstone) was encountered within 80cm, conversely on areas mapped as drift-free there could be sandy or loamy deposits covering the clay to at least 60cm.

Sometimes there were interlayers of red hCL or SL texture in the lower subsoil derived from the solid geology (i.e. sandstone within mudstone).

Soil Survey maps

Each point was located on the Soil Survey of England and Wales 1:250 000 maps [2]

25 associations are present; a full breakdown is given in second Table 25.

Experience of the surveyors was that the majority of soil profiles and their drainage corresponded to descriptions in the SSEW manuals. However the latter cite a range of textures within each association and in 26% of profiles surveyed the textures of topsoil were judged outside the generic description and 42% the textures in upper subsoil (values in red).

Soils mapped within *Arrow, Brockhurst and Clifton* Associations have very wide variation in textures which is in some cases because changes in Drift or Solid geology on the BGS maps are combined into a single larger area on the SSEW maps. The main limitations of using the BGS maps to predict profiles are the uncertain depth and variable nature of superficial deposits (often not shown) and inter-bedding in some Solid deposits.

Clearly neither SSEW nor BGS maps are safe to rely on to deduce the soil texture without field examination.

Table 24 Region B: Geology Summary and Textures

Numbers of locations unless indicated %.
Hand-Texture Class : 0 = sand ,loamy sand 1= sandy loam, sandy silt loam 2 = sandy clay loam, medium clay loam 3 = sandy clay, heavy clay loam, heavy silty clay loam, 4 = silty clay, clay P Peaty Median value emboldened.

BGS Geological designation		No	Surface	Topsoil Texture class						U. Subsoil Texture Class					
	Solid	Drift	%	0	1	2	3	4	P	0	1	2	3	4	P
Sandstones															
Butterton Sandstone	1	1	*0.2*			1					1				
Chester Mudstone & Conglomerate	17	11	*1.9*	1	**9**	1				2	**7**	2			
Chester pebbly Sandstone	4	3	*0.5*		3					1	2				
Helsby Sandstone	23	22	*3.8*	2	**15**	4	1			5	**13**	1	3		
Salop Sandstone	4	3	*0.5*		1	2				1		2			
Kenilworth Sandstone	9	8	*1.4*	1	**6**	1					**7**	1	1		
Lenton Sandstone	3	1	*0.2*		1						1				
Tile Hill Sandstone	2	2	*0.3*		1	1					2				
Wildmoor Sandstone	33	21	*3.6*	4	**15**	2				9	**6**	6			
	16%		***12%***												
Siltstones or mixed															
Arden Sandstone	2	2	*0.3*			1		1			1			1	
Ashow Mudstone & Sandstone	9	9	*1.5*		4	**4**	1				1	**4**	**4**		
Disewell Sandstone	1	1	*0.2*				1						1		
Edlingston Mudstone & Sandstone	2	2	*0.3*				2						2		
Gunthorpe Dolomitic Siltstone	1	1	*0.2*				1							1	
Halesowen Formation	16	6	*1.0*		2	**3**	1			1	1	**3**		1	
Sidmouth Dolomitic Siltstone	4	3	*0.5*			2	1						3		
Tarporley Siltstone	16	16	*2.7*		6	**8**	2			1	**6**	**5**	4		
	9%		***7%***												
Mudstones															
Branscombe Mudstone	36	15	*2.6*		4	**9**	2				2	**6**	**7**		
Gunthorpe Mudstone	64	8	*1.4*		3	**2**	1	2				3	**3**	2	
Helsby Mudstone	1	1	*0.2*		1							1			
Mercia Mudstone	52	21	*3.6*		6	**12**	3			1	1	**14**	4	1	
Mercia Mudstone & Halite	66	58	*9.9*		9	**36**	9	4		1	9	**23**	13	12	
Salop Mudstone & Conglomerate	22	16	*2.7*			**14**	2			1	1	**4**	4	6	
Sidmouth Mudstone	121	10	*1.7*			**6**	4			1		**4**	3	2	
Tarporley Mudstone	6	4	*0.7*		1	3					1	2	1		
Tile Hill Mudstone	13	2	*0.3*		1	1						2			
Wilkersley Mudstone & Halite	54	2	*0.3*		1	1					2				
	75%		***22%***												
Drift															
Alluvium		67	*11.4*		19	**21**	**22**	5		4	12	**14**	**13**	24	
Silt & Gravel		1	*0.2*				1							1	
Beeston Sand & Gravel		33	*5.6*	0	21	10	1		1	8	**17**	6	1	1	
River Terrace Sand & Gravel		34	*5.8*		**19**	8	5	2		6	**16**	4	4	4	
Glaciofluvial Sand & Gravel		82	*14.0*	7	**46**	26	3			23	**29**	16	7	7	
Glacial Till (usually reddish)		98	*16.7*	1	**24**	**65**	8			8	24	**35**	17	14	
Oadby Till (not red)		10	*1.7*		1	1	**7**	1				2	1	**7**	
Head		1	*0.2*				1						1		
Peat		4	*0.7*			4					1		1	1	1
Disturbed		4	*0.7*		1	1	3					3	2		
			58%												

Table 25 Region B: Soil Associations and hand-textures

Numbers of locations unless indicated %. Texture Classification see Table 24
Textures in red lie outside those in designation for the Soil Association
(sandy = 0, coarse loamy = 1, fine loamy = 2, 3, clayey = 3,4)

Map Code	Soil Association	Description (abbreviated)	n	%	Topsoil Texture class 0	1	2	3	4	P	U. Subsoil Texture Class 0	1	2	3	4	P
431	Worcester	Slowly permeable non- or calcareous reddish clayey soils over mudstone.	10	***1.7***		1	2	4	3				2	4	4	
543	Arrow	Deep permeable coarse loamy soils affected by groundwater	50	***8.6***	2	25	19	3	1		8	19	15	7	1	
541b	Bromsgrove	Well drained coarse loamy soils mainly over soft sandstone, locally deep.	21	***3.6***	1	17	3				2	16	2	1		
541r	Wick 1	Deep well drained sandy and coarse loamy soils, locally over gravel	57	***9.8***	1	29	19	6	2		9	19	13	8	7	1
551a	Brignorth	Well drained sandy and coarse loamy soils over soft sandstone.	47	***8.0***	5	31	9	2			16	17	12	2		
551d	Newport 1	Deep well drained sandy and coarse loamy soils.	9	***1.5***	2	5	2				4	2	1	2		
572c	Hodnet	Reddish fine and coarse loamy soils with slowly permeable subsoils.	11	***1.9***		2	7	2				2	6	3		
572f	Whimple 3	Reddish fine loamy/silty over clayey soils with slowly permeable subsoils	117	***20.0***		18	81	15	3		6	15	50	26	20	
572l	Flint	Reddish fine loamy over clayey soils with slowly permeable subsoils	2	***0.3***		1	1					1	1			
711b	Brockhurst 1	Slowly permeable reddish fine loamy over clayey and clayey soils	33	***5.7***		13	15	4	1		1	10	5	7	10	
711c	Brockhurst 2	As above with some alluvial soils affected by groundwater	4	***0.7***		2		2			1	1		2		
711m	Salop	Slowly permeable reddish fine loamy over clayey and clayey soils	13	***2.2***			3	9	1				1	6	6	
711n	Clifton	Slowly permeable reddish coarse and fine loamy soils.	100	***17.1***	3	30	57	7	1		11	25	31	16	15	
711o	Rufford	Slowly permeable coarse loamy over clayey soils	7	***1.2***		2	5				2	2	2	1		
711t	Beccles 3	Slowly permeable fine loamy over clayey soils.	3	***0.5***		1	1	1					2		1	
712f	Crewe	Slowly permeable reddish clayey and fine loamy over clayey soils	1	***0.2***			1						1			
811a	Enborne	Deep stoneless fine loamy and clayey soils (groundwater affected)	1	***0.2***			1					1				
813a	Mildeney	Stonless clayey soils mostly overlying peat (groundwater affected)	9	***1.5***		3	0	5	1			1	2	3	3	
813b	Fladbury 1	Stoneless clay soils, locally calcareous (groundwater affected)	10	***1.7***		4	2	4				3	2	1	4	
813c	Fladbury 2	Stoneless mostly clayey soils (groundwater affected)	9	***1.5***		4	2	2	1			1	2	3	3	
813e	Compton	Stoneless mostly clayey soils (groundwater affected)	4	***0.7***				3	1					1	3	
821b	Everingham	Deep permeable stoneless fine sandy soils (groundwater affected)	39	***6.7***	2	23	11	2		1	12	15	9	1	2	
831c	Wigton Moor	Permeable fine and coarse loamy soils (groundwater affected)	16	***2.7***		3	5	8				6	3	3	4	
1022a	Altcar 1	Deep peaty soils with earthy topsoil. Groundwater controlled by ditches	9	***1.5***		2	3	4			2	0	2	3	2	
U	Urban		1	***0.2***		1						1				

References

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

2 J.M.Ragg,, G.R. Beard, .H.George et al (1984) Soils and their Use in Midland and Western England. Soil Survey of England and Wales Bulletin 12

11. Regression and correlation

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 r² is improved by including the factor. Texture and stones are classes 0-4 and 0-3

11.1 Influence of topsoil parameters on subsoil P

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	*andard 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 $r^2 = 0.76$

11.2 Influence of Subsoil parameters on subsoil P

All arable data (topsoil P up to 70 mg/l)								
	Method	*Topsoil P*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*
Method	1							
Topsoil P	0.07	1						
Sub Texture	-0.04	-0.29	1					
Sub Stones	0.19	-0.04	-0.19	1				
Subsoil OM%	0.25	0.26	-0.04	0.20	1			
Subsoil pH	-0.12	0.03	0.20	-0.18	-0.14	1		
Subsoil P	0.20	0.80	-0.30	0.12	0.36	-0.02	1	
Subsoil K	0.08	0.43	0.09	0.13	0.20	0.12	0.43	1

Grass leys tpsoil P up to 70 mg/l)								
	Method	*Topsoil P*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*
Method	1							
Topsoil P	0.02	1						
Sub Texture	-0.07	-0.07	1					
Sub Stones	0.24	0.11	-0.30	1				
Subsoil OM%	0.19	0.03	-0.07	-0.02	1			
Subsoil pH	-0.02	0.27	0.09	-0.15	-0.07	1		
Subsoil P	0.11	0.78	-0.21	0.15	0.10	0.19	1	
Subsoil K	0.00	0.56	0.14	0.06	0.03	0.06	0.42	1

Extensive Grassland (topsoil P up to 70 mg/l)								
	Method	*Topsoil P*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*
Method	1							
Topsoil P	0.11	1						
Sub Texture	-0.14	-0.32	1					
Sub Stones	0.22	0.06	-0.43	1				
Subsoil OM%	0.08	0.04	0.01	0.05	1			
Subsoil pH	-0.03	-0.09	0.38	-0.12	-0.22	1		
Subsoil P	0.26	0.79	-0.38	0.20	0.13	-0.19	1	
Subsoil K	0.15	0.51	-0.08	0.14	0.22	0.16	0.39	1

The biggest determinant of subsoil P in all cases is topsoil phosphorus (*P* 0.8). Subsoil texture is of secondary importance. Subsoil Organic matter is important on arable soils but less on grassland. Sampling method is of some influence, probably via altering the organic matter in the sample.

pH has an inconsistent effect. Higher subsoil K seems associated with higher subsoil P.

