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Research Review No. 95

Analysis of top and subsoil data from the

High Speed 2 (HS2) rail project

Work package 3

London to Leamington Spa (Section C):

Clay vales and ridges

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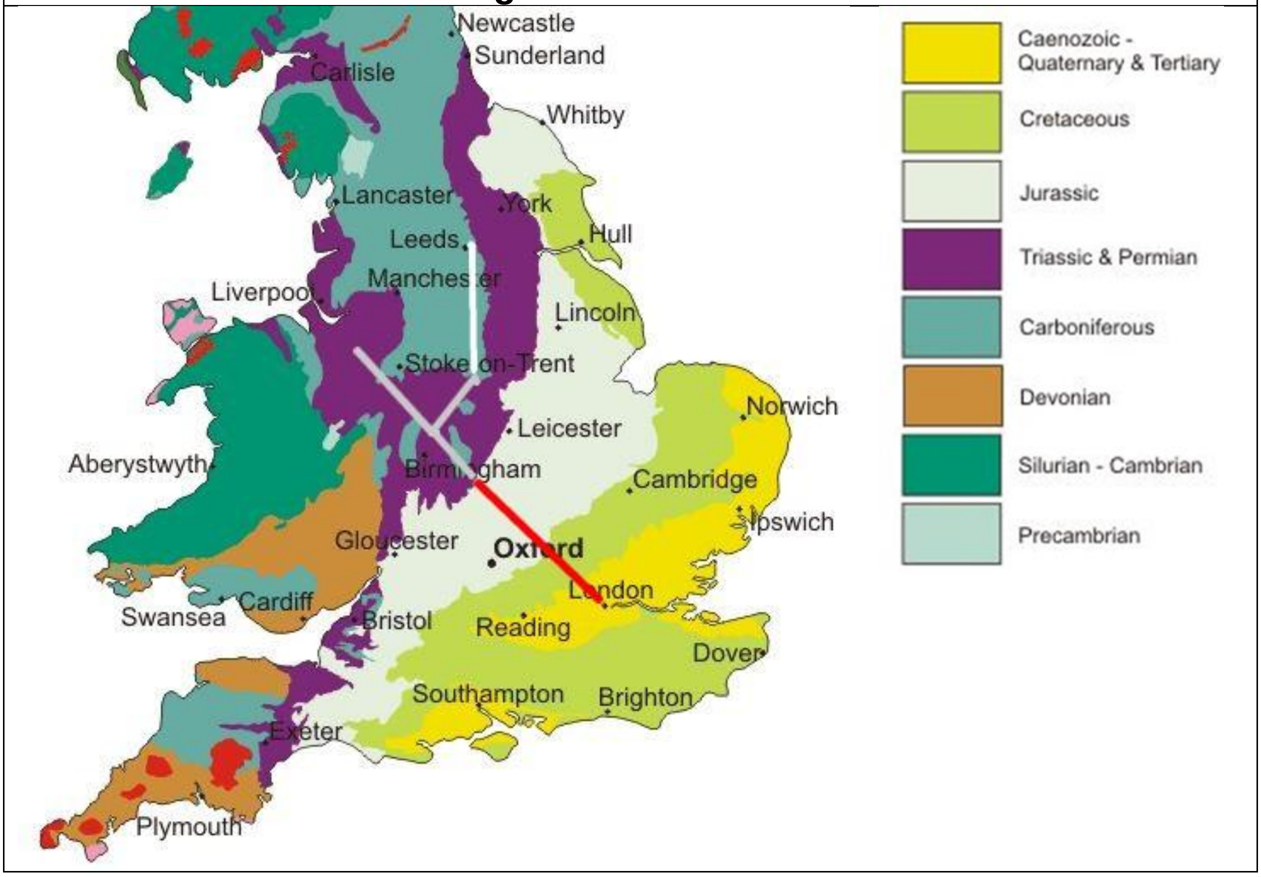
WP A : East Midlands to South Yorkshire	white
WP B : Leamington to Crewe and Nottingham	grey
WP C : London to Leamington	**red**



1. Executive Summary

This data set if from 409 sampling locations, 185 arable, 148 grassland , 28 amenity grass and 48 woodland, taken along a corridor from London to Southam at density of 1 per 3 ha with some cluster samples (up to 5 per ha).

This gives a representative coverage of soils on most of the geological sequence from London Clay in the south to Rhaetic clay-limestone in the north.

Topsoil was sampled 0 to 20-30cm depth and upper subsoil from 25-30cm to 50cm by corer or auger. There are some differences of method discussed in NW report which do not significantly distort the conclusions below.

Phosphorus

Arable land averaged 22 mg P/l (index 2). *40% of samples were below target index,* spread across all geological groups except the Chilterns. 31% of samples were above index 2 with some very high P values. The PAAG 2019 laboratory survey found less (22%) deficient though sampled to 15cm rather than the full depth of identifiable topsoil (23-30cm) here.

On grassland median P was 14 mg/l (index 1) with *51% of samples below target,* again measured on a deeper sample (20cm+) than is usually taken (7.5 or 15cm). PAAG (2019) reported 34% of grassland as deficient.

Topsoil P varied up to twofold within some larger cluster areas (4-5 ha). In small cluster groups (3-5 samples within 1ha) standard deviation from the mean was ±15% on arable and ±25% on grassland.

P did not correlate with topsoil pH and there was no clear effect of clay type. On heavier arable soils each Δ1% OM was associated with Δ1.9 mg/l increase in P.

Topsoil texture was influential: lighter soils tended to higher P except ferruginous sand. Clay topsoils (median 15 mg/l) were 9 mg/l lower than heavy loams. Woodland median was 13 mg/l but with large range - deviation of ±65% of the mean within one hectare. Some woods had good P fertility suggesting they are not ancient but planted on land that has been farmed at some point in the past.

Subsoil P averaged 8.7 mg/l arable and 6.2 mg/l grass. Lime-rich (clay) subsoils were usually <5 mg/l. Subsoil texture influenced medians on arable land:

Sandy, light loamy (21 mg/l) > medium (16) > heavy loam (13) >> clay (6 mg/l)

Clay textured upper subsoils were most likely index 0. Similar but weaker texture trends occurred on grassland and woodland.

There was variable degree of correlation of subsoil and topsoil P (r^2 0.3 – 0.8). On heavy subsoils P = topsoil P x 0.25-0.37 plus an intercept 1.4-2.9 or simply 0.45-0.47x topsoil P. Woodland was similar (subsoil P = 0.42 x topsoil P + 2.1). Topsoil and subsoil P converged at 5 mg/l.

In some groups, subsoil organic matter was influential, Δ0.9–2.9 mg/l P per Δ1% OM, due to carry-down by earthworms, deeper rooting or shallower start depth of subsoil sampling.

In heavy loam or clay subsoils, at topsoil P of 10, 20 and 30 mg/l, subsoil P is likely to be 4.5-6 mg/l, 7-10 mg/l (index 0) and 12-15 mg/l (index 1) respectively. Grassland subsoils will be at the lower end of these ranges (much lower if topsoil sampled 0-7.5cm).
There seems no difference between geological clays.

In light, medium or stony subsoils, at topsoil P of 10, 20 and 30 mg/l, subsoil P is likely to be 6-10 mg/l, 10-20 mg/l and 15-30 mg/l (index 2-3) respectively. Stony subsoils will be at the upper end of these ranges.

At very high index (5) subsoil P is typically 0.46x topsoil P but lower in some clays.

Only half the variation in subsoil P was explained by topsoil P and texture. On all research projects and crop trials, subsoil should be tested alongside topsoil and to specified depths (e.g. 0-20/25cm, 20/25-40cm and 40-50cm).

RB209 revision: despite over two decades promoting RB209 recommendations, a wide range of P levels persists across all textures in arable and grassland. In section 12 revised builds and run-downs are proposed for light/medium and heavy soils to speed convergence on target index.

The current target P of mid index 2 (20 mg/l) for arable and grassland should not be reduced. One reason (even with Precision sampling) is to counter short-range variation and avoid patches of index 1. Up to 35 mg/l (mid index 3) is unlikely to result in major P transmission from under-lying heavy subsoil into drains in most instances. Above 35 mg/l phosphate fertiliser application is usually unwarranted, but there is no need for restrictions on applying *reduced* amounts at 25-35 mg/l topsoil P, where seedbed conditions are suboptimal.

Potassium

Arable land median was above target (186 mg K/l, index 2+) with *20% of samples below target* (similar to 21*%* in PAAG, 2019). 31% of samples were index 3 or more. Levels were highest in soils on Charmouth (Lias) Mudstone, Oxfordian Clays and Kimmeridge Clay (~225 mg/l), intermediate on Glacial deposits and Whitby Mudstone (140 mg/l) and least on the Chilterns (122 mg/l).

Grassland averaged 163 mg K/l (index 2-) *with 32% of samples below target index* (slightly less than 44*% in* PAAG survey, despite being sampled to 20cm+ depth). Levels were high on Kimmeridge/Ampthill Clay (>300 mg/l), intermediate on Oxfordian clays, limestone-clay and London Clay (150-180 mg/l) and less on the Chilterns (120 mg/l). Whitby Mudstone and Glacial sandy deposits or clayey alluvium averaged index 1 (60-120 mg/l). 20% of all samples were index 3 or higher.

Topsoil K varied ± 25% in larger clusters. Analysis of 19 smaller clusters indicated less variation, arable sites ± 15% and grassland ± 20% provided the texture was uniform.

Topsoil K increases with clay content. There were ~40 mg/l (> half an index) increases between light loams, medium loams, heavy loams and clays on arable soils; 30 mg/l on grassland and woodland. Texture influence was double that found in the Midlands data. No heavy loam or clay topsoil was index 0 (< 60 mg/l) and few were index 1 (<5%); the majority of deficient soils were medium or light textured.

Subsoil K median values were 134 mg/l arable, 129 mg/l grass and 108 mg/l woodland.

On Glacial Till, Oxford Clays and alluvial clays, *subsoil* pH had a large influence : a 1.0 unit pH rise corresponding to +Δ40 mg/l subsoil K and +Δ50-90 mg/l topsoil K. It seems the persistence even of small amounts of natural lime preserves the potassium-supplying power of clay soils. K was lower where soil was influenced by (thin) Drift.

Subsoil K increased +Δ30 mg/l per texture category. In some (not all) groups, subsoil organic matter had an influence, +Δ18 mg K/l per Δ1% OM. Subsoil K was higher under one grassland cluster with high *topsoil* OM. Very low K (<15 mg/l) was found on ferruginous sand.

In heavy loam or clay subsoil <60 mg/l K was very rare. The fitted lines have slope of subsoil : topsoil K of 0.4-0.6x plus an intercept of 37-50 mg/l subsoil K (at theoretical zero topsoil K) similar to Midlands Triassic clays (45 mg/l). The general equation is Subsoil K = Topsoil K x 0.57 + 40. At topsoil mid index 1 (90 mg/l), subsoil is parity; at top and bottom of index 2- (120-180 mg/l) subsoil will be 110 and 145 mg/l. At top of index 2+ subsoil will be 175 mg/l and by mid-index 3 >200 mg/l. This is similar to the Midlands (red) clay soils (NE report).

The first 60 mg/l of K measured in clays might not be plant-available, but assuming 90 mg/l as a minimum safe level for subsoil K (if topsoil dries out), topsoil index 2- implies an adequate buffer or subsoil K in heavy loam and clay soils.

However on medium and light subsoils, slope and intercept are lower than heavier soils. To ensure > 90 mg/l in subsoil, the topsoil target should be at least mid-index 2- (150-180 mg/l).

All soils at index 3 have surplus of K in topsoil, but heavier soils have a greater buffer of K in subsoil also and are likely to run-down slower when no potash input is applied.

RB209 revision: although the heavier soils which dominate Region C generally have adequate potassium there is wide disparity of K status which could be addressed simply:

- a 3-tier classification for predicting high, intermediate and low K-releasing clays.
- modified build/run-down matrices to better utilise excess soil K reserves in heavier soils and improve lighter soils (see section 13).
- except on very sandy soils, target must be at least *mid* index 2- (150 mg/l) to ensure adequate subsoil K and offset short-range variation in topsoil K.

In zonal sampling, areas of different topsoil texture class (and calcareous versus non-calcareous soils) should be delineated.

Topsoil should be sampled to 20cm depth in arable, forage crops and conserved grassland.

Although topsoil K and texture account for 65-75% of the variation in subsoil K, in potash response trials it is prudent to measure subsoil K and specify topsoil and subsoil textures.

PAAG could do some inter-laboratory checks on coarse-sieved undried soils because soil preparation procedure can affect the potassium result. "Scoop" density is best recorded.

Magnesium

Topsoil Mg averaged 179 mg/l arable and 181 mg/l grass (index 4). 18% of arable samples and 10% of grassland were below index 2 (<50 mg/l), mostly in the Chilterns, while 27% of arable samples and 31% of grassland were >250 mg/l (Mg index 5+), more than the 12% in the PAAG (2019) national data. 6% of all data was index 6.

Grassland averaged 60 mg/l higher Mg than arable land (expected where grazed and/or heavily manured).

Mg in two large close cluster samples (high Mg) varied ±20% from the mean. On smaller clusters (within one ha) short-range variation was < ±15% (< 8 mg/l Mg) over the index 1 to 2 range provided texture was uniform.

Topsoil texture was highly important. Median values in arable soils ranked light loam (33 mg/l) < medium loam (47) < heavier loam (118) << clay (209 mg/l). Below target index (2) was very likely on light loam topsoil, common on medium topsoil but very unlikely on heavy loams or clays which were typically index 3 and 4 respectively (sometimes higher).

Under grassland topsoil Mg (to 20cm+ depth) was typically index 2 on light loams, 3 on medium loams, 4 on heavy loams and 5 on clays. Woodland was typically index 2 on light loams, 3 on heavy loams and 4 on clays.

Subsoil Mg strongly correlated with topsoil Mg. >75% of variation in subsoil Mg was explained by topsoil Mg modified for textural class. In clay subsoils Mg is 1.1–1.4x topsoil Mg, in medium subsoils 1-0.85x and in sandy, light loam or stony subsoils 0.65x.

In arable subsoils Mg increased Δ20, Δ50 and >Δ100 mg/l between light, medium, heavy loam and clay subsoil (typically index 0, 1, 2 and 4 respectively). Under grass, subsoil Mg were higher with even bigger increases due to texture. Geology was important with Mg-supplying power of clays increasing in sequence Clay-with-Flints < Jurassic limestone-&-clay, Glacial Till, Whitby Mudstone (Lias) < Dyrham siltstone, Rhaetic clay < Oxford Clay, Kimmeridge Clay < London Clay, Charmouth Mudstone (Lias). In some groups Mg decreased with increasing pH but not in others.