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

11.3 Effect of sampling method on topsoil P: subsoil P relationship

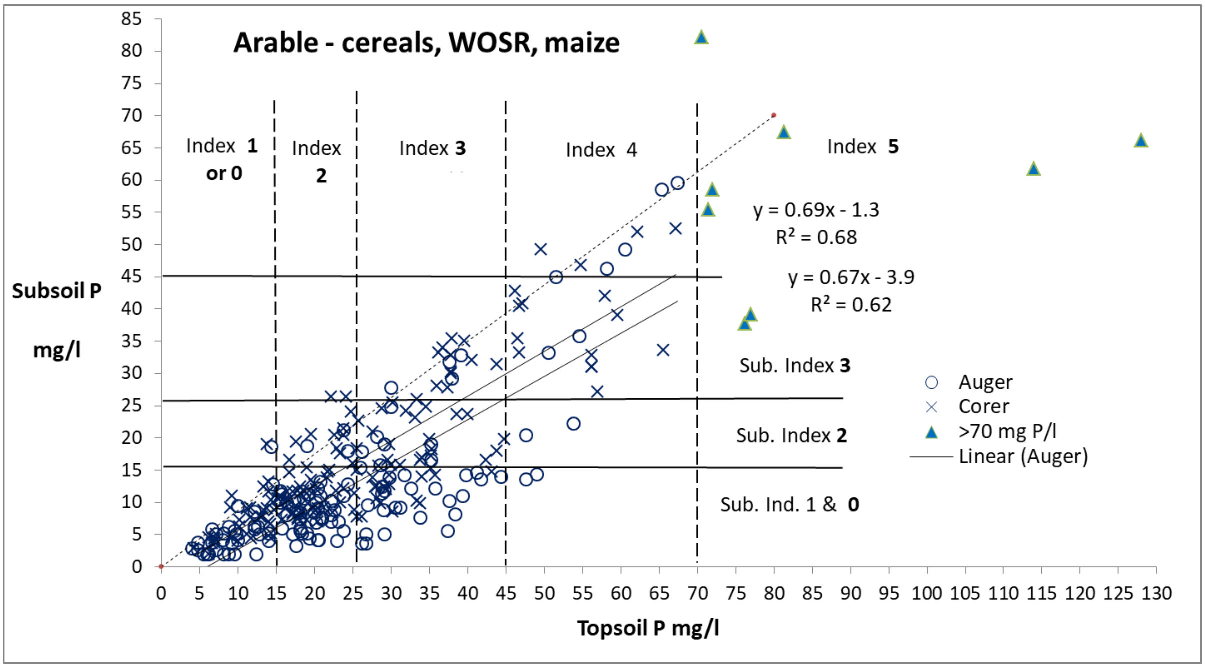


Figure 2. Region B: Phosphorus in Topsoil and Subsoil - effect of sampling method

Data above 70 mg P/l is excluded from the correlation lines though it follows a similar trend. Both techniques give significant correlation of subsoil P with topsoil P (r2 > 0.6) and similar slope but the corer (the higher line) gives subsoil P 2.6 mg/l higher than the auger technique probably due to lower start depth when taking the subsoil sample (see section 1).

The next two pages examine unified data (arable and grass minus reinstated profiles) for influence of method for different textural groups of subsoils.

All Arable and Grass up to 35 mg/l, sandy, light and medium loamy subsoil

Affect of sampling method on Subsoil P

Regression Statistics	
Multiple R	0.76
R Square	**0.57**
Adjusted R Squ	0.57
Standard Error	4.24
Observations	383

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	9135.402	4567.701	253.5747	1.1E-70
Residual	380	6845.03	18.01324		
Total	382	15980.43			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.13	0.49	0.27	0.79	-0.83	1.09	-0.83	1.09
Method	2.15	0.44	4.92	0.00	1.29	3.01	1.29	3.01
Topsoil P	0.51	0.02	21.50	0.00	0.47	0.56	0.47	0.56

Method (corer vs auger) increases subsoil by 2.2 mg P / l

Intercept is zero and proportionality is 51% of topsoil P

All Arable and Grass up to 35 mg/l, heavy loam subsoil

Affect of sampling method on Subsoil P

Regression Statistics	
Multiple R	0.79
R Square	0.62
Adjusted R Squ	0.62
Standard Error	3.16
Observations	123

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	1980.219	990.1097	99.34456	3.54E-26
Residual	120	1195.97	9.966421		
Total	122	3176.19			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.49	0.65	-0.74	0.46	-1.78	0.81	-1.78	0.81
Method	2.70	0.57	4.69	0.00	1.56	3.84	1.56	3.84
Topsoil P	0.42	0.03	13.40	0.00	0.36	0.49	0.36	0.49

Method (corer vs auger) increases subsoil by 2.7 mg P / l

All Arable and Grass up to 35 mg/l, Clay subsoil

Affect of sampling method on Subsoil P

Regression Statistics	
Multiple R	0.74
R Square	0.55
Adjusted R Squ	0.54
Standard Error	2.89
Observations	108

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	1062.35	531.1751	63.67359	7.77E-19
Residual	105	875.9265	8.342157		
Total	107	1938.277			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.80	0.55	1.46	0.15	-0.29	1.88	-0.29	1.88
Method	1.03	0.57	1.81	0.07	-0.10	2.15	-0.10	2.15
Topsoil P	0.35	0.03	10.61	0.00	0.28	0.41	0.28	0.41

Method (corer vs auger) increases subsoil by 1.0 mg P / l

All Arable and Grass 35-80 mg/l, Sand to medium subsoil								
Affect of sampling method on Subsoil P								
Regression Statistics								
Multiple F	0.56							
R Square	**0.31**							
Adjusted I	0.29							
Standard E	11.82							
Observati	87							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	2	5290.571	2645.286	18.93229	1.63E-07			
Residual	84	11736.77	139.7235					
Total	86	17027.34						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-8.50	6.74	-1.26	0.21	-21.91	4.91	-21.91	4.91
Method	4.87	2.66	1.83	0.07	-0.43	10.17	-0.43	10.17
Top P	0.79	0.13	6.10	0.00	0.53	1.05	0.53	1.05
Method (corer vs auger) increases subsoil by 5 mg P / l								
All Arable and Grass 35-80 mg/l, heavy loam or clay subsoil								
Affect of sampling method on Subsoil P								
Regression Statistics								
Multiple F	0.81							
R Square	0.65							
Adjusted I	0.62							
Standard E	10.87							
Observati	22							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	2	4244.085	2122.042	17.95288	4.19E-05			
Residual	19	2245.813	118.2007					
Total	21	6489.898						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-32.97	9.61	-3.43	0.00	-53.08	-12.87	-53.08	-12.87
Method	8.28	5.23	1.58	0.13	-2.66	19.21	-2.66	19.21
Top P	1.18	0.21	5.61	0.00	0.74	1.62	0.74	1.62
Method (corer vs auger) increases subsoil by 8 mg P / l								
Slope exceeds 1								
Woodland (all textures and topsoil P 0 - 90 mg/l								
Affect of samplng method								
Regression Statistics								
Multiple F	0.85							
R Square	0.73							
Adjusted I	0.72							
Standard E	7.03							
Observati	50							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	2	6237.66	3118.83	63.03903	4.96E-14			
Residual	47	2325.305	49.47458					
Total	49	8562.965						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-1.27	1.86	-0.68	0.50	-5.00	2.47	-5.00	2.47
Method	5.67	2.05	2.76	0.01	1.54	9.80	1.54	9.80
Top P	0.53	0.05	10.38	0.00	0.43	0.63	0.43	0.63
Method (corer vs auger) increases subsoil by 6 mg P / l								

11.4 Effect of Subsoil Organic Matter on topsoil: subsoil P relationship

All Arable and Grass up to 35 mg/l, sandy, light and medium loamy subsoil

Affect on Subsoil P on OM capped at 9%

Regression Statistics	
Multiple R	0.76
R Square	**0.58**
Adjusted R Squ	0.57
Standard Error	4.23
Observations	383

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	9190.644	4595.322	257.1836	2.35E-71
Residual	380	6789.789	17.86786		
Total	382	15980.43			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.66	0.56	-1.18	0.24	-1.75	0.44	-1.75	0.44
Subsoil OM%	0.88	0.17	5.24	0.00	0.55	1.21	0.55	1.21
Topsoil P	0.53	0.02	22.24	0.00	0.48	0.58	0.48	0.58

OM has a certain influence but 1 % OM increases subsoil P by 0.9 mg/l

Intercept is zero and proportionality is 53% of topsoil P

All Arable and Grass up to 35 mg/l, sandy, light and medium loamy subsoil

Affect on Subsoil P on OM capped at 6%

Regression Statistics	
Multiple R	0.76
R Square	**0.58**
Adjusted R Squ	0.58
Standard Error	4.18
Observations	383

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	9331.512	4665.756	266.6579	4.37E-73
Residual	380	6648.92	17.49716		
Total	382	15980.43			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-1.15	0.58	-1.99	0.05	-2.29	-0.02	-2.29	-0.02
Subsoil OM%	1.18	0.20	6.01	0.00	0.79	1.57	0.79	1.57
Topsoil P	0.53	0.02	22.39	0.00	0.48	0.57	0.48	0.57

Capping subsoil OM at 6% increases OM influence

Up to 6% each 1% increase in subsoil SOM increases subsoil P by 1.2 mg P/l

*Equation is Subsoil P = Topsoil P * 0.53 + Subsoil OM * 1.2 - 1.2*

All Arable and Grass up to 35 mg/l, heavy loam subsoil

Affect on Subsoil P OM capped at 6%

Regression Statistics	
Multiple R	0.76
R Square	**0.58**
Adjusted R Squ	0.57
Standard Error	3.35
Observations	123

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	1832.423	916.2117	81.81884	3.85E-23
Residual	120	1343.766	11.19805		
Total	122	3176.19			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.43	0.85	-0.51	0.61	-2.11	1.25	-2.11	1.25
Subsoil OM%	0.72	0.28	2.53	0.01	0.16	1.28	0.16	1.28
Topsoil P	0.43	0.03	12.73	0.00	0.36	0.50	0.36	0.50

*Equation is Subsoil P = Topsoil P * 0.43 + Subsoil OM * 0.7 - 0.4*

All Arable and Grass up to 35 mg/l, clay subsoil

Affect on Subsoil P OM capped at 6%

Regression Statistics	
Multiple F	0.73
R Square	**0.54**
Adjusted I	0.53
Standard I	2.93
Observati	108

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	2	1037.722	518.861	60.4965	3.33E-18
Residual	105	900.5547	8.576711		
Total	107	1938.277			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.81	0.79	1.03	0.31	-0.76	2.38	-0.76	2.38
Sub OM%	0.14	0.24	0.57	0.57	-0.35	0.62	-0.35	0.62
Top P	0.36	0.03	10.95	0.00	0.30	0.43	0.30	0.43

Subsoil OM has a negligible effect

*Equation is Subsoil P = Topsoil P * 0.36 + Subsoil OM * 0.15 + 0.81*

All Arable and Grass 35-80 mg/l, sandy, light and medium loamy subsoil

Affect on Subsoil P on OM capped at 6%

Regression Statistics	
Multiple F	0.55
R Square	**0.30**
Adjusted I	0.29
Standard I	11.88
Observati	87

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	2	5162.222	2581.111	18.27316	2.58E-07
Residual	84	11865.12	141.2515		
Total	86	17027.34			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-6.58	6.51	-1.01	0.32	-19.53	6.37	-19.53	6.37
Sub OM%	1.51	0.98	1.55	0.13	-0.43	3.45	-0.43	3.45
Top P	0.74	0.13	5.74	0.00	0.48	0.99	0.48	0.99

Subsoil OM makes a larger difference here?

*Equation is Subsoil P = Topsoil P * 0.74 + Subsoil OM * 1.5 - 6.6*

All Arable and Grass 35-80 mg/l, sandy, light and medium loamy subsoil

OM and method ignored

Regression Statistics	
Multiple F	0.53
R Square	**0.28**
Adjusted I	0.27
Standard I	11.98
Observati	87

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	1	4823.623	4823.623	33.59696	1.12E-07
Residual	85	12203.72	143.5732		
Total	86	17027.34			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-3.57	6.27	-0.57	0.57	-16.03	8.89	-16.03	8.89
Top P	0.75	0.13	5.80	0.00	0.49	1.01	0.49	1.01

r2 is worsened

Equation is Subsoil P = Topsoil P x 0.75 - 3.6

All Arable and Grass 35-80 mg/l, heavy loam and clay subsoil

Affect on Subsoil P on OM capped at 6%

Regression Statistics	
Multiple F	0.92
R Square	**0.85**
Adjusted I	0.84
Standard I	7.04
Observati	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	2	5548.482	2774.241	55.99076	1.08E-08
Residual	19	941.4158	49.5482		
Total	21	6489.898			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-43.88	6.55	-6.70	0.00	-57.58	-30.18	-57.58	-30.18
Sub OM%	9.70	1.71	5.68	0.00	6.13	13.27	6.13	13.27
Top P	1.07	0.14	7.71	0.00	0.78	1.36	0.78	1.36

Subsoil OM makes a large difference

*Equation is Subsoil P = Topsoil P * 1.07 + Subsoil OM * 9.7 - 44*

All Arable and Grass 35-80 mg/l, heavy loam and clay subsoil

OM ignored

Regression Statistics	
Multiple F	0.78
R Square	**0.61**
Adjusted I	0.59
Standard I	11.27
Observati	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	1	3947.695	3947.695	31.05727	1.87E-05
Residual	20	2542.203	127.1102		
Total	21	6489.898			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-32.06	9.94	-3.22	0.00	-52.80	-11.32	-52.80	-11.32
Top P	1.21	0.22	5.57	0.00	0.76	1.67	0.76	1.67

r2 is worsened now OM is omitted

Equation is Subsoil P = Topsoil P x 1.21 - 32

Woodland 0-90 mg/l topsoil P all textures

Affect on Subsoil P on OM capped at 6%

Regression Statistics	
Multiple F	0.86
R Square	**0.73**
Adjusted I	0.72
Standard I	6.98
Observati	50

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	2	6270.163	3135.081	64.26581	3.56E-14
Residual	47	2292.802	48.78303		
Total	49	8562.965			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-2.04	1.98	-1.03	0.31	-6.02	1.94	-6.02	1.94
Sub OM	1.74	0.60	2.90	0.01	0.53	2.95	0.53	2.95
Top P	0.50	0.05	9.41	0.00	0.39	0.61	0.39	0.61

Equation is Subsoil P = Topsoil P x 0.50 + OM% x 1.74 - 2.0

All data sandy to medium loams clays up to 35 mg/l P

Effect of subsoil redness

Regression Statistics	
Multiple R	0.02
R Square	**0.00**
Adjusted R Squ	0.00
Standard Error	6.47
Observations	383

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	7.47979	7.47979	0.178414	0.672978
Residual	381	15972.95	41.92376		
Total	382	15980.43			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.37	0.60	15.66	0.00	8.20	10.55	8.20	10.55
Redness 0-2	0.18	0.43	0.42	0.67	-0.66	1.02	-0.66	1.02

No correlation

All data heavy loams and clays up to 35 mg/l P

Effect of subsoil redness

Regression Statistics	
Multiple R	0.09
R Square	**0.01**
Adjusted R Squ	0.00
Standard Error	4.77
Observations	231.00

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	44.11041	44.11041	1.936335	0.165417
Residual	229	5216.701	22.78036		
Total	230	5260.812			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.10	0.56	10.83	0.00	4.99	7.21	4.99	7.21
Redness 0-2	0.52	0.38	1.39	0.17	-0.22	1.27	-0.22	1.27

May be a positive effect of redness but very small (1 mg/l)

Red 1 = 7.5YR

Red 2 = 5YR or 2.5YR

Red 0 = other colours

11.5 Multiple correlation: factors affecting topsoil or Subsoil K

Arable: inter-relationships with topsoil K

	Method	*Top Text*	*Top Stone*	*Top OM%*	*Top pH*	*Top P*	*Top K*	*Top Mg*
Method	1.00							
Top. Text	-0.11	1.00						
Top. Stone	0.04	0.05	1.00					
Top OM%	0.01	-0.05	-0.09	1.00				
Top pH	-0.07	0.11	-0.06	-0.12	1.00			
Topsoil P	0.05	-0.32	-0.06	0.20	0.14	1.00		
Topsoil K	0.02	0.07	0.03	0.13	0.21	0.56	1.00	
Topsoil Mg	-0.01	0.52	-0.04	0.11	0.14	-0.19	0.09	1.00

High data points (>400 mg K/l) excluded

There is no relationship of topsoil K and Average Annual Rainfall

Leys: inter-relationships with topsoil K

	Method	*Top Text*	*Top Stone*	*Top OM%*	*Top pH*	*Top P*	*Top K*	*Top Mg*
Method	1							
Top. Text	-0.03	1.00						
Top. Stone	0.02	-0.20	1.00					
Top OM%	0.18	0.18	0.00	1.00				
Top pH	-0.08	0.01	-0.08	-0.03	1.00			
Topsoil P	0.01	-0.07	0.16	-0.01	0.32	1.00		
Topsoil K	-0.01	0.14	0.05	0.02	0.23	0.53	1.00	
Topsoil Mg	0.13	0.39	0.07	0.27	0.10	0.11	0.25	1

High data points (>400 mg K/l) excluded

Very weak positive relationship of topsoil K and Average Annual Rainfall

Extensive Grassland: inter-relationships with topsoil K

	Method	*Top Text*	*Top Stone*	*Top OM%*	*Top pH*	*Top P*	*Top K*	*Top Mg*
Method	1.00							
Top. Text	0.00	1.00						
Top. Stone	0.10	-0.12	1.00					
Top OM%	0.08	0.01	-0.17	1.00				
Top pH	0.07	0.36	0.17	-0.16	1.00			
Topsoil P	0.09	-0.26	0.12	-0.08	-0.03	1.00		
Topsoil K	0.19	-0.04	0.15	0.14	0.19	0.63	1.00	
Topsoil Mg	0.02	0.45	-0.08	0.25	0.30	-0.21	0.11	1.00

Very weak negative relationship of topsoil K and Average Annual Rainfall

Arable: inter-relationships with subsoil K

	Method	*Top Text*	*Top K*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*	*Sub Mg*
Method	1									
Text. Top	-0.11	1.00								
Top K	0.02	0.07	1.00							
Sub Text	-0.05	0.65	0.03	1.00						
Sub stone	0.18	-0.06	-0.01	-0.18	1.00					
Subsoil OM	0.25	-0.11	0.18	-0.02	0.18	1.00				
Subsoil pH	-0.12	0.28	0.20	0.21	-0.21	-0.12	1.00			
Subsoil P	0.12	-0.29	0.45	-0.22	0.06	0.37	0.03	1.00		
Subsoil K	0.07	0.12	0.77	0.09	0.10	0.25	0.15	0.48	1.00	
Subsoil Mg	-0.01	0.48	0.04	0.55	-0.15	0.00	0.18	-0.18	0.12	1.00

Data > 400 mg K/l excluded

Leys: inter-relationships with subsoil K

	Method	*Top Text*	*Top K*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*	*Sub Mg*
Method	1.00									
Text. Top	-0.03	1.00								
Top K	-0.01	0.14	1.00							
Sub Text	-0.06	0.68	0.07	1.00						
Sub stone	0.23	-0.24	0.02	-0.30	1.00					
Subsoil OM	0.19	0.10	0.01	-0.01	-0.03	1.00				
Subsoil pH	-0.04	0.10	0.23	0.08	-0.14	-0.07	1.00			
Subsoil P	0.09	-0.21	0.30	-0.23	0.16	0.09	0.18	1.00		
Subsoil K	0.02	0.14	0.73	0.12	0.06	0.02	0.17	0.45	1.00	
Subsoil Mg	0.11	0.41	0.16	0.40	-0.02	0.25	0.20	0.02	0.27	1.00

Extensive Grassland: inter-relationships with subsoil K

	Method	*Top Text*	*Top K*	*Sub text*	*Sub stone*	*Sub OM*	*Sub pH*	*Sub P*	*Sub K*	*Sub Mg*
Method	1									
Text. Top	0.00	1.00								
Top K	0.19	-0.04	1.00							
Sub Text	-0.14	0.62	-0.19	1.00						
Sub stone	0.18	-0.30	0.12	-0.48	1.00					
Subsoil OM	0.03	-0.08	0.28	0.00	0.01	1.00				
Subsoil pH	0.01	0.37	0.04	0.39	-0.15	-0.24	1.00			
Subsoil P	0.23	-0.26	0.51	-0.38	0.19	0.14	-0.18	1.00		
Subsoil K	0.17	-0.04	0.89	-0.12	0.12	0.23	0.12	0.42	1.00	
Subsoil Mg	-0.10	0.29	0.00	0.57	-0.34	0.06	0.35	-0.26	0.07	1.00

11.6 Arable: Subsoil Organic Matter and stone category on topsoil: subsoil K

ARABLE SAND, LOAMY SAND SUBSOILS up to 240 mg K/l in topsoil

Prediction of subsoil K from topsoil K

Regression Statistics	
Multiple R	0.69
R Square	**0.48**
Adjusted R Square	0.46
Standard Error	32.02
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	35689.13	35689.13	34.79873	7.83E-07
Residual	38	38972.31	1025.587		
Total	39	74661.44			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	8.55	15.04	0.57	0.57	-21.89	38.99	-21.89	38.99
Topsoil K	0.64	0.11	5.90	0.00	0.42	0.86	0.42	0.86

Subsoil K = Topsoil K x 0.64 + 9

Arable sandy subsoils - sampling method included

Regression Statistics	
Multiple R	0.70
R Square	**0.49**
Adjusted R Square	0.46
Standard Error	32.03
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	36698.88	18349.44	17.88418	3.68E-06
Residual	37	37962.57	1026.015		
Total	39	74661.44			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.78	15.09	0.65	0.52	-20.80	40.35	-20.80	40.35
Method	11.46	11.55	0.99	0.33	-11.94	34.85	-11.94	34.85
Topsoil K	0.58	0.12	4.73	0.00	0.33	0.83	0.33	0.83

Sampling Method has small significance (but only improves correlation by 0.1 - see below

Arable - sandy subsoils, subsoil OM included

Regression Statistics	
Multiple R	0.72
R Square	**0.52**
Adjusted R Square	0.49
Standard Error	31.10
Observations	40.00

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	38885.35	19442.67	20.10781	1.23E-06
Residual	37	35776.1	966.9215		
Total	39	74661.44			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.90	15.20	0.06	0.95	-29.90	31.69	-29.90	31.69
Subsoil OM%	9.09	5.00	1.82	0.08	-1.04	19.23	-1.04	19.23
Topsoil K	0.57	0.11	5.15	0.00	0.35	0.80	0.35	0.80

Subsoil OM% improves correlation and *P* is significant

Subsoil K = Topsoil K x 0.57 + Subsoil OM x 9.1 + 1

Arable - sandy subsoils, subsoil stone class included

Regression Statistics	
Multiple R	0.72
R Square	**0.52**
Adjusted R Square	0.50
Standard Error	31.06
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	38972.83	19486.41	20.20245	1.17E-06
Residual	37	35688.62	964.5572		
Total	39	74661.44			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-2.95	15.86	-0.19	0.85	-35.08	29.19	-35.08	29.19
Subsoil stone	10.50	5.69	1.85	0.07	-1.03	22.03	-1.03	22.03
Topsoil K	0.65	0.11	6.18	0.00	0.44	0.86	0.44	0.86

Increase of one stone class increases topsoil K by 11 mg/l

Subsoil K = Topsoil K x 0.65 + Subsoil stone class x 10.5 - 3

Arable - sandy subsoils, subsoil OM% and stone class included

Regression Statistics	
Multiple R	0.74
R Square	**0.54**
Adjusted R Square	0.50
Standard Error	30.81
Observations	40

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	40499.1	13499.7	14.22587	2.84E-06
Residual	36	34162.35	948.9541		
Total	39	74661.44			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-5.69	15.88	-0.36	0.72	-37.89	26.52	-37.89	26.52
Subsoil OM%	6.70	5.28	1.27	0.21	-4.01	17.41	-4.01	17.41
Subsoil stone	7.85	6.02	1.30	0.20	-4.36	20.05	-4.36	20.05
Topsoil K	0.60	0.11	5.35	0.00	0.37	0.82	0.37	0.82

Effects of organic matter and stone class are additive, though OM contribution less