Under woodland, median topsoil Mg was 148 mg/l (index 3) with range index 1 to 8. Subsoil median was150 mg/l and showed very similar correlation with topsoil Mg as arable data.

RB209 revision: suggestions are made to clarify soil types likely to suffer Mg deficiency – sands and light loams plus medium topsoils on gravel, limestone, (Chalk) or Clay-with-flints.

The risk of potassium deficiency induced by high magnesium (K:Mg ratio > 0.5) is less in Southern clays than found in the NE and Midlands data sets, but still possible, especially on Charmouth or London Clay. A higher K index might be appropriate in such cases.

Proneness to structural instability due to more than 20% Mg on the exchange complex is unlikely until Mg reaches index 6 or when ratio of topsoil Mg (mg/l) / CEC (meq/100g) exceeds 17.4.

pH

Topsoil median pH for grass and arable data was 6.7 (optimal): 22% of arable samples were suboptimal pH (6-6.4) and 17% acid (pH <6.0). 22% of grassland was < 6.0. The PAAG (2019) survey found a similar proportion of arable land at pH <6.0 (19%). They also found 19% of grassland pH <5.5 whereas in this data only 4% was pH <5.4 and 5% at pH 5.5, although soils were sampled to 20cm+ and might be more acid if measured 0-7.5cm.

Acid soils were most common on Charmouth Mudstone, Horsehay Sand (ironstone) and Glacial deposits but could be found on all formations except Ampthill, (Kimmeridge) and Rhaetic Clay and Jurassic limestone-&-clay.

20% of topsoils had pH >7.4 (arable and grass). In cluster samples pH deviation was typically ±0.2.

Subsoil median pH was 7.2 and 7.3 on arable and grass. 50-75% of the variation in subsoil pH was explained by topsoil pH. Each 1% of subsoil OM was associated with a -Δ0.1-0.3 decline in subsoil pH in some cases. An increase in 10% stones was linked to a Δ0.1 pH decline, so pH tended to be 0.2-0.3 lower in stony or gravelly subsoils than others.

Topsoil and subsoil pH converged at pH ~7.7; at topsoil pH 6.5 subsoil was usually >7.0; at pH 6.0 subsoil was 6.5+ and at topsoil pH 5.5 subsoil was at least pH 6.0 though in some cases was similar to topsoil pH. For heavier soils the general equation was
Subsoil pH = Topsoil pH x 0.7 + 2.6 (r^2 = 0.58)

Unexplained variance might be caused because of greater seasonal pH fluctuation in topsoil than in subsoil. Soluble calcium levels in topsoil are likely to be lower in winter than summer.

36% of all subsoils were alkaline (pH >7.4) probably due to native $CaCO_3$, in many cases too little to detect by the field HCl test. On Rhaetic, Oxfordian Clays and Jurassic limestone >80% of upper subsoils were alkaline, but <30% on Lias Clays, London Clay and Glacial Till. 50% of Alluvial and Clay-with-Flints subsoils were alkaline but few gravelly subsoils.

The national soil mapping units Denchworth, Ragdale and Fladbury associations contain both calcareous and decalcified variants, and areas with admixture of non-calcareous Drift. This causes pH variation and field-scale surveying is needed to delineate effectively.

On limestone-&-clay topsoils, pH was never acid where limestones were present. The Chilterns had highly variable soil type and pH.

34% of woodland topsoils were pH <6.0 of which 14% were extremely acid (pH <5.0). Others were alkaline. Subsoil pH was typically 0.1-0.3 higher than topsoil pH though not infrequently subsoil was as acid as topsoil (unlike arable or grassland).

RB209 revision: clearer guidance could be provided:
a) when *subsoil* pH should be measured also
b) the importance on clays of pH testing 1 per ha or within ground-truthed zones
c) liming clays to maintain pH above 7 to improve soil structure?
d) separate lime recommendations for sampling depths of 10cm (permanent grassland), 15cm (leys) or 20cm (arable land).
e) *seasonal* monitoring of topsoil and subsoil pH on selected research sites.

Organic Matter

The survey data was measured for Total Organic Carbon. $CaCO_3$ was removed by acid prior to the soil being burnt at 900ºC and CO_2 measured (Dumas method). Organic matter is assumed TOC x 1.72.

Loss on Ignition method was found to include 2.6% structural water on heavy soils, and is unsatisfactory for measuring Organic Matter, C:N ratio or for Indexing soil structural condition.

Topsoil: median OM in arable soils was 4.5%, somewhat higher in some clay areas and lower in the Chilterns. Most samples lie in the 3-6% range.

In grassland median OM was 6.4%; levels were lower on Chiltern and Glacial soils. More than half samples exceeded 6% OM though 8% were <3% OM. This was measured to 20cm+ and OM is likely higher in the surface 10cm on permanent grass sites. Median in woodland floors (0 to 20-30cm) was 7.6% which included any F/H material on the surface.

Texture was highly significant. Average levels in arable soils were 3.4% in light and medium loam soils and 4.6% on heavy loams (>27% clay) or clays. On grassland levels increased from 4% on light loams to 7.5% on heavy loams. However, it decreased to 6% on clays, a trend also found on woodland, though this might reflect reduced accuracy of hand-texturing soils high of high organic matter.

Cluster analysis indicated typical short-range OM variation of ±11% of the mean in arable or grassland topsoils, higher (± 20%) under woodland.

Subsoil: median OM (to 50cm) was 2.3% in arable, 2.4% in grass and 3.2% under woodland, indicating that large increases in topsoil OM were accompanied by smaller changes in subsoil OM. Subsoil OM increased with subsoil clay content : 1.0% in loamy sands, 1.4% in light or medium loam and 2.3% in heavy loams or clays in arable land. On grassland medians were 1.5% light loams, 2.1% in medium and 2.5% in heavier subsoils.

On heavier soils at topsoil OM 3% the subsoil is typically 1.5% and for every 1.5% increase in topsoil OM subsoil increases by 0.5% so that at 7.5% topsoil OM subsoil may exceed 3%.

On light to medium soils at topsoil 3% subsoil also is 1.5%, but somewhat higher on stony soils because of deeper rooting or stones concentrating the OM% input from roots, crop residues or soil amendments.

Less than half the variation in subsoil OM was explained by topsoil OM and subsoil texture. Start depth of subsoil sample is important because OM% decreases with depth over the 25cm to 50cm range. OM penetration is affected by historical deep cultivation and amount of earthworm activity may be involved. Predictability was worst under high OM grassland or woodland where clayey subsoil could vary from <1.5 to >4.5% OM. Under woodland subsoil OM was higher in heavy loam than clay subsoils.

Soil Organic Matter Index: the system proposed by Prout et al. (2020) classed soils as "degraded", "moderate", "good" and "very good" quality based on clay:SOC ratio. In the NSI data base 38% arable, 15% leys, 7% permanent grassland and 6% woodland were classed "degraded". Their method was applied to the data here assuming representative clay% for the hand-texture classes. Accordingly, *65% of the arable land in Region C would be classed degraded, 13% of grassland and 19% of woodland.*

Topsoil texture was the main driver of index: in arable land 8% of light loams were rated degraded, 37% of medium and heavy loams and >90% of clay-textured topsoils. Proportion in the "very good" class dropped from 54% of light loams to 0% of clays. Under grassland 11% of heavy loam and 30% of clay topsoils were "degraded" (20 and 28% under wood).

Land Quality protocols: the Index's allowance for clay % is a big improvement on the fixed OM divisions used hitherto. However, it classes much productive clay land (of <5.5% OM) as 'degraded' whereas 'would benefit from some improvement' might be fairer. The ratios might need review on the heaviest soils.

- depth of topsoil sampling for assessment should be standardised at 0-20cm.
- 20-40 cm sample may be worthwhile also. The latter might have a minimum of 2.5% OM as a gauge of porosity.
- 40-50/55cm sample is sometimes useful. It has much lower OM and P and could assess risk of transmission to field drains.

Topsoil could be uprated where pH >7.4 and subsoil uprated if > pH 7.4 or >2% $CaCO_3$ since this improves structural stability significantly.

PAAG need to ascertain that the TOC analysers used at Rothamstead and in the main commercial laboratories are in agreement, as well as their methods of clay measurement, avoiding distortion by clay-sized carbonates.

Monitoring (retesting after 5 years) should be based on a composite of 20 subsamples taken in a grid in GPS-referenced or delimited areas either in a) small (~0.2 ha) areas or b) larger (1-4 ha) zones of uniform soil type.

Carbon: in Region C the mean to 50cm depth was calculated as 122 t C/ha on arable land, 153 t C/ha on grassland and 184 t C/ha under woodland. Soil texture and stones make a significant difference; the proportion at 25-50cm in subsoil is greater on arable land.

The calculation method needs peer review before further details can be given.

Total Nitrogen

A subset of 137 cluster samples were measured for Total N (Dumas method). Average TN of topsoil was 0.3% on arable and amenity grass, 0.45% on grassland and woodland, higher than in the Midlands data which comprised lighter textures and lower OM than the Southern set. Both regions had similar C:N ratios.

TN in subsoil averaged 0.18% arable, 0.23% grass, 0.13% amenity grass and 0.23% wood.

Average C:N ratio was 9.5 in arable land, 10.5 in grassland and 12 in woodland, slightly lower in subsoil than topsoil. Where carbon was estimated from OM by Loss on Ignition there were erroneously high C:N ratios of 13-16 in topsoil and 16-20 subsoil.

When Southern data and Midlands was combined (484 data) average topsoil TN was 0.22% arable/leys, 0.3% in permanent grass and 0.4% in woodland (subsoil 0.11, 0.14 and 0.16%).

C:N ratio declines in soils of higher clay content and increases with increasing organic matter content, regardless of whether arable, grass or wood, topsoil or subsoil.

C:N is higher in organic soils. At normal OM content (<10%) C:N was typically 12 in sands, 10 in medium soils and 9.5% in clays. Lines fitting total N and OM had a significant intercept (at theoretical zero OM) of 0.02-0.04% TN in topsoil and 0.01-0.03 in subsoil. Slope increased from 0.4 in sandy and light loams to 0.55 in medium to heavy soils (C:N 10 gives 0.58). High TN may accumulate in some waterlogged subsoils.

RB209 revision: 15% of arable topsoils in Region C were >0.34% N triggering a 40 kg/ha expected increase in SNS due to mineralisation (HGCA wheat guide); 74% were 0.23-0.34% (20 kg/ha adjustment). RB209 uses OM measurement a surrogate for Total N assuming C:N of 10. This assumption is dubious because C:N varies from 8-12:1. Accuracy is improved by texture-based equations in this report but standard error remains ± 0.04% TN.

In laboratories where N is measured on the same machine as TOC, TN could be measured routinely alongside OM for minimal extra cost.

The author hypothesises that Total N exists in four different forms

a) mineral N
b) non-exchangeable ammonium inside clays
c) N trapped in clay-organic complexes
d) organic N in 'free' humus

a) is very small. The contribution of b) is worth investigation. d) material may be higher C:N than c) but the N in d) more likely to be mineralised. This warrants a research project because better estimation of d) and b) might enable better prediction of release in N over the growing season than by OM or TN measurements alone.

2. Methodology, Land Use and Parent Material

Region C: London to Leamington

Sampling Methodology

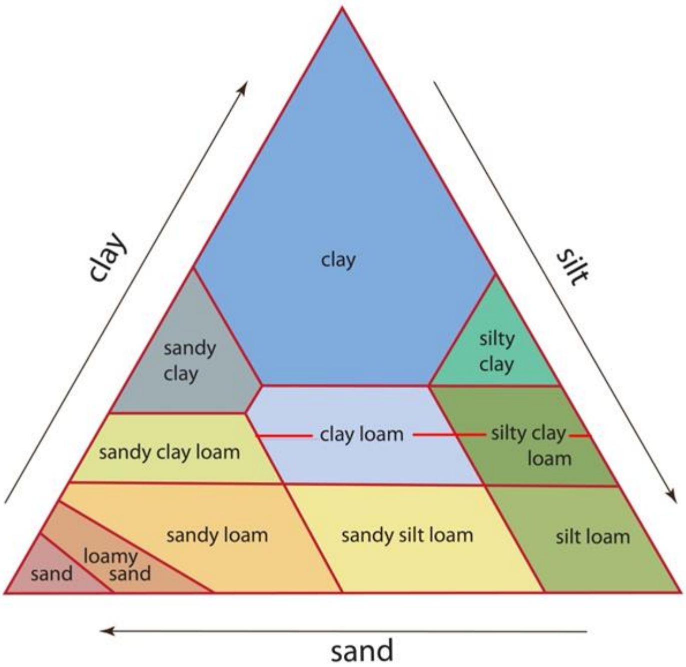
Samples for the laboratory were taken either by corer or Dutch auger, a composite of five cores from topsoil and subsoil to 50cm. Methodology is discussed in NE and NW reports. The corer tends to somewhat shallower start depth of subsoil sample and slightly higher organic matter (OM) and P values, but this does not alter the main findings of this report.

Soil samples under woodland were taken from the main floor rather than close to the trees. Litter material was excluded but surface F and H layers included in the topsoil sample.

'Subsoil' in this report refers to upper subsoil, typically starting from 25-32 cm depth and extending to 50cm. Topsoil was sampled to at least 20cm depth. Profile horizons were described to 120cm or impenetrable layer if less. Wetness Class I-IV was ascribed from mottling and estimated permeability (denoted m, m/p or p in data base). The hand-textures, by experienced soil surveyors, for analysis are sorted into six main groups as in Table 2.1.

Most points sampled and surveyed were 1 per 3 hectare but some were in closer clusters (up to 5 per ha), especially in woodland.   Parts of the Southern transept were not in the survey because existing detailed information was already available from national data sources.

Soil texture



The middle categories in the texture diagram are split upper and lower. In this report "medium loams" refers to category 2 in Table 2.1 and "heavy loams" to category 3 (which includes "heavy silts"). In RB209 and SSEW manuals both are termed 'medium' or 'fine silty/loamy' but the +/- 26% clay distinction is important for judging the workability of land as reflected in the 1988 guidelines for land classification [3].

Table 2.1 : Soil Texture and Stone categorisation

Class	Soil Texture	Estimated clay %
0	Very light LS (S)	< 10% %
1	Light Loam SL, fSL, SZL	10 - 18 %
2	Medium SCL, mCL, mZCL	19 - 26 %
3	Heavier hCL, hZCL, SC	27- 35%
4	Clayey ZC, C	> 35 %
P	Peaty loam or peaty sand	>20% OM

Class	Estimated **stones** by vol
0	< 5%
1	5 - 14%
2	15 - 24%
3	25 - 40%
4	> 40%

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 the upper subsoil comprised two textures within 50cm the average clay content is ascribed, e.g. mCL over C is grouped with hCL and placed in category 3.