ARABLE : LIGHT LOAM SUBSOILS - up to 300 mg/l topsoil K

Relationship with subsoil K

Regression Statistics	
Multiple R	0.84
R Square	**0.70**
Adjusted R Square	0.70
Standard Error	27.19
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	128050.1	128050.1	173.1914	4.57E-21
Residual	74	54712.33	739.3558		
Total	75	182762.4			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.18	8.05	0.52	0.60	-11.86	20.23	-11.86	20.23
Topsoil K	0.71	0.05	13.16	0.00	0.61	0.82	0.61	0.82

Subsoil K = Topsoil K x 0.71 + 4

Arable light loam subsoils - inclusion of sampling method

Regression Statistics	
Multiple R	0.84
R Square	**0.71**
Adjusted R Square	0.70
Standard Error	26.98
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	129625.6	64812.82	89.04068	2.62E-20
Residual	73	53136.79	727.9012		
Total	75	182762.4			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-2.08	9.06	-0.23	0.82	-20.13	15.96	-20.13	15.96
Method	9.69	6.59	1.47	0.15	-3.44	22.82	-3.44	22.82
Topsoil K	0.71	0.05	13.23	0.00	0.60	0.82	0.60	0.82

Method may be significant and similar average increase with corer of 10 mg/l as auger method

Arable Light Loam subsoils - inclusion of Subsoil organic matter %

Regression Statistics	
Multiple R	0.85
R Square	**0.72**
Adjusted R Square	0.72
Standard Error	26.29
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	132305.7	66152.84	95.70884	3.96E-21
Residual	73	50456.75	691.1883		
Total	75	182762.4			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-9.21	9.47	-0.97	0.33	-28.09	9.67	-28.09	9.67
Subsoil OM%	7.93	3.20	2.48	0.02	1.56	14.31	1.56	14.31
Topsoil K	0.71	0.05	13.52	0.00	0.61	0.81	0.61	0.81

Highly significant P value, and increases r2 marginally

Subsoil K = Topsoil K x 0.71 + Subsoil OM x 7.9 - 9

Arable Light Loam subsoils - inclusion of subsoil stone class

Regression Statistics	
Multiple R	0.85
R Square	**0.72**
Adjusted R Square	0.71
Standard Error	26.69
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	130770.6	65385.3	91.80536	1.18E-20
Residual	73	51991.81	712.2166		
Total	75	182762.4			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-4.73	9.13	-0.52	0.61	-22.92	13.46	-22.92	13.46
Subsoil stone	8.88	4.55	1.95	0.05	-0.18	17.94	-0.18	17.94
Topsoil K	0.71	0.05	13.21	0.00	0.60	0.81	0.60	0.81

Increase of one stone class increases topsoil K by 9 mg/l

Subsoil K = Topsoil K x 0.71 + Subsoil stone class x 8.8 - 5

Arable Light Loam subsoils - inclusion of susboil OM and stone class

Regression Statistics	
Multiple R	0.86
R Square	**0.73**
Adjusted R Square	0.72
Standard Error	26.04
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	133944.7	44648.24	65.85054	1.35E-20
Residual	72	48817.72	678.0239		
Total	75	182762.4			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-14.64	10.01	-1.46	0.15	-34.60	5.32	-34.60	5.32
Subsoil OM%	6.98	3.23	2.16	0.03	0.55	13.41	0.55	13.41
Subsoil stone	7.02	4.52	1.55	0.12	-1.98	16.03	-1.98	16.03
Topsoil K	0.70	0.05	13.50	0.00	0.60	0.81	0.60	0.81

Effects of OM and stone class are additive, 7 mg/l per stone class

ARABLE : MEDIUM SUBSOILS - up to 300 mg/l topsoil K

Relationship with subsoil K

Regression Statistics	
Multiple R	0.73
R Square	**0.54**
Adjusted R Square	0.53
Standard Error	35.90
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	110578.8	110578.8	85.8227	5.28E-14
Residual	74	95345.77	1288.456		
Total	75	205924.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	15.00	10.94	1.37	0.17	-6.80	36.81	-6.80	36.81
Topsoil K	0.69	0.07	9.26	0.00	0.54	0.84	0.54	0.84

Subsoil K = Topsoil K x 0.69 + 15

Arable medium subsoils - inclusion of sampling method

Regression Statistics	
Multiple R	0.73
R Square	**0.54**
Adjusted R Square	0.53
Standard Error	36.10
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	110792.3	55396.16	42.5084	5.74E-13
Residual	73	95132.24	1303.181		
Total	75	205924.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	16.66	11.75	1.42	0.16	-6.75	40.07	-6.75	40.07
Sampling method	-3.36	8.29	-0.40	0.69	-19.89	13.17	-19.89	13.17
Topsoil K	0.69	0.07	9.20	0.00	0.54	0.84	0.54	0.84

Method not significant

Arable medium subsoils - inclusion of susboil OM

Regression Statistics	
Multiple R	0.74
R Square	**0.54**
Adjusted R Square	0.53
Standard Error	35.86
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	112060.7	56030.34	43.57602	3.51E-13
Residual	73	93863.89	1285.807		
Total	75	205924.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.04	14.96	0.27	0.79	-25.78	33.86	-25.78	33.86
Subsoil OM%	6.07	5.66	1.07	0.29	-5.20	17.34	-5.20	17.34
Topsoil K	0.69	0.07	9.26	0.00	0.54	0.83	0.54	0.83

Inclusion of subsoil OM does not improve r2 but is a logical positive correction

Subsoil K = Topsoil K x 0.69 + Subsoil OM x 6.1 + 4

Arable medium subsoils - inclusion of subsoil stone category

Regression Statistics	
Multiple R	0.74
R Square	**0.55**
Adjusted R Square	0.54
Standard Error	35.61
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	113360.8	56680.39	44.70072	2.11E-13
Residual	73	92563.79	1267.997		
Total	75	205924.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.51	12.28	0.53	0.60	-17.96	30.98	-17.96	30.98
Subsoil stone	8.45	5.70	1.48	0.14	-2.92	19.81	-2.92	19.81
Topsoil K	0.69	0.07	9.35	0.00	0.54	0.84	0.54	0.84

Subsoil K = Topsoil K x 0.69 + Subsoil stone class x 8.5 + 7

Arable medium subsoils - inclusion of susboil OM and subsoil stones

Regression Statistics	
Multiple R	0.75
R Square	**0.56**
Adjusted R Square	0.54
Standard Error	35.53
Observations	76

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	115043.4	38347.8	30.3808	8.41E-13
Residual	72	90881.15	1262.238		
Total	75	205924.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-5.50	16.07	-0.34	0.73	-37.53	26.54	-37.53	26.54
Subsoil OM%	6.48	5.61	1.15	0.25	-4.71	17.66	-4.71	17.66
Subsoil stone	8.76	5.70	1.54	0.13	-2.60	20.11	-2.60	20.11
Topsoil K	0.69	0.07	9.36	0.00	0.54	0.83	0.54	0.83

Organic Matter and stone have additive improvement

ARABLE HEAVY LOAM AND CLAY SUBSOILS

Affect of topsoil K on subsoil K

Regression Statistics	
Multiple R	0.68
R Square	**0.47**
Adjusted R Square	0.46
Standard Error	27.90
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	55616.62	55616.62	71.46033	9.57E-13
Residual	81	63041.22	778.2867		
Total	82	118657.8			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	49.88	8.39	5.94	0.00	33.18	66.57	33.18	66.57
Topsoil K	0.43	0.05	8.45	0.00	0.33	0.53	0.33	0.53

Subsoil K = Topsoil K x 0.43 + 50

Arable heavy loam and clay subsoils - inclusion of sampling method

Regression Statistics	
Multiple R	0.72
R Square	**0.51**
Adjusted R Square	0.50
Standard Error	26.91
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	60713.74	30356.87	41.91194	3.54E-13
Residual	80	57944.1	724.3013		
Total	82	118657.8			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	38.92	9.09	4.28	0.00	20.84	57.01	20.84	57.01
Sampling method	15.83	5.97	2.65	0.01	3.95	27.71	3.95	27.71
Topsoil K	0.45	0.05	9.03	0.00	0.35	0.55	0.35	0.55

Method is highly significant - corer about 16 mg/l more subsoil K than by auger method

Arable heavy loam and clay subsoils - inclusion of subsoil OM%

Regression Statistics	
Multiple R	0.69
R Square	**0.48**
Adjusted R Square	0.46
Standard Error	27.90
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	56370.56	28185.28	36.20036	6.37E-12
Residual	80	62287.28	778.591		
Total	82	118657.8			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	41.96	11.63	3.61	0.00	18.82	65.10	18.82	65.10
Subsoil OM%	4.34	4.41	0.98	0.33	-4.44	13.12	-4.44	13.12
Topsoil K	0.43	0.05	8.50	0.00	0.33	0.53	0.33	0.53

Inclusion of subsoil OM marginally improves r2 but is a logical positive correction

Subsoil K = Topsoil K x 0.43 + Subsoil OM x 4.4 + 42

Arable heavy loam and clay subsoils - inclusion of subsoil stone class

Regression Statistics	
Multiple R	0.69
R Square	**0.48**
Adjusted R Square	0.47
Standard Error	27.77
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	56977.61	28488.8	36.95032	4.31E-12
Residual	80	61680.23	771.0029		
Total	82	118657.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	54.10	8.94	6.05	0.00	36.32	71.89	36.32	71.89
Subsoil stones	-6.22	4.68	-1.33	0.19	-15.55	3.10	-15.55	3.10
Topsoil K	0.43	0.05	8.46	0.00	0.33	0.53	0.33	0.53

Negative affect of subsoil stones

Subsoil K = Topsoil K x 0.43 - Subsoil stone class x 6.2 + 54

Arable heavy loam and clay subsoils - inclusion of subsoil OM and stone class

Regression Statistics	
Multiple R	0.70
R Square	**0.49**
Adjusted R Square	0.47
Standard Error	27.70
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	58063.63	19354.54	25.23358	1.5E-11
Residual	79	60594.22	767.0154		
Total	82	118657.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	45.04	11.72	3.84	0.00	21.70	68.38	21.70	68.38
Subsoil OM%	5.26	4.42	1.19	0.24	-3.54	14.06	-3.54	14.06
Subsoil stone	-7.01	4.72	-1.49	0.14	-16.40	2.38	-16.40	2.38
Topsoil K	0.43	0.05	8.54	0.00	0.33	0.53	0.33	0.53

Improvement by consideration of stones (negative) and OM (positive)

11.7 Grassland: effect of Subsoil OM and stone category on topsoil: subsoil K

In all cases soils on Alluvium and Disturbed profiles are excluded, as as samples of topsoil K > 240 mg/l

GRASS, SAND SUBSOILS

Regression Statistics	
Multiple R	0.81
R Square	**0.65**
Adjusted R Squa	0.64
Standard Error	25.98
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	32804.62	32804.62	48.61476	2.11E-07
Residual	26	17544.47	674.7873		
Total	27	50349.09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	8.32	9.12	0.91	0.37	-10.43	27.07	-10.43	27.07
Topsoil K	0.58	0.08	6.97	0.00	0.41	0.75	0.41	0.75

Subsoil K = Topsoil K x 0.58 + 8

Grass, Sand subsoils - influence of sampling method

Regression Statistics	
Multiple R	0.83
R Square	**0.69**
Adjusted R Squa	0.67
Standard Error	24.88
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	34876.23	17438.11	28.17531	3.93E-07
Residual	25	15472.87	618.9146		
Total	27	50349.09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	7.70	8.74	0.88	0.39	-10.30	25.71	-10.30	25.71
Method	20.07	10.97	1.83	0.08	-2.52	42.66	-2.52	42.66
Topsoil K	0.51	0.09	5.96	0.00	0.34	0.69	0.34	0.69

Significant effect of method (20 mg K/l more by corer method)

Grass, Sand subsoils - influence of subsoil OM%

Regression Statistics	
Multiple R	0.81
R Square	**0.65**
Adjusted R Squa	0.63
Standard Error	26.41
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	32913.88	16456.94	23.59727	1.75E-06
Residual	25	17435.21	697.4085		
Total	27	50349.09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	5.96	11.03	0.54	0.59	-16.75	28.67	-16.75	28.67
Subsoil OM%	1.73	4.38	0.40	0.70	-7.28	10.74	-7.28	10.74
Topsoil K	0.57	0.09	6.67	0.00	0.39	0.75	0.39	0.75