Subsoils of >50% clay are included in the same category as 'loamy' or silty clays (4).

Stoniness is divided in four classes as in Table 2.1. Stone is any particle >2mm and estimates are subject to greater error than hand-texturing, especially in subsoil.

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.

Each result was classified according to the index system in The Fertiliser Manual RB209 [5] which ascribes the result to an index category, as reproduced in table below.

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

In principle moderate is the *Target level* for arable and grass; "good" is target for rotations with vegetable crops. K index 2 is subdivided in RB209. In some parts of this 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.

Organic Matter

Total Organic Carbon was measured by Dumas analyser on all samples and converted to Organic Matter (1.72x).

Table 2.2 : Organic Matter categorisation by Soil Survey of England and Wales

Category	Adaption	Organic Matter
Very low		< 1.5%
Low		1.5-2.9%
Moderate		3 - 4.4%
High	Good	4.5 - 6%
Very High	High	> 6%
Humose	Organic	> 6[1]-10[2] %
Peaty loam/sand	Peaty	> 20[1]-25[2] %

[1,2] sliding threshold for soils of 0% to 50% clay

The categories in SSEW manuals [2] and ALC guidelines [3] are in Table 2.2. For ease of understanding in the report "Good" and "High" are substituted for High and Very High. SSEW usually measured OM by wet oxidation. Not all methods of OM determination give similar results; this is fully discussed in the Organic Matter Overview.

The drawback of the SSEW classification is that it makes no adjustment for soil texture unless the soil has very high organic matter. It is known that soils with more clay retain higher OM levels and that the ameliorative effect of added organic matter is diluted as clay content increases.

Soil Organic Matter index was recently proposed by Prout et al. (2020) [4] selecting key clay to organic carbon ratios of 13, 10 and 8:1 for assessing soil structural condition. So for this data a macro was written to ascribe an index to every datum point using ascribing a representative clay % for each hand texture class as in Table 2.3. OM is SOC x 1.72.

Table 2.3 Soil Organic Matter index. Values are maximum OM% for each structure class for topsoil of texture classes 0 – 4. Percentages are the representative clay contents used.

Class	Soil Structure	Clay/SOC	**0** (LS) 9%	**1** 13%	**2** 22%	**3** 31%	**4** (ZC) 38%	**4** (C) 42%
A	Very good	< 8						
B	Good	8-10	1.94	2.8	4.75	6.65	8.2	9.0
C	Moderate	10-13	1.55	2.2	3.75	5.35	6.5	7.2
D	Degraded	> 13	1.15	1.7	2.9	4.1	5.0	5.5

For example, a measured SOM of 3.5% in a sandy loam soil (1) would be classed as very good structure (A), in a medium loam (2) as moderate (C) and 3.5% in a heavy loam (3) would be classed degraded (D).

Hand texturing was done by experienced surveyors, who have checked themselves against samples analysed for particle size distribution by the full pipette method. Clearly surveying cannot give precise clay contents, but the criteria Table 2.3 should minimise *systematic* error when the assessing data sets *as a whole*.

The SOM Index is reviewed in the Organic Matter Overview.

Land Use

409 samples were taken along a corridor from London to Southam.at density of 1 per 3 ha with some cluster samples (5 per ha). Land use was noted while surveying.

The corridor stretches from west London to Leamington with significant representations of arable (185), grassland (148) and woodland (48) samples with some amenity (28) areas towards the London end.

The data should not be extrapolated to gauge land use across this region. Other national data bases are available to do this. However, differences in nutrient, pH and OM levels between arable, grass and wood are tabulated in this report.

Soil parent material

Each data point was pinpointed to a British Geological classification[1] and soil association [2]

However each point's location is not in the data base passed to AHDB, but described only under its general section location in order to preserve client confidentiality.

As shown on the introduction page, this transept covers soils formed along the Geological Column from the younger Tertiary deposits in London, through Cretaceous (chalkland) to the series of various Jurassic rocks in Oxon, Bucks and south Warwickshire.

For this report the data has been grouped according to parent material in north-south order as in Table 2.4. All are "solid" geologies apart from a) Glacial Deposits (typically overlying Jurassic limestone), b) Alluvium (small areas on all geologies) and c) the Chiltern region is dominated by Drift (Clay-with-Flints or Sand-and-Gravel, usually overlying Chalk).

Table 2.4: Geological member, soil texture distribution and Soil Associations

Geological Grouping	**% Topsoil Category**				**% Subsoil Category**				**Soil Association**
BGS maps	**0,1**	**2**	**3**	**4**	**0,1**	**2**	**3**	**4**	SSEW maps
Rhaetic Clay / limestone			***100***			*25*	***50***	*25*	*Evesham*
Charmouth Mudstone		*6*	*15*	***79***				***100***	*Denchworth*
Whitby Mudstone			***87***	*13*			*13*	***87***	*Denchworth*
Horsehay Sand	***67***	*33*			***67***	*33*			*Banbury*
Jurassic clay / limestone		*9*	***91***			*18*	***73***	*9*	*Aberford*
Glacial Deposits	*8*	*28*	***50***	*10*	*8*	*13*	*15*	***64***	*Ragdale, Wickham II*
Peterborough Member		*5*	*32*	***63***			*3*	***97***	*Denchworth*
Stewartby Mudstone				***100***				***100***	*Denchworth*
Weymouth Mudstone			*14*	***86***				***100***	*Denchworth*
West Walton Formation				***100***				***100***	*Denchworth*
Ampthill Clay			*31*	***69***				***100***	*Denchworth*
Kimmeridge Clay			***57***	*43*			*29*	***71***	*Denchworth*
Chilterns – clayey	*8*	***41***	***32***	*19*			***50***	*50*	*Batcombe etc*
Chilterns–other subsoil*	*44*	***56***			*39*	***61***			*Sonning I & II, Charity*
London Clay	*2*	*42*	***49***	*7*		*5*	*13*	***82***	*Wickham II, Windsor*
Alluvium		*14*	***36***	***50***	*1*		*14*	***85***	*Fladbury I & III*

Main texture category(s) emboldened. Arable and grass data (undifferentiated).

"Oxford Clay" has been subdivided into Peterborough, Stewartby, West Walton and Weymouth Members and Ampthill Clay which is often mapped with Kimmeridge Clay.

The dominant *upper subsoil* texture is clay (class 4) as shown above. Topsoil texture is most often heavy loam (3), probably due to inclusion of silty or loamy 'cover loam' too thin to indicate as Drift on BGS maps (or due to clay eluviation). However some formations have predominantly clay topsoil, e.g. the Charmouth Mudstone and middle members of the Oxford Clay group, whereas Chiltern clays and London Clay have significant proportion of medium textured topsoils (2). Light loam topsoils (1) are rare except on Glacial and Chiltern gravels or on the Horsehay (ferruginous) Sand.

Soil association (SSEW) [2] maps do not differentiate the different types of swelling clay (all mapped as Denchworth association) apart from London Clay. The same association [2] may permit both calcareous and non-calcareous variants, and has latitude in texture and sometimes stoniness. The Chilterns have a complex soil pattern though it tallied fairly well with the BGS maps which are higher resolution than SSEW.

References

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

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

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

4 Prout JM, Shepherd KD, McGrath SP, Kirk GJD, Haefele SM. (2020) What is a good level of soil organic matter? An index based on organic carbon to clay ratio. European Journal of Soil Science 1-11

5 AHDB (2017) The Fertiliser Manual RB209

Two more summary reference tables are referred throughout the text and so shown here as well as in the Overview sections.

Table 2.5 : Geological member and magnesium and potassium status

Geological Grouping (BGS maps)	Topsoil Mg mg/l median	Topsoil Mg mg/l 25-75%	Subsoil Mg mg/l median	Subsoil Mg mg/l 25-75%	Subsoil K mg/l median	Subsoil K mg/l 25-75%	*Sub K:Mg*	*n (grass)*
Rhaetic Clay / limestone	**138**	128-151	**164**	130-209	**208**		*1.3*	*4 (4)*
Charmouth Mudstone	**280**	165-452	**324**	211-586	**156**	128-220	*0.5*	*62 (6)*
Whitby Mudstone	**83**	67-113	**80**	58-141	**87**	52-112	*1.1*	*8 (3)*
Horsehay Sand *	**34**	27-78	**21**	19-29	**32**	15-43	*1.5*	*6 (2)*
Dyrham Siltstone ^	**154**	125-184	**175**	133-199	**72**	66-85	*0.4^*	*6 (2)^*
Jurassic clay / limeston*	**96**	57-123	**69**	31-113	**201**	113-439	*2.9*	*7 (7)*
Glacial Till	**111**	90-125	**92**	81-115	**106**	93-143	*1.2*	*25 (6)*
Peterborough Member	**155**	112-233	**202**	153-242	**134**	120-150	*0.7*	*32 (3)*
Stewartby Mudstone	**265**	241-284	**359**	306-402	**246**	230-257	*0.7*	*4 (1)*
Weymouth Mudstone	**226**	193-261	**262**	225-344	**188**	169-254	*0.7*	*21(11)*
West Walton Formation	**206**	152-259	**237**	166-331	**173**	164-179	*0.7*	*4 (3)*
Ampthill Clay	**265**	234-344	**285**	237-312	**191**	162-317	*0.7*	*15 (7)*
Kimmeridge Clay	**236**	197-321	**262**	181-361	**160**	146-180	*0.6*	*6 (4)*
Chilterns – clayey	**55**	42-73	**58**	41-88	**103**	70-129	*1.8*	*29 (15)*
Chilterns–other subsoil*	**46**	38-76	**40**	28-56	**84**	67-107	*2.1*	*27 (9)*
London Clay	**256**	202-402	**485**	277-613	**132**	108-137	*0.27*	*63 (60)*

Only cases with heavy loam or clay upper subsoil are included, except *.
^ Alluvium on Dyrham Siltstone which includes 4 wood samples and so may not be representative

Table 2.6 : pH in relation to Geological member

Geological Grouping (BGS maps)	**Topsoil pH** median	**Topsoil pH** 25-75%	**Topsoil pH** > 7.4	**Subsoil pH** median	**Subsoil pH** 25-75%	**Subsoil pH** *> 7.4*	*n (grass)*
Rhaetic clay & limestone	**7.8**	7.2-8.0	75%	**8.0**	7.8-8.2	*100*	*4 (4)*
Charmouth Mudstone	**6.2**	5.9-6.8	10%	**6.9**	6.6-7.3	*18%*	*62 (5)*
Whitby Mudstone	**6.6**	5.8-7.1	13%	**7.1**	6.7-7.4	*25%*	*8 (3)*
Horsehay Sand *	**5.7**	5.5-6.1	0%	**6.3**	6.1-6.6	*0%*	*6 (2)*
Jurassic clay & limestone *	**7.6**	6.8-7.9	57%	**7.9**	7.2-8.2	*86%*	*7 (7)*
Glacial Till	**6.6**	6.0-6.9	16%	**6.9**	6.7-7.3	*24%*	*25 (6)*
Peterborough Member	**6.7**	6.3-6.9	9%	**7.1**	6.6-7.4	*25%*	*32 (3)*
Stewartby Mudstone	**7.3**	6.9-7.7	50%	**7.8**	7.6-7.9	*75%*	*4 (1)*
Weymouth Mudstone	**7.3**	6.8-7.7	48%	**7.9**	7.6-8.1	*86%*	*21(11)*
West Walton Formation	**7.6**	7.2-7.9	50%	**7.9**	7.6-8.0	*75%*	*4 (3)*
Ampthill Clay	**7.0**	6.7-7.5	27%	**7.7**	7.5-8.0	*80%*	*15 (7)*
Kimmeridge Clay	**6.6**	6.3-6.8	0%	**7.8**	7.5-7.9	*67%*	*6 (4)*
Chilterns – clayey	**7.1**	6.2-7.8	38%	**7.5**	6.6-7.8	*54%*	*24 (15)*
Chilterns – other subsoil *	**6.7**	6.1-7.4	22%	**7.0**	6.6-7.3	*22%*	*27 (9)*
London Clay	**6.4**	5.9-6.9	2%	**7.1**	6.3-7.4	*22%*	*63 (60)*
Alluvium	**6.5**	5.9-7.3	29%	**7.3**	6.8-7.7	*50%*	*14 (12)*

Only cases with heavy loam or clay upper subsoil are included, except *.

3. Soils on Charmouth Mudstone

This set comprises 57 samples in arable land taken along a transept south of Southam, Warwickshire. Sampling density was variable including 21 samples taken close spaced (5 per ha) in the same field. So it could challenged how representative this data is of the whole area. There were also clusters of 5 samples in grassland and in a nearby wood.

Land Use and Soils

9% of topsoils were heavy (silty) clay loam, 7% silty clay and the remainder clays. 5% of subsoils were silty clay or sandy clay and the rest heavy clay; there was some variation in stoniness (0-10%). Colour was mottled greyish (olive) brown. Natural drainage status was judged poor (84% WC IV and the rest III or II) however the arable land is thoroughly under-drained and crops were evenly established.

43% of samples were taken by corer method. Median start depth of subsoil sampling was 25cm by corer and 30cm by auger method.

Table 3.1 : Nutrient Summary for soils on Charmouth mudstone (arable)

	Topsoil			Upper Subsoil			Topsoil frequency % in Index					
	mean	median	10-90%	mean	median	10-90%	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	13.4	**12.6**	9-19	6.2	**5.6**	3.4-11	18	63	15	4		
Potassium	224	**225**	137-306	174	**160**	115-251		4	30+24	42		
Magnesium	317	**308**	86-548	399	**327**	110-699		2	12	16	15	55
K:Mg ratio	1.1	**0.7**	0.4-2.2	0.7	**0.4**	0.2-1.6						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.4**
pH	6.4	**6.3**	5.9-7.4	7.0	**6.9**	6.5-7.8	2	23	37	23	5	11
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	4.5	**4.6**	3.6-5.1	2.7	**2.7**	1.7-3.7			38	58	4	
Clay/SOC	16	**15**	13-20		**Index**	**D-A**	91	9	-	-		

Phosphorus

81% of the topsoil samples were index 1 or 0. There was significant variation within the 21 cluster samples spaced 45m apart (10-90% range was 8-13 mg P/l); the cluster of 5 in a grass field ranged 7-13 mg/l and in the wood 6-29 mg/l. Topsoil P was not significantly related to topsoil texture, pH or organic matter.

Subsoil P averaged 5.6 mg/l (mid index 0) and correlated strongly with topsoil P (Figure 3.1). When topsoil was index 1, subsoil was <10 mg/l (index 0), at topsoil index 2 subsoil was variable but <15 mg/l. Samples taken by corer method averaged 1.8 mg/l higher topsoil P and 1.4 mg/l greater subsoil P than by auger method (an effect of sampling depth). Each 1% increase in subsoil OM% corresponded to +Δ1.3 mg P/l (see Table 3.2).

On the grassland cluster subsoil P was the same (4-5 mg/l) irrespective of variation in topsoil, but broadly fits the arable regression line. On the wood cluster subsoil was 5-10 mg/l and not well correlated with topsoil P (Figure 3.1).

Despite good topsoil organic matter the topsoil P is inadequate. Either the farmers have been obtaining a higher P index using 0-15 cm sampling, or there is a high rate of P occlusion due to the high clay content preventing target index being obtained.

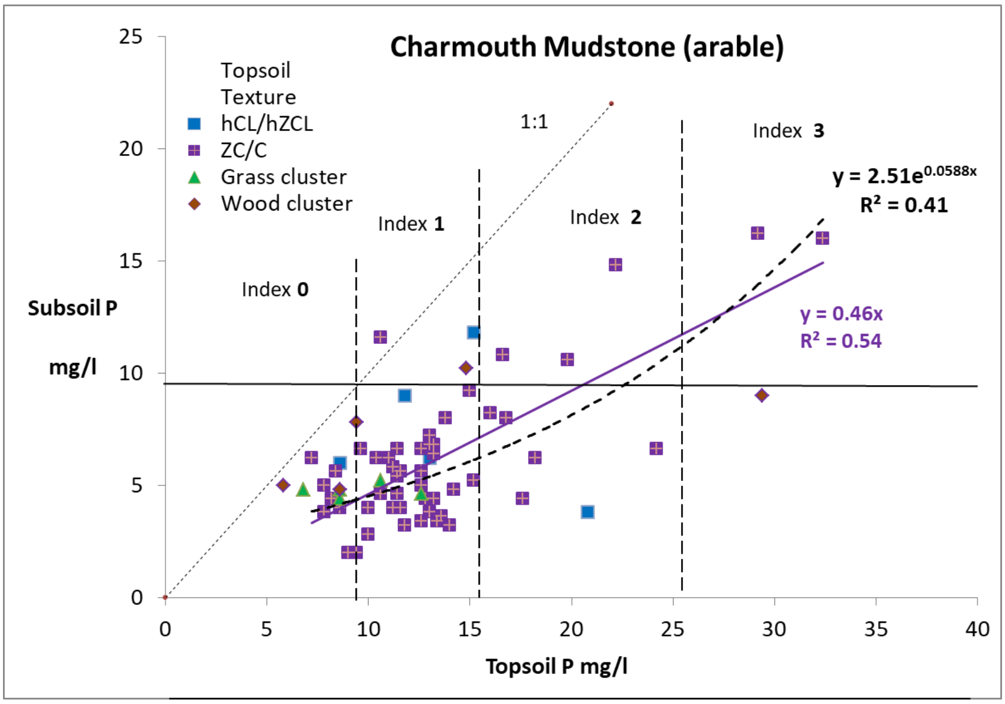


Figure 3.1: heavy soils on Charmouth Mudstone: Phosphorus in topsoil and subsoil

Potassium

Topsoil K levels in arable data were good - median index 2+ (225 mg/l) with 42% at index 3. There was a significant 10-90% range within the 21 cluster (172-305 mg K/l). Topsoil K was not significantly related to topsoil texture (heavy loam versus clay), pH or organic matter.

Small clusters on a grass field and wood had lower K (94 and 158 mg/l). There was a two-fold variation in the former. These had medium or heavy loam topsoil.

Subsoil K shows a linear correlation with topsoil K (Figure 3.2) with a significant intercept of 32 mg/l subsoil K at theoretical zero topsoil K. There is weak relationship with organic matter, each 1% increase in subsoil OM% corresponding to +Δ18 mg K/l, and very weak negative relationship with subsoil pH.

At topsoil was index 2+ the subsoil was typically 2-; at topsoil index 2- the subsoil K was above 100 mg/l and likely to be adequate if required by crops.

Agronomic: It was not possible to ask farmers about their potash applications, however assuming they have been adjusting K fertiliser according to RB209, the high K indices (2+ and 3) indicate a high rate of natural potassium release here, possibly matching offtake. However, the presence also of indifferent K levels in some places is caution against banking on such high release from the soil without analysis. Possibly local differences in mineralogy or weathering (historical pH) are influential.

* 33 of the samples were taken in May and 24 in October. The former, sampled during the growing season, did not have lower topsoil K (median 237 vs 216 mg/l) implying that month of sampling was not a cause of variable K levels found.

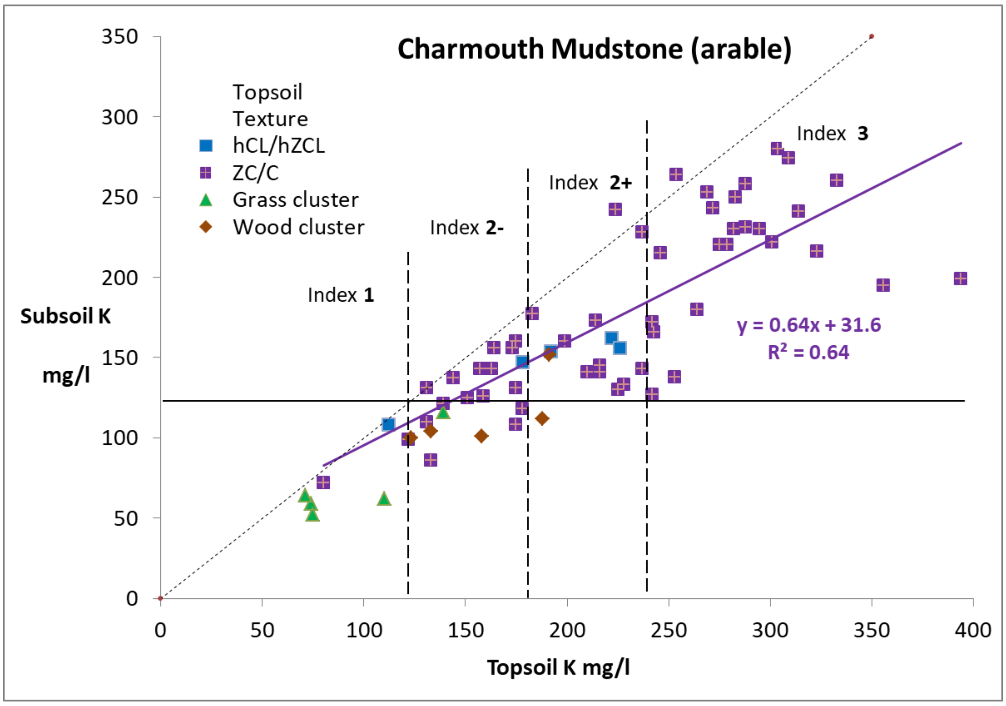


Figure 3.2: Heavy soils on Charmouth Mudstone: Potassium in topsoil and subsoil

Magnesium

Topsoil Mg levels were median index 5 (very high) but ranged from index 2 to 7. The large cluster field had higher Mg (10-90% range 410-627 mg/l) than the other fields.

Grass cluster averaged 130 mg/l Mg (one point was 280 mg/l) and wood averaged 173 mg/l.

On arable data there was a significant decline of Mg with increasing topsoil pH, each unit corresponding to -Δ200 mg/l Mg (Figure 3.3). This may be because Mg leaches less than calcium, especially if calcitic (i.e. low Mg) limestones have been applied. There is a weak influence of topsoil OM, each 1% increase in OM associated with Δ48 mg/l Mg (see Table 3.2), and Mg may be somewhat less on heavy loam topsoils than clays. However on wood and grass sites, acid pHs were not associated with high Mg (it was lower).

Mg in subsoil was 25% greater than in topsoil (strongly correlated, Figure 3.4). Arable grass and woodland fit to similar trend. In arable data there is a decline of -Δ200 mg/l Mg per pH unit rise but less well related (r^2 = 0.20) than in topsoil.

Most pHs were not alkaline so the high Mg levels are not due to dolomitic material. The wide of Mg levels may result from pH differences and natural variation (of mineralogy) within the Charmouth Mudstone itself (or possibly thin Drifts though not obvious to the surveyors).

Agronomic: despite the generally good potassium levels, 28% of topsoils and 56% of subsoils have a K:Mg ratio (mg/l:mg/l) of < 0.5 and the high magnesium raises the issue of whether K index 2+ should be the target for this type of land. Clearly Mg-containing lime sources should be avoided here.

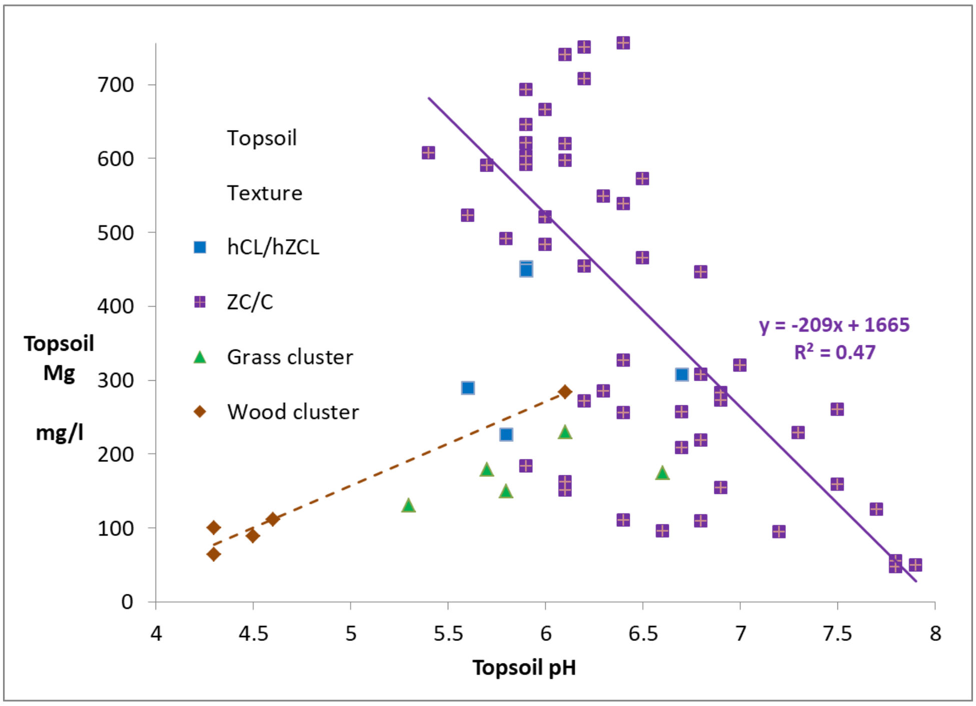


Figure 3.3: Heavy soils on Charmouth Mudstone: Topsoil Magnesium versus Topsoil pH

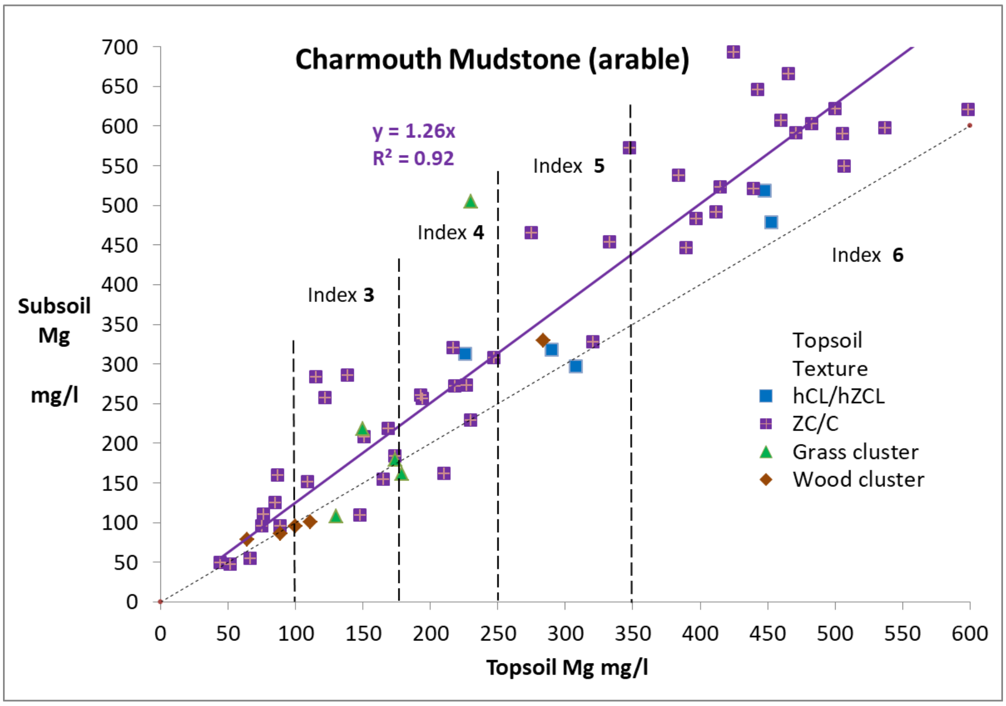


Figure 3.4 : Heavy soils on Charmouth Mudstone: Magnesium in topsoil and subsoil

pH

In 37% of arable cases topsoil was slightly acid (6-6.4) and 25% below pH 6. The low pHs were mainly in the cluster field (10-90% range 5.7-6.4). Significantly alkaline (pH 7.5+) topsoil could occur in other fields (11% of total data).

The grass cluster was acid (pH 5.9 ±0.5) and the wood very acid (4.3-4.6 with one sample 6.1).

At topsoil pH 7.5 subsoil pH tends to parity but as topsoil pH drops below optimal the subsoil pH was at least 0.5 higher and never below 6.0 (Figure 3.5). There is a weak negative influence of subsoil organic matter each 1% OM associated with -Δ0.1 pH (Table 3.2).

19% of the subsoils were pH 7.5 or higher, probably due to traces of carbonate though none was detected in upper subsoil according to the field 10% HCl test. However, in several cases the lower subsoil became obviously calcareous within 1m depth. It is very likely the original mudstone was variably calcareous and we now are seeing the result of decalcification; a few places are still able to maintain topsoil pH above 7.0, whilst others need agricultural lime. This points to the importance of spot pH testing such soils.