Inclusion of subsoil OM does not help correlation

Grass, Sand subsoils - influence of subsoil stone class

Regression Statistics	
Multiple R	0.83
R Square	**0.69**
Adjusted R Squa	0.67
Standard Error	24.90
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	34845.97	17422.98	28.09592	4.03E-07
Residual	25	15503.13	620.125		
Total	27	50349.09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.37	9.34	0.25	0.80	-16.87	21.60	-16.87	21.60
Subsoil stone	12.00	6.61	1.81	0.08	-1.62	25.62	-1.62	25.62
Topsoil K	0.56	0.08	6.97	0.00	0.39	0.72	0.39	0.72

Improvement in correlation

Subsoil K = Topsoil K + subsoil stone class x 12 + 2.4

Grass, Sand subsoils - influence of subsoil OM and stone class

Regression Statistics	
Multiple R	0.83
R Square	**0.70**
Adjusted R Squa	0.66
Standard Error	25.24
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	35055.3	11685.1	18.33701	2.11E-06
Residual	24	15293.79	637.2414		
Total	27	50349.09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-1.08	11.22	-0.10	0.92	-24.24	22.07	-24.24	22.07
Subsoil OM%	2.41	4.20	0.57	0.57	-6.26	11.07	-6.26	11.07
Subsoil stone	12.33	6.73	1.83	0.08	-1.55	26.22	-1.55	26.22
Topsoil K	0.55	0.08	6.64	0.00	0.38	0.72	0.38	0.72

Does not improve OM contribution sufficiently to be relevant

GRASS, LIGHT LOAM SUBSOILS

Regression Statistics	
Multiple R	0.73
R Square	**0.53**
Adjusted R Squa	0.53
Standard Error	25.68
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	67729.41	67729.41	102.6999	1.34E-16
Residual	91	60013.44	659.4883		
Total	92	127742.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	22.65	5.36	4.23	0.00	12.01	33.29	12.01	33.29
Topsoil K	0.48	0.05	10.13	0.00	0.39	0.58	0.39	0.58

Subsoil K = Topsoil K x 0.48 + 23

Grass, light loam subsoils - effect of sampling method

Regression Statistics	
Multiple R	0.73
R Square	**0.53**
Adjusted R Squa	0.52
Standard Error	25.72
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	68188.4	34094.2	51.5239	1.22E-15
Residual	90	59554.45	661.7161		
Total	92	127742.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	20.11	6.17	3.26	0.00	7.85	32.37	7.85	32.37
Method	5.07	6.09	0.83	0.41	-7.03	17.18	-7.03	17.18
Topsoil K	0.47	0.05	9.54	0.00	0.38	0.57	0.38	0.57

Weak influence of sampling method, possibly 5 mg/l

Grass, light loam subsoils - subsoil OM effect

Regression Statistics	
Multiple R	0.73
R Square	**0.53**
Adjusted R Squa	0.52
Standard Error	25.77
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	67989.35	33994.68	51.20237	1.42E-15
Residual	90	59753.5	663.9278		
Total	92	127742.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	19.86	6.98	2.84	0.01	5.99	33.73	5.99	33.73
Subsoil OM%	1.34	2.14	0.63	0.53	-2.91	5.59	-2.91	5.59
Topsoil K	0.48	0.05	10.07	0.00	0.39	0.58	0.39	0.58

Weak influence of subsoil OM%

Grass, light loam subsoils - subsoil stones effect

Regression Statistics	
Multiple R	0.73
R Square	**0.53**
Adjusted R Squa	0.52
Standard Error	25.70
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	68310.29	34155.14	51.72187	1.11E-15
Residual	90	59432.56	660.3618		
Total	92	127742.8			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	19.92	6.10	3.27	0.00	7.80	32.04	7.80	32.04
Subsoil stones	3.09	3.30	0.94	0.35	-3.46	9.65	-3.46	9.65
Topsoil K	0.48	0.05	10.03	0.00	0.39	0.58	0.39	0.58

Weak effect but each stone class associated with 3 mg/l increase in subsoil K

GRASS MEDIUM SUBSOILS up to 240 mg/l topsoil K (alluvium excluded)

Prediction of subsoil K

Regression Statistics								
Multiple R	0.82							
R Square	**0.67**							
Adjusted R Squa	0.66							
Standard Error	24.19							
Observations	95							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	108231.5	108231.5	184.9688	7.79E-24			
Residual	93	54417.47	585.1341					
Total	94	162649						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	11.53	5.17	2.23	0.03	1.28	21.79	1.28	21.79
Topsoil K	0.67	0.05	13.60	0.00	0.57	0.77	0.57	0.77

Subsoil K = Topsoil K x 0.67 + 12

No significant difference to equations when light loam topsoils were isolated from medium topsoils

Subsoil K = Topsoil K x 0.63 + 15

Subsoil K = Topsoil K x 0.68 + 10

Grass medium subsoils - allowance for sampling method

Regression Statistics								
Multiple R	0.82							
R Square	**0.67**							
Adjusted R Squa	0.66							
Standard Error	24.22							
Observations	95							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	108674.8	54337.41	92.61911	9.18E-23			
Residual	92	53974.19	586.676					
Total	94	162649						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.89	5.51	1.80	0.08	-1.05	20.83	-1.05	20.83
Method	4.38	5.04	0.87	0.39	-5.63	14.39	-5.63	14.39
Topsoil K	0.67	0.05	13.52	0.00	0.57	0.77	0.57	0.77

Makes no improvement in r2, possible a slight difference (4 mg/l more with corer)

Grass, medium subsoils - inclusion of subsoil OM%

Regression Statistics							
Multiple R	0.82						
R Square	**0.67**						
Adjusted R Squa	0.66						
Standard Error	24.30						
Observations	95						
ANOVA							
	df	*SS*	*MS*	*F*	*gnificance F*		
Regression	2	108312.1	54156.05	91.69377	1.25E-22		
Residual	92	54336.91	590.6186				
Total	94	162649					
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	13.03	6.58	1.98	0.05	-0.05	26.10	-0.05	26.10
Subsoil OM%	-0.98	2.66	-0.37	0.71	-6.27	4.30	-6.27	4.30
Topsoil K	0.67	0.05	13.36	0.00	0.57	0.77	0.57	0.77

Subsoil OM not significant

Grass, medium subsoils - inclusion of subsoil stone category

Regression Statistics								
Multiple R	0.82							
R Square	0.67							
Adjusted R Squa	0.66							
Standard Error	24.32							
Observations	95							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	108231.7	54115.85	91.49031	1.34E-22			
Residual	92	54417.32	591.4926					
Total	94	162649						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	11.50	5.58	2.06	0.04	0.42	22.58	0.42	22.58
Subsoil stone	0.06	3.58	0.02	0.99	-7.05	7.17	-7.05	7.17
Topsoil K	0.67	0.05	13.47	0.00	0.57	0.77	0.57	0.77

No effect of subsoil stone class

GRASS HEAVY LOAM SUBSOILS (no alluvium topsoil up to 240 mg K/l)

Regression Statistics	
Multiple R	0.63
R Square	**0.39**
Adjusted R Squa	0.38
Standard Error	30.35
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	33149.78	33149.78	35.98885	1.53E-07
Residual	56	51582.3	921.1125		
Total	57	84732.08			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	32.41	9.65	3.36	0.00	13.09	51.73	13.09	51.73
Topsoil K	0.47	0.08	6.00	0.00	0.31	0.63	0.31	0.63

Subsoil K = Topsoil K x 0.47 + 32

Grass heavy loam subsoils - effect of sampling method

Regression Statistics	
Multiple R	0.63
R Square	**0.40**
Adjusted R Squa	0.37
Standard Error	30.52
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	33507.4	16753.7	17.98847	9.76E-07
Residual	55	51224.67	931.3577		
Total	57	84732.08			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	29.93	10.49	2.85	0.01	8.91	50.96	8.91	50.96
Method	5.06	8.17	0.62	0.54	-11.31	21.43	-11.31	21.43
Topsoil K	0.47	0.08	5.89	0.00	0.31	0.63	0.31	0.63

Sampling method has a weak influence

Grass heavy loam subsoils - effect of subsoil OM%

Regression Statistics	
Multiple R	0.63
R Square	**0.40**
Adjusted R Squa	0.38
Standard Error	30.33
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	34137.36	17068.68	18.55485	6.94E-07
Residual	55	50594.72	919.904		
Total	57	84732.08			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	40.64	12.49	3.25	0.00	15.61	65.67	15.61	65.67
Subsoil OM%	-4.19	4.04	-1.04	0.30	-12.29	3.91	-12.29	3.91
Topsoil K	0.47	0.08	5.97	0.00	0.31	0.63	0.31	0.63

Subsoil OM% has a negative effect and marginally improves correlation

GRASS: CLAY SUBSOILS (topsoil up to 240 mg K/l, no alluvium)

Regression Statistics	
Multiple R	0.58
R Square	**0.33**
Adjusted R Squa	0.32
Standard Error	27.42
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	18389.87	18389.87	24.46247	9.31E-06
Residual	49	36836.16	751.7583		
Total	50	55226.02			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	46.84	9.14	5.12	0.00	28.47	65.22	28.47	65.22
Topsoil K	0.37	0.08	4.95	0.00	0.22	0.52	0.22	0.52

Subsoil K = Topsoil K x 0.37 + 47

Grass ; clay subsoils - allowance for sampling method

Regression Statistics	
Multiple R	0.58
R Square	**0.33**
Adjusted R Squa	0.31
Standard Error	27.67
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	18464.67	9232.336	12.05484	5.73E-05
Residual	48	36761.35	765.8614		
Total	50	55226.02			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	47.68	9.61	4.96	0.00	28.36	67.00	28.36	67.00
Method	-2.51	8.02	-0.31	0.76	-18.63	13.62	-18.63	13.62
Topsoil K	0.37	0.08	4.91	0.00	0.22	0.53	0.22	0.53

Sampling method irrelevant and poor r2 is due to other unknowns

Grass ; clay subsoils - allowance for subsoil OM

Regression Statistics	
Multiple R	0.59
R Square	**0.35**
Adjusted R Squa	0.32
Standard Error	27.38
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	19229.8	9614.898	12.82121	3.46E-05
Residual	48	35996.22	749.9213		
Total	50	55226.02			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	51.87	10.29	5.04	0.00	31.18	72.56	31.18	72.56
Subsoil OM%	-3.40	3.21	-1.06	0.30	-9.85	3.06	-9.85	3.06
Topsoil K	0.39	0.08	5.06	0.00	0.23	0.54	0.23	0.54

Subsoi OM% has a negative effect and its inclusion improves correlation

GRASS: CLAY SUBSOILS (topsoil up to 240 mg K/l, no alluvium)

Regression Statistics	
Multiple R	0.58
R Square	**0.33**
Adjusted R Squa	0.32
Standard Error	27.42
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	18389.87	18389.87	24.46247	9.31E-06
Residual	49	36836.16	751.7583		
Total	50	55226.02			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	46.84	9.14	5.12	0.00	28.47	65.22	28.47	65.22
Topsoil K	0.37	0.08	4.95	0.00	0.22	0.52	0.22	0.52

Subsoil K = Topsoil K x 0.37 + 47

Grass ; clay subsoils - allowance for sampling method

Regression Statistics	
Multiple R	0.58
R Square	**0.33**
Adjusted R Squa	0.31
Standard Error	27.67
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	18464.67	9232.336	12.05484	5.73E-05
Residual	48	36761.35	765.8614		
Total	50	55226.02			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	47.68	9.61	4.96	0.00	28.36	67.00	28.36	67.00
Method	-2.51	8.02	-0.31	0.76	-18.63	13.62	-18.63	13.62
Topsoil K	0.37	0.08	4.91	0.00	0.22	0.53	0.22	0.53