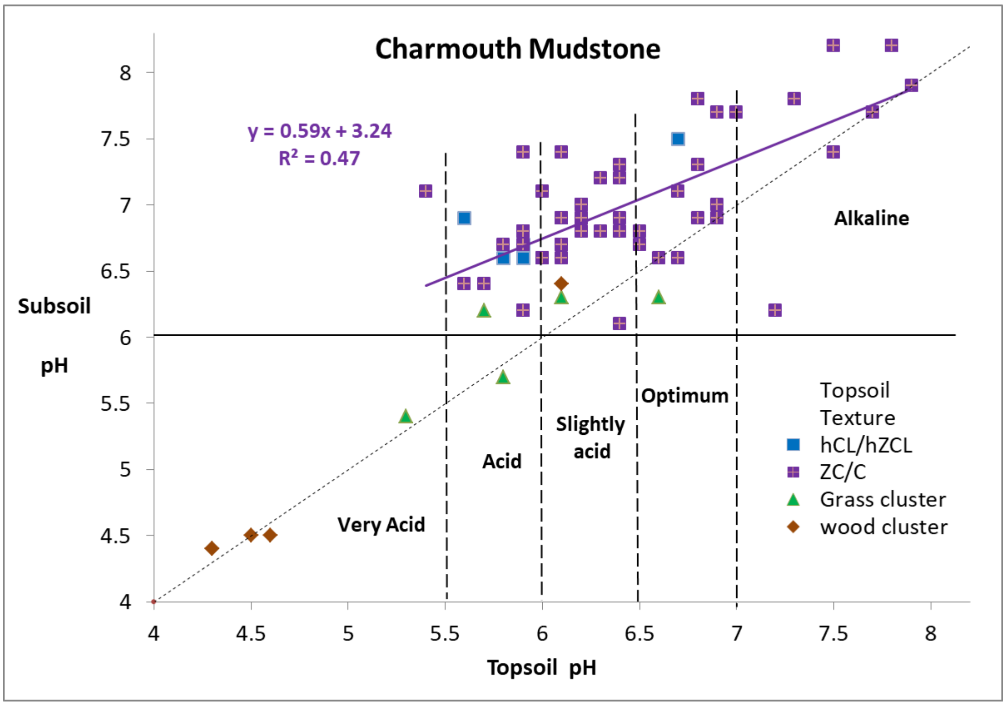


Figure 3.5 : Heavy soils on Charmouth Mudstone: pH in topsoil and subsoil

In the grass and woodland sites, subsoil pH was similar to topsoil. Possibly long neglect of liming means some sort of equilibration has been obtained.

Organic Matter

Topsoil OM was never <3% and averaged 'Good' (4.6%) linked to the high proportion of clay-textured topsoils. In the cluster field 10-90% range in 18 close samples was 4.0–5.0%.

However median Clay/SOM ratio of 15 would put 91% of the land is into structure class D (degraded) and of the 5 profiles in the C (moderate) class were heavy loam textures rather than clay. However this is well farmed clay land supporting high yields of cereals (see Organic Matter overview section).

The subsoil OM was weakly related to topsoil and typically was more than half (Figure 3.6).

On these soils, moderate topsoil OM% corresponded to 1.5-3% in the subsoil and Good topsoil OM was accompanied by 1.5-4.5% OM in the subsoil, suggesting there has been variable extent of taking down topsoil material into the subsoil. This could also explain the negative relationship of subsoil pH with OM.

Compared to auger sampling, the corer method averaged 0.25% OM greater in topsoil and 0.53% higher in subsoil, attributable to slightly deeper sampling by the auger. Sampling method displaces subsoil OM ±0.2% from the line shown.

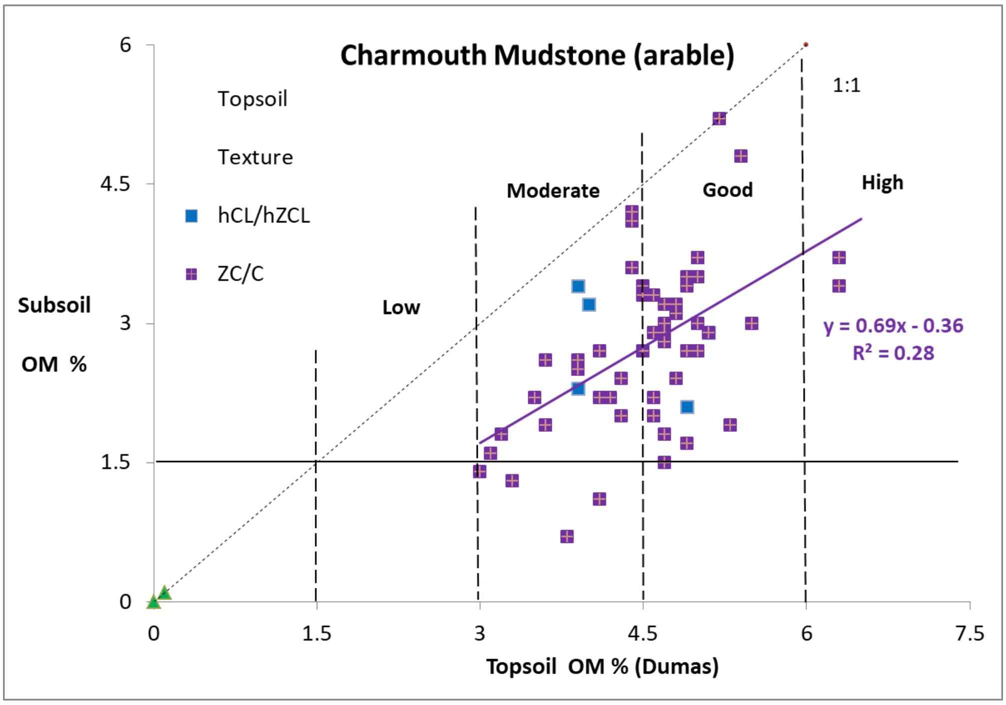


Figure 3.6 : Heavy soils on Charmouth Mudstone: Organic Matter in topsoil and subsoil

Table 3 : best fit multiple regressions. Soils on Charmouth Mudstone

Regression equation (see Appendix 3)	r^2
Subsoil P = Topsoil P x 0.46	0.54
= Topsoil P x 0.37 + Subsoil OM% x 1.3 - 2.21	0.57
Subsoil K = Topsoil K x 0.64 + 32	0.64
Subsoil K = Topsoil K x 0.60 + Subsoil OM% x 19 - 11	0.73
Topsoil Mg = Topsoil OM% x 48 - Topsoil pH x 186 + 1295	0.46
Subsoil Mg = Topsoil Mg x 1.26	0.92
Subsoil pH = Topsoil x 0.59 + 3.24	0.47
Topsoil pH x 0.56 - Subsoil OM% x 0.10 + 3.70	0.50
Subsoil OM% = Topsoil OM% x 0.63 - 0.29 + 0.38 if corer method	0.32

The weak relationship of subsoil K with subsoil pH (-Δ11 mg K/l per unit pH) may be due to the effect relationship of pH to OM%.

4. Soils on Whitby Mudstone and Ironstone

These are 14 data from west of Banbury formed on earlier Jurassic (Liassic) Whitby Mudstone or the overlying the iron-rich deposits of Horsehay and Northampton Sand.

Similar soils run in a broad belt from Mendips to Teeside and on SSEW maps are mapped as Denchworth or Banbury Associations.

Over Whitby Mudstone the topsoil texture was heavy (silty) clay loam and upper subsoil was clay or silty clay. Natural drainage was variable, judged WC II to IV.

Over the Horsehay Sand the topsoil was loamy fine sand to medium clay loam (with lighter textures on the arable (4) than grass (2)). Subsoil varied from fine sand to sandy clay loam and in one place ironstone was encountered at 40cm. Drainage was WC I or II.

Average start depth of subsoil sampling was 27cm and 29 cm on the two geological types. .

Table 4.1 : Nutrient summary - soils on Whitby Mudstone (median values)

	Topsoil			Upper Subsoil			Arable topsoil frequency *% in Index*					
	arable	10-90%	grass	arable	10-90%	grass	**0**	**1**	**2**	**3**	**4**	**5**
Phosphorus	**28**	18-44	**6**	**26**	8-31	**5**		*20*	*20*	*40*	*20*	
Potassium	**129**	77-137	**73**	**117**	73-127	**52**		*60*	*40+0*			
Magnesium	**70**	55-95	**135**	**64**	54-108	**212**			*80*	*20*		
K:Mg ratio	1.3	1.0-1.3	0.7	1.2	0.5-2.0	0.3						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	**7.0**	6.5-7.6	**5.5**	**7.4**	7.0-7.7	**6.7**			*20*	*20*	*40*	*20*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	**3.5**	2.6-4.0	**8.2**	**1.4**	1.2-3.8	**2.3**		*20*	*80*			
Clay/SOC	**17**	14-21	6.5		**Index**	**D-A**	100	-	-	100		

Table 4.2 : Nutrient summary - soils on Horsehay Sand and Northampton Sand

	Topsoil			Upper Subsoil			Arable topsoil frequency *% in Index*					
	arable	10-90%	grass	arable	10-90%	grass	**0**	**1**	**2**	**3**	**4**	**5**
Phosphorus	**13**	8-25	**17**	**12**	6-32	**16**	*25*	*50*	*25*			
Potassium	**32**	25-42	**156**	**18**	12-39	**65**	*100*					
Magnesium	**29**	23-35	**108**	**19**	12-22	**39**	*50*	*50*				
K:Mg ratio	1.2	1.1-2.0	1.6	1.2	0.5-1.3	1.6						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	**5.7**	5.4-6.3	**5.9**	**6.3**	6.1-6.7	**6.3**	*25*	*50*	*25*			
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	**2.2**	1.7-2.6	**5.8**	**1.3**	1.0-1.8	**2.2**		*100*				
Clay/SOC	**11**	14-21	5		**Index**	**D-A**	50	-	50	100		

Phosphorus

On the Whitby Mudstone the arable soils had variable P index (median 28, index 3); grassland was index 0. The Horsehay Sands arable soils were low P index (an effect either of the low organic matter or iron-rich mineralogy).

Subsoil P is plotted against topsoil in Figure 4.1. At topsoil index 3, subsoil P is unpredictable; on the lighter soils at index 0 to 2, subsoil P is almost equal to topsoil P indicating either strong carry down or deep cultivation at some stage in the past.

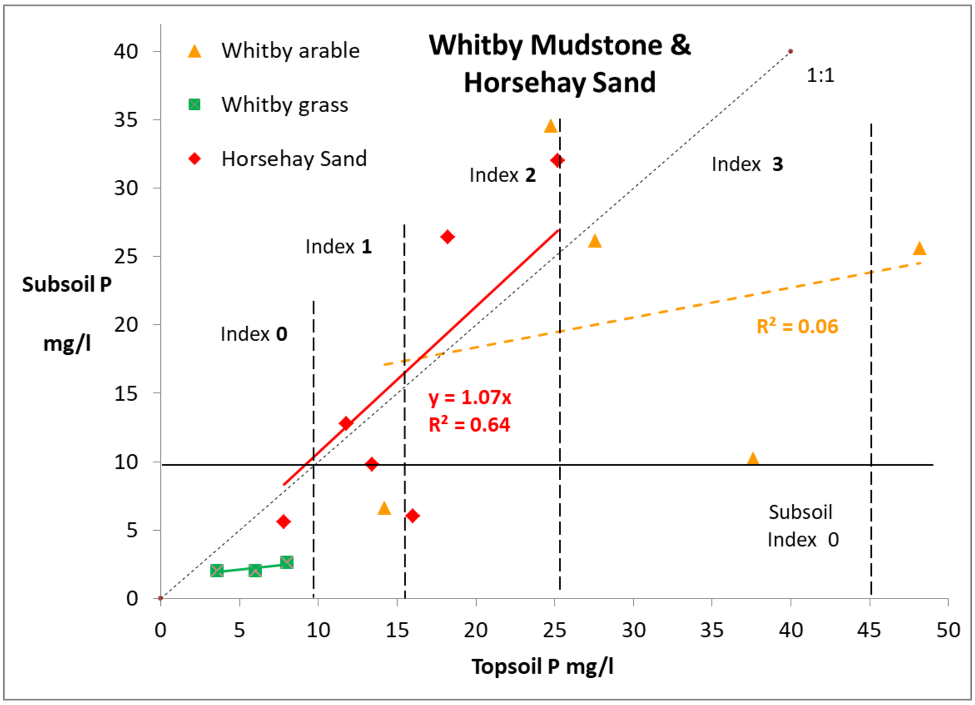


Figure 4.1 : Whitby Mudstone and Horsehay Sand : phosphorous in topsoil and subsoil

Potassium

On Whitby Mudstone the arable soils had indifferent K levels (median 129 mg/l with 60% below target); grassland was all low K index. As with phosphorus there was poor topsoil:subsoil correlation on the arable data (some points had higher K in subsoil, Figure 4.2). We do not know if manure had been recently incorporated on some of the fields.

The grassland data (only 3) fits an intercept of 36 mg/l subsoil K at theoretical zero topsoil K, similar to values found on other clay data sets. From this limited data we might infer that Whitby clay subsoils are poorer potassium supply than other clays, and the topsoil textures tend to be heavy loam rather than clay (see reference Table 2.5).

In soils formed on Horsehay Sand the potassium values are extremely low on the arable site though OK on the grass. The former lie in *lower index 0* (two were below the NRM detection limit of 15 mg/l). There is insufficient data to know if this is a general characteristic of this geology. The small intercept (10 mg/l) in Figure 4.2 seems typical for lighter soils.

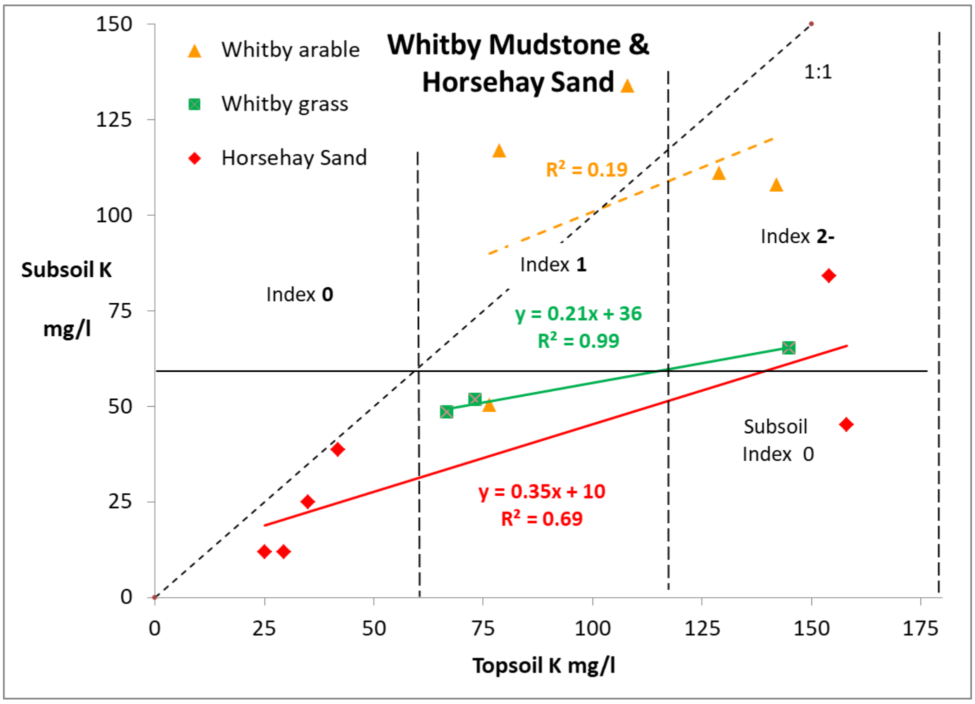


Figure 4.2 : Whitby Mudstone and Horsehay Sand : potassium in topsoil and subsoil

Magnesium

On Whitby Mudstone the arable sites were index 2 and grassland index 3. The subsoil increases in proportion being 14% higher than topsoil (Figure 4.3). The fit is in line with other heavy loam over clay soils, though the absolute levels of Mg tend to be less than other geological clays (table 4.3). Low K:Mg ratio should not be an issue on this geology provided target K index is maintained.