Sampling method irrelevant and poor r2 is due to other unknowns

Grass ; clay subsoils - allowance for subsoil OM

Regression Statistics	
Multiple R	0.59
R Square	**0.35**
Adjusted R Squa	0.32
Standard Error	27.38
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	19229.8	9614.898	12.82121	3.46E-05
Residual	48	35996.22	749.9213		
Total	50	55226.02			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	51.87	10.29	5.04	0.00	31.18	72.56	31.18	72.56
Subsoil OM%	-3.40	3.21	-1.06	0.30	-9.85	3.06	-9.85	3.06
Topsoil K	0.39	0.08	5.06	0.00	0.23	0.54	0.23	0.54

Subsoi OM% has a negative effect and its inclusion improves correlation

GRASS ALLUVIAL SOILS WITH HEAVY LOAM OR CLAY SUBSOILS

Regression Statistics	
Multiple R	0.72
R Square	**0.52**
Adjusted R Squa	0.51
Standard Error	14.08
Observations	46

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	9360.018	9360.018	47.23832	1.76E-08
Residual	44	8718.363	198.1446		
Total	45	18078.38			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	23.80	5.50	4.33	0.00	12.71	34.89	12.71	34.89
Topsoil K	0.46	0.07	6.87	0.00	0.33	0.60	0.33	0.60

Grass alluvial soils - heavy loam or clay -effect of sampling method

Regression Statistics	
Multiple R	0.72
R Square	**0.52**
Adjusted R Squa	0.50
Standard Error	14.23
Observations	46

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	9373.666	4686.833	23.15226	1.5E-07
Residual	43	8704.715	202.4352		
Total	45	18078.38			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	23.53	5.66	4.15	0.00	12.10	34.95	12.10	34.95
Method	1.14	4.39	0.26	0.80	-7.71	9.99	-7.71	9.99
Topsoil K	0.46	0.07	6.49	0.00	0.31	0.60	0.31	0.60

No significant influence

Grass alluvial soils - heavy loam or clay - effect of subsoil OM%

Regression Statistics	
Multiple R	0.76
R Square	**0.57**
Adjusted R Squa	0.55
Standard Error	13.39
Observations	46

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	10373.53	5186.766	28.94683	1.09E-08
Residual	43	7704.848	179.1825		
Total	45	18078.38			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	13.61	6.73	2.02	0.05	0.04	27.17	0.04	27.17
Subsoil OM%	4.14	1.72	2.41	0.02	0.67	7.62	0.67	7.62
Topsoil K	0.43	0.06	6.72	0.00	0.30	0.56	0.30	0.56

Organic matter improves correlation

Subsoil K = Topsoil K x 0.43 + Subsoil OM x 4.1 + 14

Grass ALLUVIAL SOILS - light or medium subsoils

Prediction of subsoil K

Regression Statistics	
Multiple R	0.64
R Square	**0.41**
Adjusted R Squa	0.39
Standard Error	37.89
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	26062.28	26062.28	18.15154	0.000236
Residual	26	37331.24	1435.817		
Total	27	63393.53			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.24	18.85	0.12	0.91	-36.51	40.99	-36.51	40.99
Topsoil K	0.89	0.21	4.26	0.00	0.46	1.32	0.46	1.32

Subsoil K = Topsoil K x 0.89 + 2

Grass ALLUVIAL SOILS - light or medium subsoils - effect of subsoil OM%

Regression Statistics	
Multiple R	0.65
R Square	**0.42**
Adjusted R Squa	0.37
Standard Error	38.47
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	26390.15	13195.08	8.914779	0.001195
Residual	25	37003.37	1480.135		
Total	27	63393.53			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-4.57	24.00	-0.19	0.85	-54.01	44.86	-54.01	44.86
Subsoil OM%	2.88	6.11	0.47	0.64	-9.71	15.46	-9.71	15.46
Topsoil K	0.88	0.21	4.17	0.00	0.45	1.32	0.45	1.32

Organic matter does not improve correlation

Subsoil K = Topsoil K x 0.88 + Subsoil OM x 2.9 - 5

Grass ALLUVIAL SOILS - light or medium subsoils - effect of subsoil stone class

Regression Statistics	
Multiple R	0.68
R Square	**0.46**
Adjusted R Squa	0.42
Standard Error	36.86
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	29435.29	14717.64	10.83511	0.000409
Residual	25	33958.24	1358.33		
Total	27	63393.53			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	38.09	29.22	1.30	0.20	-22.09	98.28	-22.09	98.28
Subsoil stone	-24.60	15.61	-1.58	0.13	-56.75	7.55	-56.75	7.55
Topsoil K	0.84	0.21	4.08	0.00	0.42	1.26	0.42	1.26

Subsoil stoniness has a negative effect on subsoil K

If light loam textured subsoils are isolated stone effect is greater (-29 mg/l) and very significant with topsoil K becoming insignificant

11.8 Effect of sampling method and organic matter on topsoil pH

Arable data

Affect of sampling method on topsoil pH (all data up to pH 7.0)

Regression Statistics	
Multiple R	0.01
R Square	0.00
Adjusted R Square	-0.01
Standard Error	0.41
Observations	196

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.004636	0.004636	0.027903	0.867511
Residual	194	32.2321	0.166145		
Total	195	32.23673			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.39	0.05	141.09	0.00	6.30	6.48	6.30	6.48
Method	0.01	0.06	0.17	0.87	-0.11	0.13	-0.11	0.13

No influence

Grass data (leys, extensive and amenity)

Affect of sampling method on topsoil pH (all data up to pH 7.0

Regression Statistics	
Multiple R	0.07
R Square	0.01
Adjusted R Square	0.00
Standard Error	0.46
Observations	342

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.388773	0.388773	1.863944	0.173073
Residual	340	70.91567	0.208576		
Total	341	71.30444			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.19	0.04	172.01	0.00	6.12	6.26	6.12	6.26
Method	-0.07	0.05	-1.37	0.17	-0.16	0.03	-0.16	0.03

Very weak influence (0.7 less by corer)

All data pH up to 7.0

Correlation of topsoil pH with OM capped at 10%

Regression Statistics	
Multiple R	0.20
R Square	0.04
Adjusted R Square	0.04
Standard Error	0.45
Observations	538

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	4.334833	4.334833	21.83616	3.76E-06
Residual	536	106.4047	0.198516		
Total	537	110.7396			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.45	0.05	131.52	0.00	6.36	6.55	6.36	6.55
Topsoil OM%	-0.05	0.01	-4.67	0.00	-0.08	-0.03	-0.08	-0.03

Weak correlation, 0.05 pH less per 1% increase in SOM

Arable data only pH up to 7.0

Correlation of topsoil pH with OM capped at 10%

Regression Statistics	
Multiple R	0.13
R Square	0.02
Adjusted R Square	0.01
Standard Error	0.40
Observations	196

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.561763	0.561763	3.440635	0.065129
Residual	194	31.67497	0.163273		
Total	195	32.23673			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.55	0.09	75.73	0.00	6.38	6.72	6.38	6.72
X Variable 1	-0.05	0.02	-1.85	0.07	-0.09	0.00	-0.09	0.00

Taking out grass makes correlation even weaker though factor similar (-0.05)

11.9 Effect of topsoil pH and texture on subsoil pH

ALL DATA – sandy, light loamy and medium topsoil (pH up to 7.0)

Effect of topsoil pH only

Regression Statistics	
Multiple R	0.75
R Square	**0.56**
Adjusted R Square	0.56
Standard Error	0.33
Observations	539

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	75.70009	75.70009	693.3748	9.6E-99
Residual	537	58.62767	0.109176		
Total	538	134.3278			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.34	0.20	6.80	0.00	0.95	1.72	0.95	1.72
Top pH	0.83	0.03	26.33	0.00	0.77	0.89	0.77	0.89

Effect of topsoil pH and sampling method

Regression Statistics	
Multiple R	0.75
R Square	0.57
Adjusted R Square	0.57
Standard Error	0.33
Observations	539

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	76.21643	38.10822	351.4978	2.97E-98
Residual	536	58.11132	0.108417		
Total	538	134.3278			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.38	0.20	7.02	0.00	1.00	1.77	1.00	1.77
Method	-0.06	0.03	-2.18	0.03	-0.12	-0.01	-0.12	-0.01
Topsoil pH	0.82	0.03	26.35	0.00	0.76	0.89	0.76	0.89

Small but genuine effect of sampling method (-0.06 units by corer)

Effect of topsoil texture and topsoil pH

Regression Statistics	
Multiple R	0.76
R Square	**0.58**
Adjusted R Square	0.57
Standard Error	0.33
Observations	538

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	77.20439	38.6022	362.5434	3E-100
Residual	535	56.9647	0.106476		
Total	537	134.1691			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.23	0.20	6.24	0.00	0.84	1.61	0.84	1.61
Topsoil Texture	**0.10**	0.03	3.86	0.00	0.05	0.15	0.05	0.15
Topsoil pH	0.82	0.03	26.45	0.00	0.76	0.88	0.76	0.88

Subsoil pH = Topsoil pH x 0.82 + Topsoil texture class x 0.10 + 1.23

Effect of subsoil texture and topsoil pH								
Regression Statistics								
Multiple R	0.76							
R Square	**0.58**							
Adjusted R Square	0.57							
Standard Error	0.33							
Observations	538							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	77.23175	38.61588	362.8461	2.6E-100			
Residual	535	56.93734	0.106425					
Total	537	134.1691						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.22	0.20	6.23	0.00	0.84	1.61	0.84	1.61
Subsoil Texture	**0.05**	0.01	3.89	0.00	0.02	0.07	0.02	0.07
Topsoil pH	0.83	0.03	26.80	0.00	0.77	0.89	0.77	0.89
subsoil texture is significant but makes a smaller increase than *topsoil* texture class								

Effect of subsoil OM (capped at 6%) and topsoil pH								
Regression Statistics								
Multiple R	0.76							
R Square	**0.58**							
Adjusted R Square	0.58							
Standard Error	0.32							
Observations	538							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	77.73963	38.86982	368.5195	2.4E-101			
Residual	535	56.42945	0.105476					
Total	537	134.1691						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.56	0.20	7.81	0.00	1.16	1.95	1.16	1.95
Subsoil OM%	-0.06	0.01	-4.48	0.00	-0.08	-0.03	-0.08	-0.03
Topsoil pH	0.81	0.03	26.07	0.00	0.75	0.87	0.75	0.87
Subsoil OM seems to have a significant negative effect on pH								
Increasing OM from 1 to 4% reduces pH about 0.2 units								

ALL DATA – heavy loam and clay topsoil (pH up to 7.0)

Effect of topsoil pH ONLY								
Regression Statistics								
Multiple R	0.67							
R Square	**0.44**							
Adjusted R Square	0.44							
Standard Error	0.37							
Observations	100							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	10.87628	10.87628	78.5249	3.57E-14			
Residual	98	13.57372	0.138507					
Total	99	24.45						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.35	0.61	2.22	0.03	0.14	2.55	0.14	2.55
Topsoil pH	0.84	0.10	8.86	0.00	0.65	1.03	0.65	1.03

Effect of sampling method and topsoil pH

Regression Statistics	
Multiple R	0.67
R Square	**0.45**
Adjusted R Square	0.43
Standard Error	0.37
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	10.88754	5.443772	38.93438	3.86E-13
Residual	97	13.56246	0.139819		
Total	99	24.45			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.33	0.61	2.16	0.03	0.11	2.54	0.11	2.54
Sampling method	0.02	0.08	0.28	0.78	-0.13	0.18	-0.13	0.18
Topsoil pH	0.84	0.10	8.82	0.00	0.65	1.03	0.65	1.03

No effect of sampling method

Effect of topsoil texture and topsoil pH

Regression Statistics	
Multiple R	0.67
R Square	**0.45**
Adjusted R Square	0.44
Standard Error	0.37
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	10.93873	5.469365	39.26562	3.22E-13
Residual	97	13.51127	0.139291		
Total	99	24.45			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.14	0.68	1.67	0.10	-0.22	2.49	-0.22	2.49
Topsoil Texture	0.08	0.13	0.67	0.50	-0.16	0.33	-0.16	0.33
Topsoil pH	0.84	0.10	8.68	0.00	0.64	1.03	0.64	1.03

Barely significant but possible 0.08 increase between heavy loam and clay topsoils

Subsoil pH = Topsoil pH x 0.84 + Topsoil texture class x 0.08 + 1.14

Effect of Subsoil texture and topsoil pH

Regression Statistics	
Multiple R	0.68
R Square	**0.46**
Adjusted R Square	0.45
Standard Error	0.37
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	11.17642	5.588208	40.83722	1.36E-13
Residual	97	13.27358	0.136841		
Total	99	24.45			

	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.96	0.66	1.47	0.15	-0.34	2.26	-0.34	2.26
Subsoil Texture	0.07	0.05	1.48	0.14	-0.02	0.16	-0.02	0.16
Topsoil pH	0.87	0.10	9.04	0.00	0.68	1.06	0.68	1.06

Possible effect of subsoil texture

Intercept effetively 1.14 for medium subsoils, 1.21 for heavier loams and 1.28 for clay subsoils

Effect of subsoil OM (capped at 6%) and topsoil pH								
Regression Statistics								
Multiple R	0.67							
R Square	0.44							
Adjusted R Square	0.43							
Standard Error	0.37							
Observations	100							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	10.87686	5.438431	38.86558	4.01E-13			
Residual	97	13.57314	0.139929					
Total	99	24.45						
	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.34	0.62	2.16	0.03	0.11	2.57	0.11	2.57
Subsoil OM%	0.00	0.03	0.06	0.95	-0.06	0.07	-0.06	0.07
Topsoil pH	0.84	0.10	8.80	0.00	0.65	1.03	0.65	1.03
No effect of subsoil organic matter								

All data – sandy, light loamy and medium topsoil (pH 7.1+)

Effect of topsoil pH and topsoil texture								
Regression Statistics								
Multiple R	0.45							
R Square	**0.20**							
Adjusted R Square	0.19							
Standard Error	0.38							
Observations	84							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	2.98225	1.491125	10.42328	9.37E-05			
Residual	81	11.58763	0.143057					
Total	83	14.56988						
	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.60	1.32	1.21	0.23	-1.03	4.23	-1.03	4.23
Topsoil Texture	0.15	0.07	2.14	0.04	0.01	0.30	0.01	0.30
Topsoil pH	0.74	0.18	4.16	0.00	0.39	1.10	0.39	1.10
Subsoil pH = Topsoil pH x 0.75 + Topsoil texture class x 0.15 + 1.6								
Poor r2 but gives a seamless fit with the up to 7.0 data								

All data – heavy loam and clay topsoil (pH 7.1 +)

Effect of topsoil pH and topsoil texture								
Regression Statistics								
Multiple R	0.62							
R Square	**0.38**							
Adjusted R Square	0.30							
Standard Error	0.40							
Observations	19							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	1.550811	0.775406	4.905323	0.021806			
Residual	16	2.529189	0.158074					
Total	18	4.08						
	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.81	2.20	0.37	0.72	-3.85	5.47	-3.85	5.47
Topsoil Texture	0.15	0.27	0.57	0.58	-0.41	0.72	-0.41	0.72
Topsoil pH	0.84	0.31	2.70	0.02	0.18	1.50	0.18	1.50
Subsoil pH = Topsoil pH x 0.84 + Topsoil texture class x 0.15 + 0.81								
For texture class 3 = Topsoil pH x 0.84 + 1.30								
Topsoil texture not demonstrably significant								

Woodland all textures for topsoil up to pH 7.0

Woodland SANDY-MEDIUM textures								
Affect of topsoil pH and topsoil texture								
Regression Statistics								
Multiple R	0.88							
R Square	**0.77**							
Adjusted R Square	0.76							
Standard Error	0.40							
Observations	37							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	18.9004	9.450198	58.45809	9.92E-12			
Residual	34	5.49636	0.161658					
Total	36	24.39676						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.85	0.51	1.67	0.10	-0.19	1.88	-0.19	1.88
Topsoil Textue	0.13	0.10	1.29	0.21	-0.08	0.35	-0.08	0.35
Topsoil pH	0.85	0.10	8.50	0.00	0.65	1.06	0.65	1.06
Affect of topsoil pH only								
Regression Statistics								
Multiple R	0.87							
R Square	**0.76**							
Adjusted R Square	0.76							
Standard Error	0.41							
Observations	37							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	18.63343	18.63343	113.1587	1.64E-12			
Residual	35	5.763322	0.164666					
Total	36	24.39676						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.63	0.48	1.30	0.20	-0.35	1.61	-0.35	1.61
Topsoil pH	0.92	0.09	10.64	0.00	0.75	1.10	0.75	1.10
Woodland all textures for topsoil pH up to 7.0								
Affect of topsoil pH and sampling method on subsoil pH								
Regression Statistics								
Multiple R	0.85							
R Square	**0.73**							
Adjusted R Square	0.72							
Standard Error	0.45							
Observations	46							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	23.46401	11.732	57.67079	6.73E-13			
Residual	43	8.747516	0.203431					
Total	45	32.21152						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.72	0.50	1.44	0.16	-0.28	1.72	-0.28	1.72
Sampling method	0.06	0.14	0.45	0.66	-0.22	0.35	-0.22	0.35
Topsoil pH	0.90	0.08	10.66	0.00	0.73	1.07	0.73	1.07
Sampling method not relevant								

Affect of topsoil pH only								
Regression Statistics								
Multiple R	0.85							
R Square	**0.73**							
Adjusted R Square	0.72							
Standard Error	0.45							
Observations	46							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	23.42358	23.42358	117.2787	5.4E-14			
Residual	44	8.787937	0.199726					
Total	45	32.21152						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.79	0.46	1.71	0.09	-0.14	1.72	-0.14	1.72
Topsoil pH	0.89	0.08	10.83	0.00	0.73	1.06	0.73	1.06
Subsoil pH = topsoil pH x 0.89 + 0.79								

11.10 Effect of Sampling method, Stones and Texture on OM

ALL ARABLE DATA

Affect of sampling method on topsoil OM%

Regression Statistics	
Multiple R	0.01
R Square	0.00
Adjusted R Square	0.00
Standard Error	1.17
Observations	290

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.010261	0.010261	0.007455	0.931255
Residual	288	396.403	1.376399		
Total	289	396.4132			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	3.31	0.10	32.03	0.00	3.11	3.51	3.11	3.51
Method	0.01	0.14	0.09	0.93	-0.26	0.28	-0.26	0.28

No significant effect

GRASS LEYS

Affect of sampling method on topsoil OM%

Regression Statistics	
Multiple R	0.18
R Square	**0.03**
Adjusted R Square	0.03
Standard Error	2.02
Observations	287

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	40.97902	40.97902	10.05861	0.001682
Residual	285	1161.097	4.074023		
Total	286	1202.076			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	3.87	0.17	23.01	0.00	3.54	4.20	3.54	4.20
Method	0.76	0.24	3.17	0.00	0.29	1.22	0.29	1.22

A big difference of 0.75%. 4 corer samples were organic as opposed to 2 by auger but this does not acco

EXTENSIVE & AMENITY GRASS

Affect of sampling method on topsoil OM%

Regression Statistics	
Multiple R	0.08
R Square	**0.01**
Adjusted R Square	0.00
Standard Error	2.35
Observations	149

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	4.985484	4.985484	0.901201	0.344018
Residual	147	813.2102	5.532042		
Total	148	818.1957			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.87	0.31	15.49	0.00	4.25	5.49	4.25	5.49
Method	0.38	0.40	0.95	0.34	-0.41	1.16	-0.41	1.16

Method affect of 0.38% higher with corer which is probably real

ARABLE DATA

Effect of sampling method and topsoil OM% on subsoil OM

Regression Statistics				2 points excluded for high or v.low topsoil OM				
Multiple R	0.64							
R Square	**0.41**							
Adjusted R Square	0.41							
Standard Error	0.65							
Observations	286							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	84.9926	42.4963	99.97409	1.43E-33			
Residual	283	120.2957	0.425073					
Total	285	205.2883						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.04	0.13	0.31	0.76	-0.22	0.30	-0.22	0.30
Method	0.43	0.08	5.49	0.00	0.27	0.58	0.27	0.58
Topsoil OM%	0.46	0.04	13.07	0.00	0.39	0.53	0.39	0.53

Sampling method is relevant with an increase of 0.4% in the subsoil OM by corer method

ARABLE DATA

Affect of topsoil OM% on subsoil OM% auger data only

Regression Statistics								
Multiple R	0.46							
R Square	**0.21**							
Adjusted R Square	0.21							
Standard Error	0.75							
Observations	127							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	18.99256	18.99256	33.65676	5.08E-08			
Residual	125	70.53768	0.564301					
Total	126	89.53024						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.30	0.23	1.32	0.19	-0.15	0.75	-0.15	0.75
Topsoil OM%	0.38	0.07	5.80	0.00	0.25	0.51	0.25	0.51

Subsoil OM% = topsoil OM% x 0.38 + 0.30

Low r2. Corer data below gives better r2, same intercept but bigger slope.

ARABLE DATA

Affect of topsoil OM% on subsoil OM% corer data only

Regression Statistics								
Multiple R	0.72872							
R Square	**0.53**							
Adjusted R Square	0.53							
Standard Error	0.56							
Observations	159							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	54.87674	54.87674	177.7783	1.33E-27			
Residual	157	48.46288	0.308681					
Total	158	103.3396						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.31	0.13	2.30	0.02	0.04	0.57	0.04	0.57
Topsoil OM%	0.51	0.04	13.33	0.00	0.43	0.59	0.43	0.59

Subsoil OM% = topsoil OM% x 0.51 + 0.30

ARABLE DATA

Effect of subsoil texture and topsoil OM% on subsoil OM (sand subsoils excluded)

Regression Statistics	
Multiple R	0.64
R Square	**0.41**
Adjusted R Square	0.41
Standard Error	0.66
Observations	241

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	71.4472	35.7236	82.76016	5.18E-28
Residual	238	102.7332	0.431652		
Total	240	174.1804			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.46	0.15	3.10	0.00	0.17	0.76	0.17	0.76
Subsoil Texture Cla	-0.14	0.04	-3.26	0.00	-0.23	-0.06	-0.23	-0.06
Subsoil OM%	0.51	0.04	12.85	0.00	0.43	0.59	0.43	0.59

Subsoil OM = Topsoil OM x 0.51 - Subsoil Texture class x 0.14 + 0.46

For each texture category subsoil OM% decreases by 0.15%

ARABLE DATA

Effect of subsoil texture, subsoil stones and topsoil OM% on subsoil OM (sand subsoils excluded)

Regression Statistics	
Multiple R	0.66
R Square	**0.43**
Adjusted R Square	0.43
Standard Error	0.65
Observations	241

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	75.33182	25.11061	60.20535	5.71E-29
Residual	237	98.84859	0.417083		
Total	240	174.1804			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.21	0.17	1.27	0.21	-0.12	0.54	-0.12	0.54
Subsoil texture clas	-0.10	0.04	-2.29	0.02	-0.19	-0.01	-0.19	-0.01
Subsoil stone class	**0.18**	0.06	3.05	0.00	0.06	0.30	0.06	0.30
Topsoil OM%	0.51	0.04	13.04	0.00	0.43	0.58	0.43	0.58

Inclusion of stones has a positive effect on subsoil OM% (one class increases subsoil OM by about 0.2%)

And improves r2 above inclusion of texture class only

ARABLE DATA

Effect of subsoil stones and topsoil OM% on subsoil OM. Sand subsoils only

Regression Statistics	
Multiple R	0.52
R Square	**0.28**
Adjusted R Square	0.24
Standard Error	0.72
Observations	45

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	8.375929	4.187964	7.989368	0.001147
Residual	42	22.01607	0.524192		
Total	44	30.392			

	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.18	0.39	0.45	0.66	-0.62	0.97	-0.62	0.97
Subsoil stones	**0.19**	0.12	1.53	0.13	-0.06	0.44	-0.06	0.44
Topsoil OM%	0.39	0.10	3.83	0.00	0.18	0.59	0.18	0.59