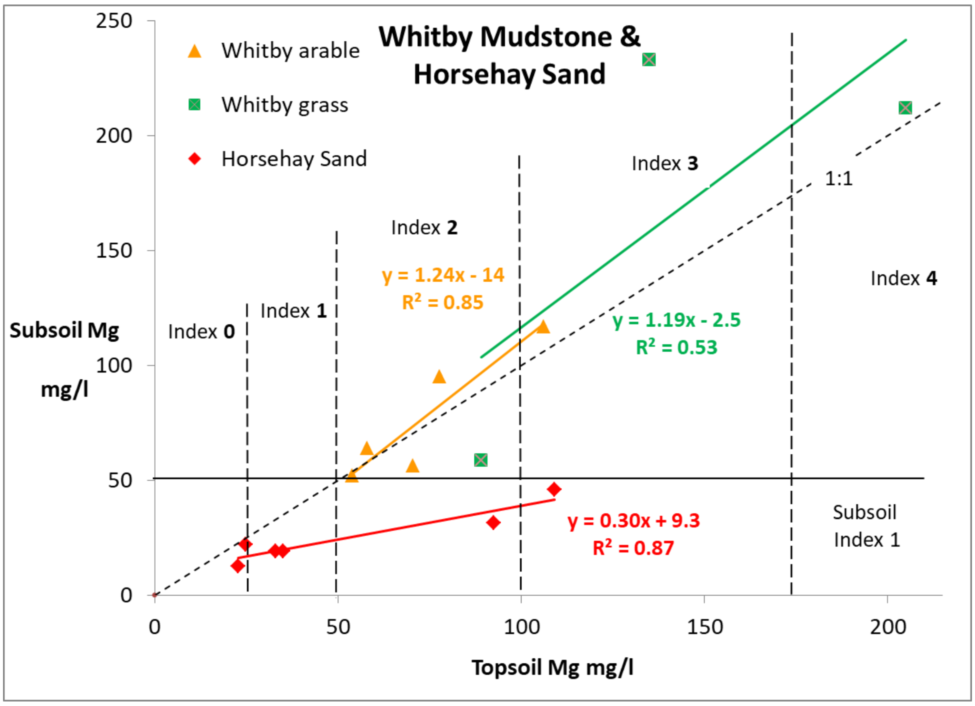


Figure 4.3: Whitby Mudstone and Horsehay Sand : magnesium in topsoil and subsoil

On the Horsehay sands, Mg levels in the arable sites were index 0 or 1 (median 29 mg/l). Subsoil Mg is significantly lower than topsoil Mg as found for sandier soils elsewhere in this data. Possibly Mg containing fertilisers or manures have been top applied at some stage. On the grassland (higher 2 points) there is input from the top in grazing animals and the higher OM may retain Mg (and K) better.

pH

On Whitby Mudstone the pH of arable sites varied from slightly acid to neutral with subsoils slightly or quite strongly alkaline (40% > pH 7.4) although none registered as calcareous by the HCl test. The fields under grass were all acid. BGS records indicate that Whitby Mudstone can contain horizons with limestone nodules but (as this data suggests) it is not generally calcareous and so is more prone to going acid than other Clays.

On the Horsehay Sand most samples (arable or grass) were acid (pH < 6.0). This material can contain calcareous as well as ferruginous sandstone, but $CaCO_3$ is likely to have been leached out of the soil long ago. These soils seem very prone to acidity, though the data set is too small to be definitive.

Subsoil pH converged with topsoil pH about 8.0 and at topsoil pH ~5.5 the subsoil pH was most likely to be 0.6 greater than topsoil and never less than topsoil pH. Where topsoil pH is below 6.0 some additional lime will likely be needed to correct subsoil acidity.

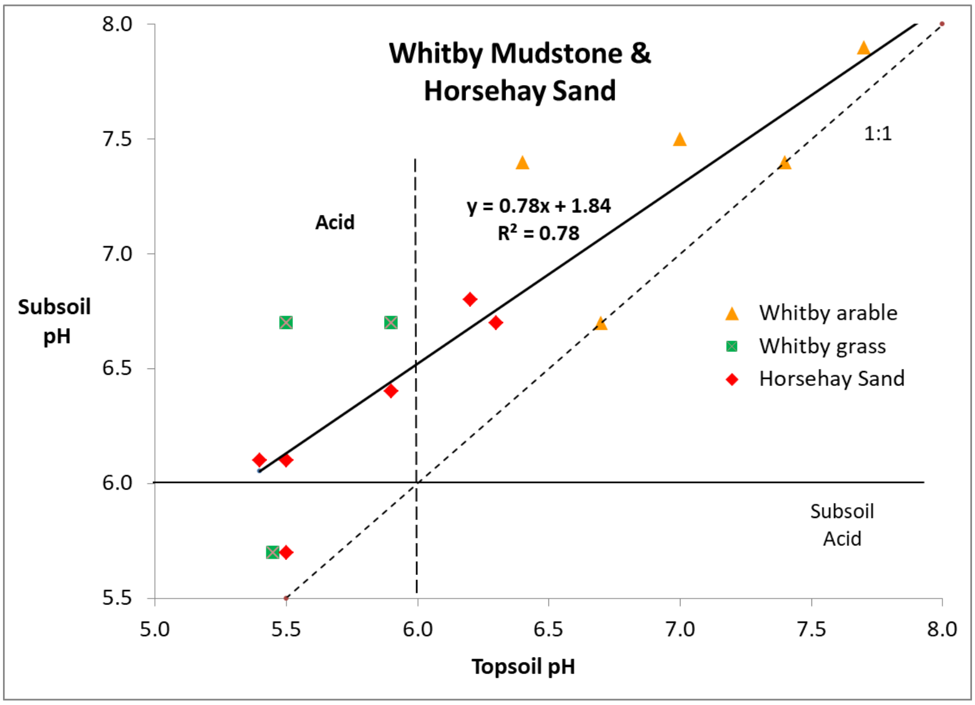


Figure 4.4 : Whitby Mudstone and Horsehay Sand : pH in topsoil and subsoil

Organic Matter

The arable soils on Whitby Mudstone had mediocre OM (3.4%), clay:SOM of 17 and so is clearly rated by SOM Index as "degraded". The permanent grassland fields were >8% OM, clay:SOM 6.5 and classed as "very good" structure.

As Figure 4.5 shows, in the arable subsoils the OM varied from very low to moderate for reasons that are not apparent. Under the permanent grass the subsoil OM was <3% indicating a lower degree of carry-down from topsoil than arable samples.

On the Horsehay Sands the topsoil OM <3% is classed as low by SSEW. Values varied 1.7-2.6% and OM Index ranged from "degraded" to "good" which is a large difference for relatively small changes in OM (texture varied from LS to SCL). The two sites on grass had OM >4.5% and "very good" rating.

The four subsoils on Horsehay Sand under arable use contained 0.6x the OM% of the topsoil, but the two grass samples were proportionately less, not exceeding 3% and indicating limited carry-down of material from topsoil (Figure 4.5).

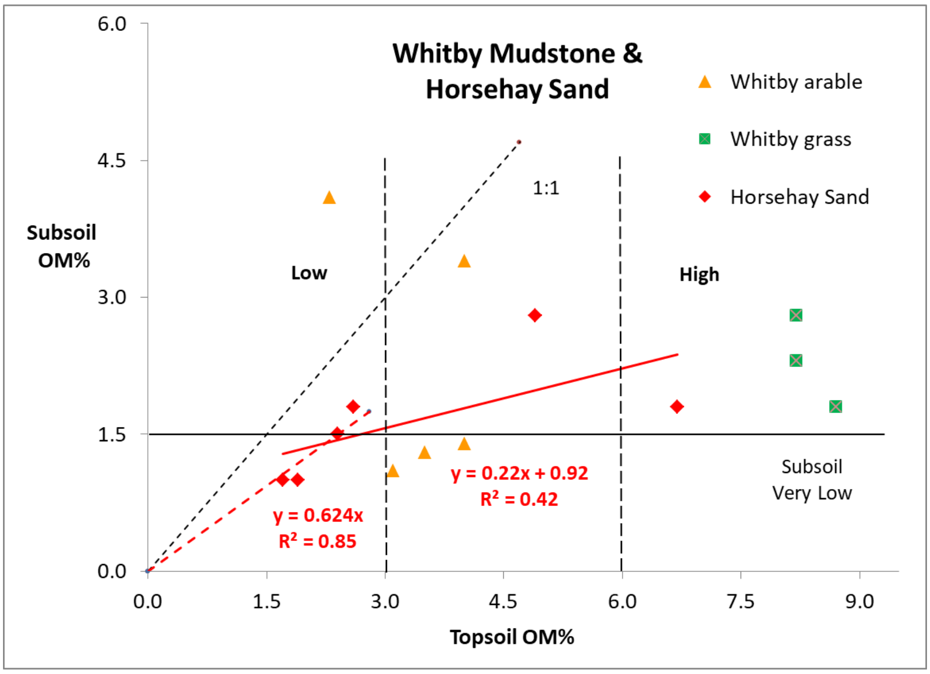


Figure 4.5: Whitby Mudstone and Horsehay Sand: Organic Matter in topsoil and subsoil

Table : best fit regressions. Soils on Horsehay Sand and Whitby Mudstone

Equation (see Appendix 4)				r^2
Light-medium subsoil:	Subsoil P	=	Topsoil P x 1.07	0.64
Light-medium subsoil:	Subsoil K	=	Topsoil K x 0.37 + 10	0.69
Clay subsoil (grass):	Subsoil K	=	Topsoil K x 0.21 + 36	0.99
Light-medium subsoil	Subsoil Mg	=	Topsoil Mg x 0.3 + 9.3	0.87
Clay subsoil:	Subsoil Mg	=	Topsoil Mg x 1.14	0.75
All subsoil textures	Subsoil pH	=	Topsoil pH x 0.78 + 1.84	0.78
	Subsoil pH = Topsoil pH x 0.82 - Subsoil OM% x 0.09 + 1.78			0.79
Light-medium subsoil	Subsoil OM%	=	Topsoil OM% x 0.22 + 0.92	0.42

5. Soils on Limestone and Clay

This comprises 4 data on Langport Limestone and the associated Penarth clays (Rhaetic) and 11 on Taynton Stone or White or Blisworth Limestone (Jurassic). No samples were arable. Included are clusters of four in a wood and grassland.

Though such soils are widespread in the Cotswolds and South Wales they are poorly represented in the transept because such geologies were usually covered by Glacial Drift.

On SSEW maps they are mapped as Aberford or Evesham associations, where bands of limestone rock alternate with deeper calcareous clays. Topsoil texture was heavy clay loam, locally organic and usually calcareous. Subsoil stoniness varied from 5-30% and subsoil texture from medium clay loam to clay. Wetness Class was I except where the clay was deep it was WC III ($CaCO_3$ in the upper subsoil improved the drainage).

Most were sampled by corer method. Start depth of subsoil sampling was 20 to 25cm.

Table 5.1: Nutrient summary - grassland soils on Jurassic Limestone & Clay

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	mean	median	10-90%	mean	median	10-90%	**0**	**1**	**2**	**3**	**4**	**5**
Phosphorus	32	**8.6**	2-10	15	**4.2**	2-45	*55*		*18*	*9*		*18*
Potassium	286	**228**	171-512	237	**207**	117-349			*18+45*	*18*		*18*
Magnesium	119	**103**	67-151	114	**98**	38-209		*9*	*36*	*45*		*9*
K:Mg ratio	2.4	**1.8**	1.1-4.3	2.3	**2.1**	0.9-3.9						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	7.5	**7.8**	6.8-8.0	7.8	**7.9**	7.4-8.2				*18*	*18*	*64*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	8.1	**8.7**	4.8-8.8	3.1	**3.1**	1.0-5.6			*14*	*14*	*72*	
Clay:SOC		**6.6**	5-12		**Index**	**D-A**	14	-	28	58		

Phosphorus

This data set is characterised by extreme variation in available phosphorus levels. Samples on the Rhaetic clay/limestone were in lower half of index 0 (< 5mg/l) whereas those on Jurassic limestone were much higher. In the grass cluster samples (4 within a hectare) P ranged from 22-156 mg/l (index 7). Four samples in a wood varied from 8-71 mg/l suggesting variable fertility in the soil before the wood was planted (or natural heterogeneity of the forest floor which had diverse vegetative cover).

P levels in subsoil were strongly correlated with topsoil P (Figure 5.1): 0.47x topsoil P may be a useful equation for stony calcareous soils over the whole range (whether in grass or wood). High available P has persisted despite the alkaline pH predisposing to "fixation" of P.

On these soils if topsoil is index 2 the subsoil P is unlikely to exceed 10 mg/l.

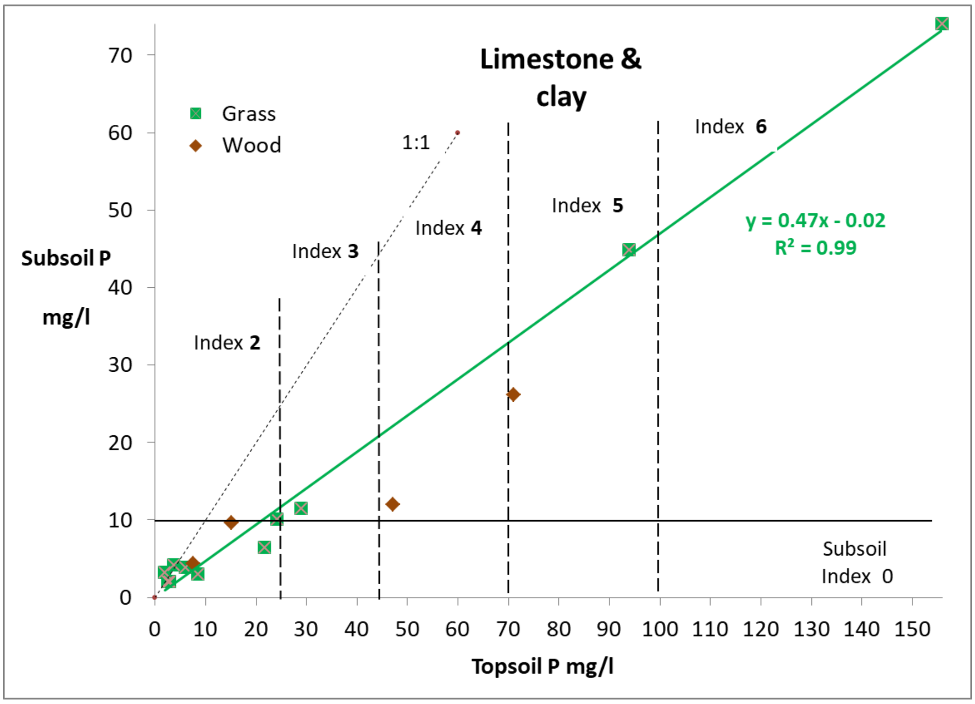


Figure 5.1: Limestone and Clay: Phosphorus in topsoil and subsoil

Potassium

Topsoil K levels in arable soils were good - median index 2+ (228 mg/l) with none in index 1. Subsoil K correlates with topsoil K (though at very high index it is difficult to predict how high the subsoil K will be). In five cases the subsoil could not be sampled to the full 50cm.

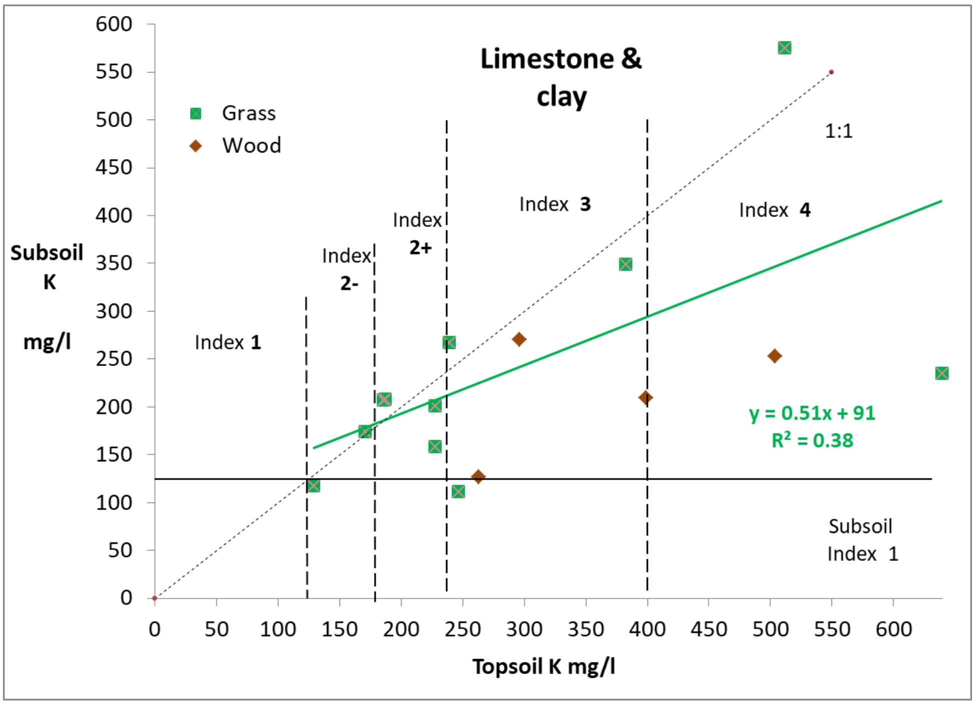


Figure 5.2: Limestone and Clay: Potassium in topsoil and subsoil

Excluding the two very high data, the regression line has an intercept of 29 mg/l K at theoretical zero topsoil K, similar to heavy loam subsoil in other data sets, but the slope is steeper, possibly due to subsoil stones. Each increase in subsoil stone class is associated with +Δ10 mg/l K though inclusion of stone hardly improves the regression (Table 5.2).

In the wood cluster, the topsoil varied from 263-504 mg/l K, evidence of fertility before the wood was planted or an accumulation of K release since.

Agronomic: on soils with stony upper subsoil overlying limestone and associated clay, the topsoil K is most likely to be 2+. Where index 2-, subsoil K is likely to be similar. Stoniness reduces the net subsoil K available to roots. In other parts of Cotswolds soils can be shallower than here with fragmented limestone starting within 30 cm.

Topsoil should be maintained at least at 150 mg/l K (mid index 2-) on this soil type with 180 mg/l as target.

Magnesium

Topsoil Mg was typically index 2-3 (though 302 mg/l was found on Rhaetic clay). Mg was unrelated to pH. All samples are grass. On arable land on limestone, the author's experience is that index 1 is common on medium or heavy loam topsoil (not if clay textured).

Subsoil Mg follows a 1:1 correlation with topsoil Mg on grass and wood (Figure 5.3). Topsoil and subsoil were similar. In three cases subsoil was clay and one was very calcareous medium loam (index 0).

Agronomic: for crops liable to Mg deficiency at index 1, if the subsoil is stony, supply of Mg from subsoil will be worse and treatment should be recommended.

K:Mg ratio was >0.5 in topsoil and subsoil in all cases, so Mg-induced K deficiency is unlikely on these soils.

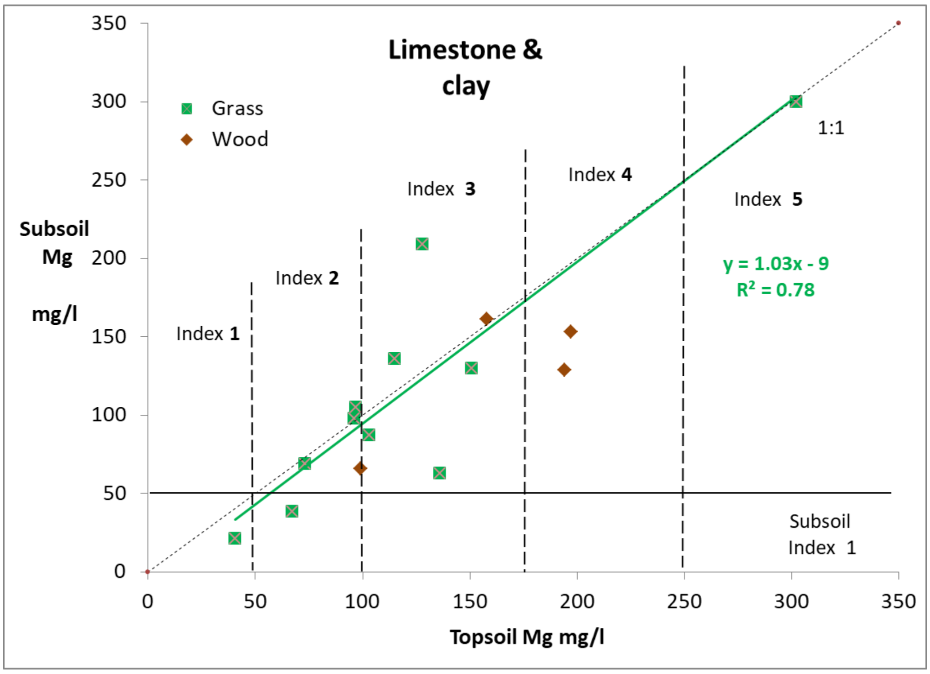


Figure 5.3: Limestone and Clay: Magnesium in topsoil and subsoil

pH

On the Rhaetic deposits topsoil pH was 7.2-8.0 and on the Jurassic 6.8-7.8. Subsoil pH was alkaline (7.0–8.3%) due to small limestone particles in the <2mm fine earth. In a woodland cluster it varied from 7.1-7.7.

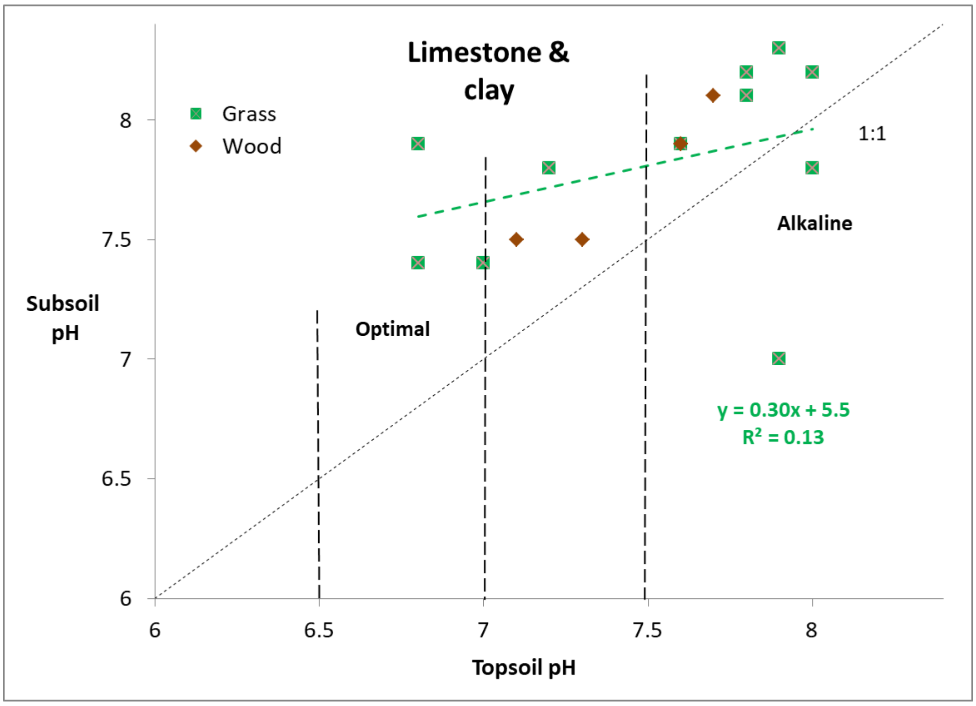


Figure 5.4: Limestone and Clay: pH in topsoil and subsoil

Figure 5.4 shows that subsoil pH is higher than topsoil pH. Most horizons of pH >7.4 registered as slightly to very calcareous by the field HCl test. NB it is normally impossible to find pH > 8.4 because of the influence of atmospheric CO_2 on the $CaCO_3$ equilibrium (see pH overview).

Topsoils of pH <7.0 (decalcified) were all very slightly stony (up to 5% v/v) and author's own experience is that such small amounts of limestones can prevent soils going acid.

Organic Matter

Some data was done by Loss On Ignition method giving much higher than normal values than expected from surveyors. See Organic Matter overview.

On the Dumas data median topsoil OM was high, 7.8% and 58% of data had very good structural Index. In the grass cluster OM varied 7.5-8.7% and in the wood 7-11%.

Median OM in upper subsoil was 3.1% and it was about 0.45x topsoil OM but variable. The very low subsoil OM cases correspond to upper subsoils comprised of finely fragmented limestone and loam which were all crushed <2mm in the laboratory.

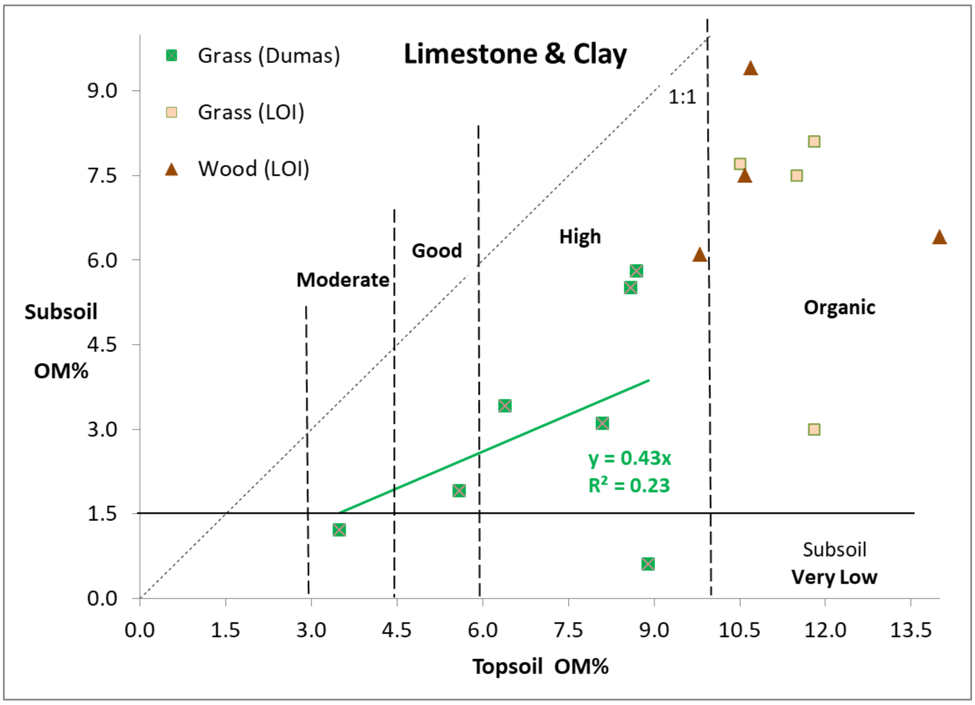


Figure 5.5: Limestone and Clay: Organic Matter in topsoil and subsoil

Table 5.2 : best fit regressions. Soils on Limestone and Clay

Equation (see Appendix 5)	r^2
Subsoil P = Topsoil P x 0.47	0.99
Subsoil K = Topsoil K x 0.77 + 29	0.54
Subsoil K = Topsoil K x 0.72 + stone class x 10 + 24	0.55
Subsoil Mg = Topsoil Mg - 9	0.74
Subsoil OM = Topsoil OM% x 0.43	0.23

6. Soils on Glacial Deposits

The Glacial deposits surveyed extended from north of Brackley with diminishing occurrence southwards towards Aylesbury. On BGS maps most are mapped as Glacial Till. This data set included 9% of points on Glacial Sand & Gravel and 9% on River Terrace deposits. The underlying solid geology is Jurassic limestone in the north and Oxford or Kimmeridge Clays in the south.

SSEW maps designate these areas as Ragdale association (north), Essendon association on sand & gravel and Wickham 2 or Denchworth associations where the Drift is sporadic on underlying clay.

Soils on (non-red) Glacial Till are widespread across central England into East Anglia (where they tend to be less decalcified, "Chalky Boulder Clay").

In this data the predominant topsoil texture is heavy loam and upper subsoil is clay with WC varying from II to IV except on the gravels.

Most samples were taken at 1 per 3 ha, 10 were in a close clusters and 5 in a wood.
Average start depth of subsoil sampling was 25cm and 19/32 samples were taken by corer.
78% of main data in table was arable with the rest in grassland.