Possible affect of stones (one class increases subsoil OM% by 0.2%

ALL GRASSLAND (excluding samples of >10% topsoil OM)									
Affect of topsoil OM on subsoil OM									
Regression Statistics									
Multiple R	0.62								
R Square	**0.38**								
Adjusted R Square	0.38								
Standard Error	1.05								
Observations	443								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	1	298.5335	298.5335	271.9972	6.03E-48				
Residual	441	484.0243	1.097561						
Total	442	782.5577							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	0.10	0.13	0.74	0.46	-0.16	0.36	-0.16	0.36	
Topsoil OM%	0.47	0.03	16.49	0.00	0.41	0.52	0.41	0.52	
Subsoil OM% = Topsoil OM% x 0.47 + 0.1									

ALL GRASSLAND (excluding samples of >10% topsoil OM)									
Affect of sampling method and topsoil OM on subsoil OM									
Regression Statistics									
Multiple R	0.63								
R Square	0.39								
Adjusted R Square	0.39								
Standard Error	1.04								
Observations	443								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	2	305.7991	152.8995	141.1108	4.49E-48				
Residual	440	476.7587	1.083542						
Total	442	782.5577							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	0.01	0.13	0.10	0.92	-0.25	0.28	-0.25	0.28	
Sampling method	0.26	0.10	2.59	0.01	0.06	0.46	0.06	0.46	
Topsoil OM%	0.45	0.03	15.85	0.00	0.40	0.51	0.40	0.51	
On average subsoil OM is 0.26% greater by corer technique									

ALL GRASSLAND (excluding samples of >10% topsoil OM)									
Topsoil OM on subsoil OM - auger data only									
Regression Statistics									
Multiple R	0.50								
R Square	**0.25**								
Adjusted R Square	0.25								
Standard Error	1.19								
Observations	203								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	1	97.22754	97.22754	68.4842	1.75E-14				
Residual	201	285.3612	1.419708						
Total	202	382.5888							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	0.22	0.21	1.07	0.29	-0.19	0.63	-0.19	0.63	
Topsoil OM	0.40	0.05	8.28	0.00	0.30	0.49	0.30	0.49	
Rather poor r2 and intercept may not be signficant									

ALL GRASSLAND (excluding samples of >10% topsoil OM)

Topsoil OM on subsoil OM Corer data only

Regression Statistics	
Multiple R	0.70
R Square	**0.49**
Adjusted R Square	0.48
Standard Error	0.89
Observations	240

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	178.0427	178.0427	225.0962	2.92E-36
Residual	238	188.2491	0.790963		
Total	239	366.2918			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.07	0.16	0.42	0.67	-0.25	0.39	-0.25	0.39
Topsoil OM	0.50	0.03	15.00	0.00	0.43	0.56	0.43	0.56

Better r2 and intercept is not signficantly different to corer

Slope is greater by corer.

GRASSLAND, Sand subsoils

Topsoil OM and subsoil stones, effect on subsoil OM

Regression Statistics	
Multiple R	0.59
R Square	**0.34**
Adjusted R Square	0.30
Standard Error	0.98
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	17.20285	8.601424	8.89314	0.000783
Residual	34	32.88472	0.967198		
Total	36	50.08757			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.76	0.34	2.21	0.03	0.06	1.45	0.06	1.45
Subsoil stone class	-0.31	0.25	-1.25	0.22	-0.82	0.19	-0.82	0.19
Topsoil OM	0.34	0.08	4.22	0.00	0.18	0.50	0.18	0.50

Probable negative effect of stones (0.3% per stone class)

GRASSLAND, Light Loam subsoils

Topsoil OM and subsoil stones, effect on subsoil OM

Regression Statistics	
Multiple R	0.79
R Square	**0.63**
Adjusted R Square	0.62
Standard Error	0.88
Observations	83

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	105.7226	52.86131	68.47958	4.66E-18
Residual	80	61.75425	0.771928		
Total	82	167.4769			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.53	0.29	-1.82	0.07	-1.10	0.05	-1.10	0.05
Subsoil stone class	-0.38	0.15	-2.55	0.01	-0.67	-0.08	-0.67	-0.08
Topsoil OM	0.76	0.07	11.44	0.00	0.62	0.89	0.62	0.89

Negative effect of stones (0.4% per stone class)

WOODLAND								
Affect of sampling method on topsoil OM%								
Regression Statistics								
Multiple R	0.28							
R Square	**0.08**							
Adjusted R Square	0.06							
Standard Error	4.74							
Observations	50							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	90.31697	90.31697	4.018669	0.050658			
Residual	48	1078.769	22.47435					
Total	49	1169.086						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	5.11	1.09	4.69	0.00	2.92	7.29	2.92	7.29
Method	2.77	1.38	2.00	0.05	-0.01	5.55	-0.01	5.55
This difference is exaggerated because 9 organic samples were sampled by corer versus 3 by auger								

WOODLAND								
Effect of topsoil OM% on Subsoil OM%								
Regression Statistics								
Multiple R	0.59							
R Square	**0.35**							
Adjusted R Square	0.35							
Standard Error	0.68							
Observations	286							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	72.17992	72.17992	154.0031	1.52E-28			
Residual	284	133.1084	0.468691					
Total	285	205.2883						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.28	0.13	2.18	0.03	0.03	0.54	0.03	0.54
Topsoil OM%	0.46	0.04	12.41	0.00	0.39	0.53	0.39	0.53
Subsoil OM% = 0.46 x Topsoil OM% + 0.28								

WOODLAND Sand and light loam subsoils								
Affect of topsoil OM on subsoil OM								
Regression Statistics								
Multiple R	0.90							
R Square	**0.81**							
Adjusted R Square	0.80							
Standard Error	1.41							
Observations	25							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	192.8791	192.8791	97.22894	9.96E-10			
Residual	23	45.62653	1.983762					
Total	24	238.5056						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.09	0.46	0.19	0.85	-0.86	1.03	-0.86	1.03
Topsoil OM	0.50	0.05	9.86	0.00	0.39	0.60	0.39	0.60
Cannot check effect of method because the 2 very high samples were both by corer method								
Subsoil OM% = Topsoil OM% x 0.50 + 0.1								

WOODLAND Medium to heavy subsoils								
Affect of topsoil OM on subsoil OM								
Regression Statistics								
Multiple R	0.61							
R Square	**0.38**							
Adjusted R Square	0.35							
Standard Error	0.92							
Observations	25							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	11.6906	11.6906	13.88877	0.001106			
Residual	23	19.3598	0.84173					
Total	24	31.0504						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.32	0.37	3.56	0.00	0.56	2.09	0.56	2.09
Topsoil OM	0.21	0.06	3.73	0.00	0.09	0.32	0.09	0.32

WOODLAND Medium to heavy soils								
Affect of sampling method and topsoil OM on subsoil OM								
Regression Statistics								
Multiple R	0.61							
R Square	**0.38**							
Adjusted R Square	0.32							
Standard Error	0.94							
Observations	25							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	11.72917	5.864585	6.677673	0.005416			
Residual	22	19.32123	0.878238					
Total	24	31.0504						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.30	0.40	3.23	0.00	0.46	2.13	0.46	2.13
Sampling method	0.08	0.38	0.21	0.84	-0.71	0.88	-0.71	0.88
Topsoil OM	0.21	0.06	3.53	0.00	0.08	0.33	0.08	0.33
Sampling method not signifcant though average 0.08 higher with corer								

11.11 Relationship of Total Nitrogen and Organic Matter

ARABLE data								
Topsoil Organic Matter and Topsoil Nitrogen								
Regression Statistics								
Multiple R	0.81							
R Square	**0.66**							
Adjusted R Sq	0.66							
Standard Erro	0.04							
Observations	128							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.321943	0.321943	249.2004	1.21E-31			
Residual	126	0.16278	0.001292					
Total	127	0.484723						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.039	0.010	3.839	0.000	0.019	0.059	0.019	0.059
Topsoil OM	0.045	0.003	15.786	0.000	0.039	0.050	0.039	0.050
Total N = OM	x 0.045	+ 0.04						

ARABLE data								
Subsoil Organic Matter and Subsoil Total Nitrogen								
Regression Statistics								
Multiple R	0.78							
R Square	**0.60**							
Adjusted R Sq	0.60							
Standard Erro	0.03							
Observations	128							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.152219	0.152219	190.008	6.33E-27			
Residual	126	0.100941	0.000801					
Total	127	0.25316						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.030	0.006	5.039	0.000	0.018	0.042	0.018	0.042
Subsoil OM	0.041	0.003	13.784	0.000	0.035	0.047	0.035	0.047
Total N = OM	x 0.041	+ 0.03						

LEYS								
Topsoil Organic Matter and Topsoil Nitrogen								
Regression Statistics								
Multiple R	0.80							
R Square	**0.63**							
Adjusted R Sq	0.63							
Standard Erro	0.07							
Observations	132							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.959338	0.959338	225.0023	3.82E-30			
Residual	130	0.554278	0.004264					
Total	131	1.513616						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.049	0.014	3.516	0.001	0.021	0.076	0.021	0.076
Topsoil OM	0.047	0.003	15.000	0.000	0.041	0.053	0.041	0.053
Total N = OM	x 0.047	+ 0.05						

LEYS

Subsoil Organic Matter and Subsoil Total Nitrogen

Regression Statistics	
Multiple R	0.84
R Square	**0.71**
Adjusted R Sq	0.71
Standard Erro	0.03
Observations	132

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.254284	0.254284	315.0861	1.5E-36
Residual	130	0.104914	0.000807		
Total	131	0.359198			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.039	0.005	8.424	0.000	0.030	0.049	0.030	0.049
Subsoil OM%	0.038	0.002	17.751	0.000	0.034	0.043	0.034	0.043

Total N = OM x 0.038 + 0.04

EXTENSIVE GRASSLAND

Topsoil Organic Matter and Topsoil Nitrogen

Regression Statistics	
Multiple R	0.93
R Square	**0.86**
Adjusted R Sq	0.86
Standard Erro	0.04
Observations	94

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.945384	0.945384	556.0185	8.97E-41
Residual	92	0.156425	0.0017		
Total	93	1.101809			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.007	0.012	0.641	0.523	-0.015	0.030	-0.015	0.030
Topsoil OM	0.053	0.002	23.580	0.000	0.048	0.057	0.048	0.057

Total N = OM x 0.053 + 0.01 (intercept insignficant)

EXTENSIVE GRASSLAND

Subsoil Organic Matter and Subsoil Total Nitrogen

Regression Statistics	
Multiple R	0.88
R Square	**0.77**
Adjusted R Sq	0.77
Standard Erro	0.04
Observations	94

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.423585	0.423585	305.9024	5.24E-31
Residual	92	0.127393	0.001385		
Total	93	0.550978			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.021	0.008	2.693	0.008	0.005	0.036	0.005	0.036
Subsoil OM%	0.047	0.003	17.490	0.000	0.042	0.052	0.042	0.052

Total N = OM x 0.047 + 0.02

WOODLAND								
Topsoil Organic Matter and Topsoil Nitrogen								
Regression Statistics								
Multiple R	0.91							
R Square	**0.82**							
Adjusted R Sq	0.81							
Standard Erro	0.08							
Observations	34							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.913104	0.913104	145.9666	1.83E-13			
Residual	32	0.200178	0.006256					
Total	33	1.113283						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.065	0.024	2.720	0.010	0.016	0.114	0.016	0.114
Topsoil OM	0.035	0.003	12.082	0.000	0.029	0.041	0.029	0.041
Total N = OM x	0.035	+ 0.06						

WOODLAND								
Subsoil Organic Matter and Subsoil Total Nitrogen								
Regression Statistics								
Multiple R	0.93							
R Square	**0.87**							
Adjusted R Sq	0.86							
Standard Erro	0.03							
Observations	34							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.203357	0.203357	207.1579	1.58E-15			
Residual	32	0.031413	0.000982					
Total	33	0.23477						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.032	0.010	3.384	0.002	0.013	0.052	0.013	0.052
Subsoil OM	0.036	0.003	14.393	0.000	0.031	0.041	0.031	0.041
Total N = OM x	0.036	+ 0.03						