Table 6.1: Nutrient summary - Soils on Glacial Drift – median values

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	main	10-90%	wood	main	10-90%	wood	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	**20**	6-42	6	**7**	4-12	4	*24 **	*18*	*24*	*26*	*3*	*6*
Potassium	**136**	59-298	127	**96**	45-162	85	*13 **	*23*	*26+19*	*13*	*12*	
Magnesium	**90**	46-153	151	**81**	22-125	131		*19*	*39*	*35*		*7*
K:Mg ratio	1.7	1.0-2.5	0.8	1.2	0.9-2.1	0.6						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	**6.5**	5.6-7.5	5.1	**6.8**	6.3-7.7	5.3		*29*	*23*	*29*	*6*	*13*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	**5.4**	2.8-8.2	5.7	**2.4**	1.5-3.8	3.6		*17*	*17*	*28*	*38*	
clay:SOC	**9.4**	6-15			**Index**	**D-A**	*27*	*12*	*35*	*26*	arable	
"	**7.5**	4-10			**"**	**"**	-	*17*	*33*	*50*	grass	

* mainly in grass

Phosphorus

Median topsoil P was 20 mg/l (mid index 2). 85% of grassland (extensive) was index 0 (sampled 0-20cm). 31% of arable samples were below target, with similar medians on medium and heavier topsoils (20 and 22 mg P/l respectively).

In one arable cluster of five close samples the topsoil P was 13-25 mg/l; all were taken by same (corer) method. In the wood cluster P was uniform (4-7 mg/l).

Figure 6.1 shows weak relationships of subsoil P to topsoil P over the normal range, though the exponential fit is useable. Arable, grass and wood data show convergence of topsoil and subsoil P at about 4 mg/l (the minimum natural level in the subsoil?). On the heavier (usually clay) subsoil, subsoil P was unlikely to exceed index 0 unless topsoil P exceeded 30 mg/l. Two very high points are not shown {119,112} and {106,77} on clayey arable land that may have been heavily manured. In these subsoil P = 0.8x topsoil P.

On the heavier soils variation in subsoil P is attributable to variation in subsoil OM: each 1% increase in OM associated with a 1.8 mg/l increase in subsoil P (see Table 6.3).

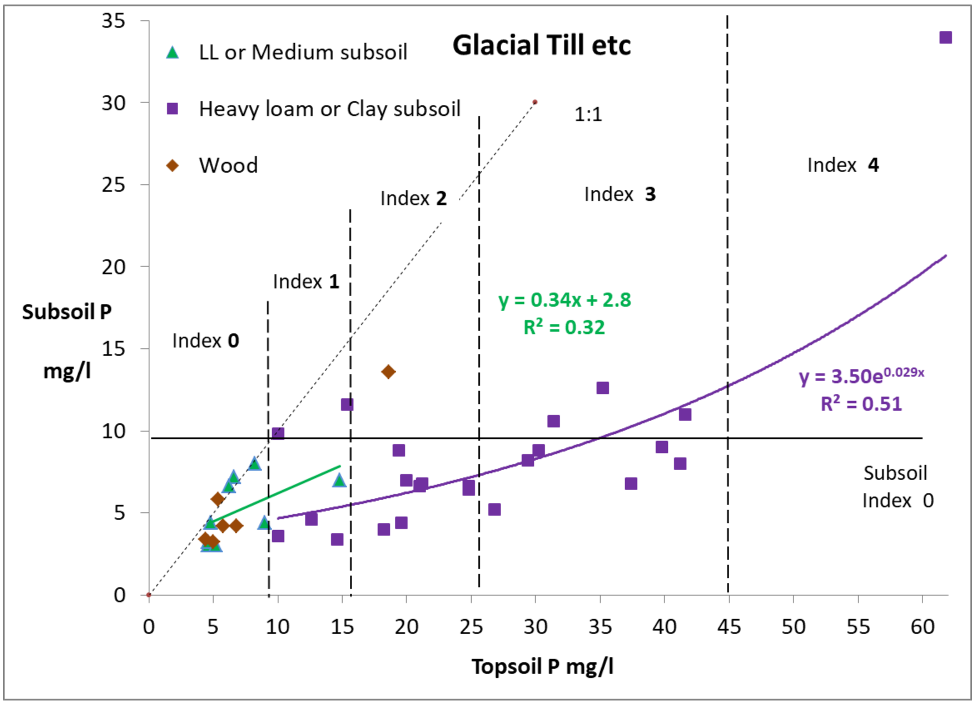


Figure 6.1: Soils on Glacial Deposits : phosphorus in topsoil and subsoil

Potassium

Median topsoil K was 136 mg/l (index 2-) with 28% of arable samples and 67% of grassland below target. Topsoil texture is influential; arable median for medium loams is 131 mg/l and for heavier topsoil 163 mg/l, an increase of 30 mg/l.

In the five cluster of close arable samples topsoil K was 106-176 mg/l.

Subsoil K is strongly correlated with topsoil K as shown in Figure 6.2. For medium or light loam textured subsoil, the subsoil K is 0.7x topsoil K. For clay subsoils there is a more gradual rise and a positive intercept of 39 mg/l, in line with findings for other types of clay. This is not influenced by subsoil OM content but 40% of the variation can be explained for by subsoil pH (Figure 6.3). Each unit pH increase corresponds to +Δ42 mg/l K in subsoil and +Δ95 mg/l in topsoil. Interestingly topsoil K correlates poorly with *topsoil* pH which may have been altered by liming, whereas differences in subsoil pH 7 to 8 indicate degree of retention of natural $CaCO_3$.

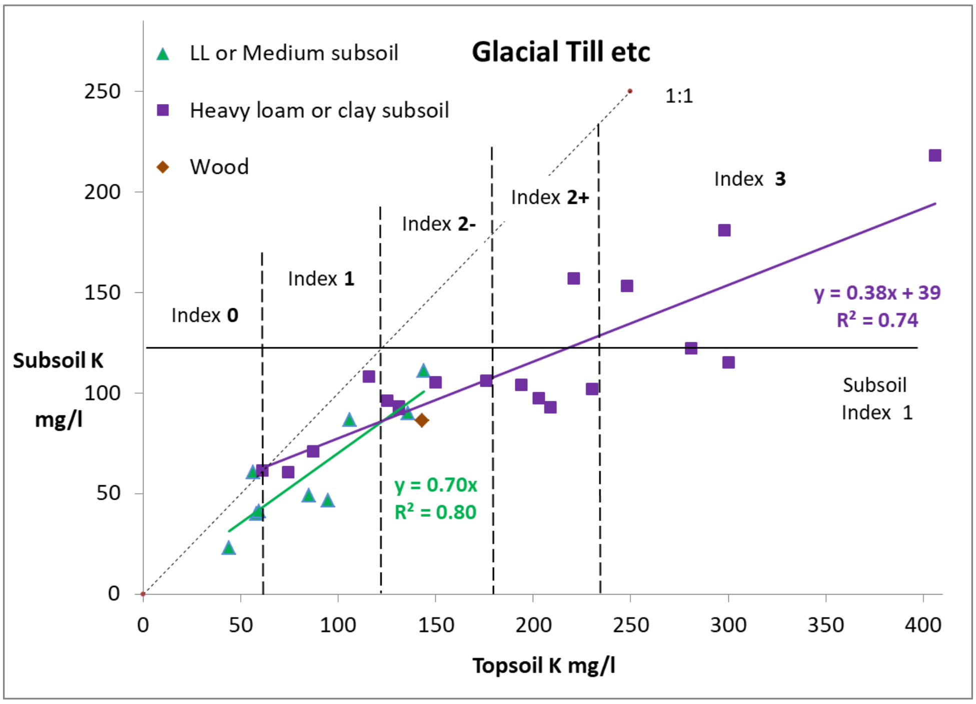


Figure 6.2: Region C, Soils on Glacial deposits: potassium in topsoil and subsoil (one higher point not shown).

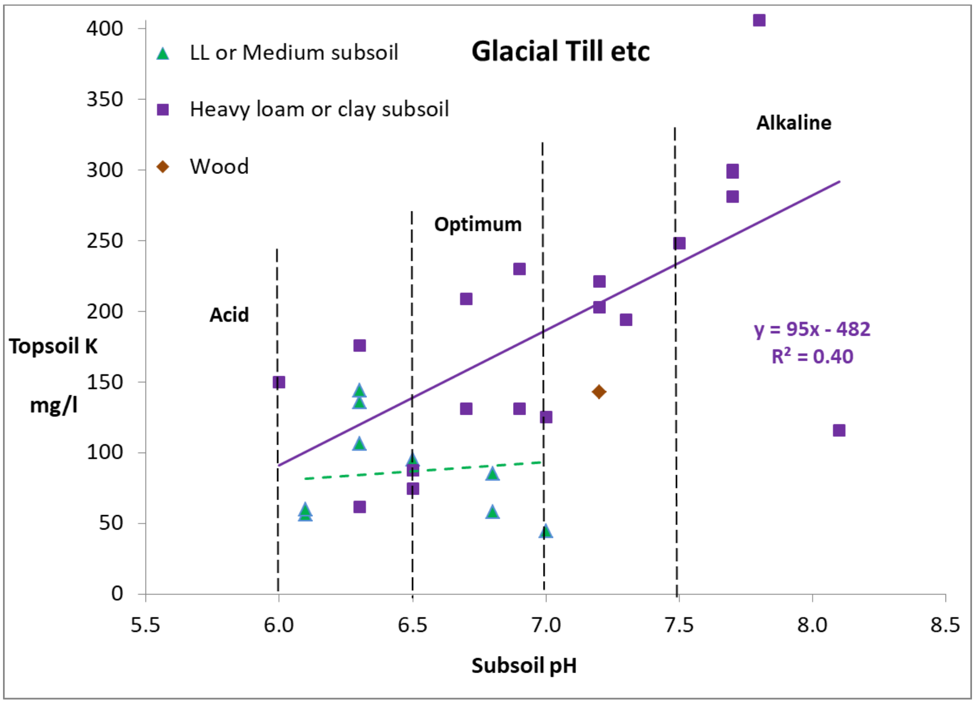


Figure 6.3: Region C, soils on Glacial deposits: subsoil pH and topsoil K

Agronomic: soils on Glacial Till which remain calcareous have better potassium supply than decalcified variants. Not only is this important regionally (Till is more calcareous in East Anglia) but within the same field there may be differences, which points to the importance of precision testing for potassium. Although Chalky Boulder Clay soils are held up as releasing soils (in RB209), variants decalcified in the upper subsoil may be less K-releasing.
Subsoil K is probably not a problem provided topsoil is index 2- or above :

- at topsoil index 1, subsoil is likely to be index 1 in heavy subsoils and 0 for others.

- at topsoil index 2- subsoil is likely to exceed mid index 1 (90 mg/l) on all soil types and therefore probably a "safe" target level.
- at topsoil index 3, subsoil is likely to be index 2- (>120 mg/l)

Magnesium

Median topsoil Mg is 90 mg/l (index 2) and 19% of samples were index 1. In the five cluster of arable samples the topsoil Mg was 86-118 mg/l. Topsoil Mg increased with topsoil texture class. Medians were:

light loams (53 mg/l) < medium soil (72 mg/l) < heavy loam (111mg/l) < clay (129 mg/l)
n = 4, 8,17 and 2 respectively.

Topsoil Mg appeared weakly positively related to pH (r^2 = 0.23) only because the lighter soils, naturally lower in Mg, tend to be more acid.

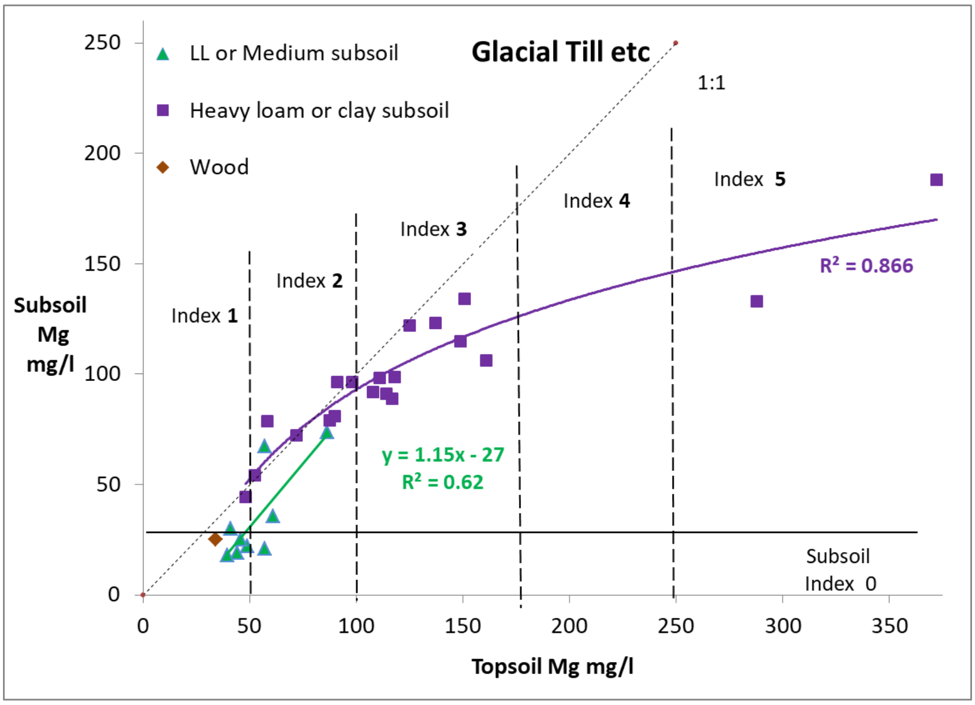


Figure 6.4: Soils on Glacial Deposits : Magnesium in topsoil and subsoil

Subsoil Mg levels were greatly influenced by subsoil texture class :

light loams (21) < medium soil (25) << heavy loam (107), clay (96 mg/l).
n = 3, 5, 4 and 18 respectively.

Figure 6.4 shows that subsoil Mg is strongly related to topsoil Mg though (unusually) Mg is lower in subsoil than topsoil on medium soils and even on clay subsoils where Mg tends to parity or *lower* than topsoil, contrary to most other clays.

Agronomic: if topsoil is Mg index 1, subsoil is likely to be index 0 if subsoil is medium or light loam. Index 2 topsoil should ensure subsoil Mg is >25 mg/l on all textures.

The median Mg in Glacial Till subsoil is 96 mg/l (index 2), lower than most other clays but higher than Clay-with-Flints (reference Table 2.5). However, median subsoil K is also somewhat lower than other clays, and median K:Mg ratio of 1.7 in topsoil and 1.2 in subsoil implies that Mg-induced K deficiency is unlikely.

pH

Median topsoil pH was 6.3 and 29% of samples were acid (pH < 6.0), 23% were suboptimal pH (6-6.4) and 13% alkaline (pH >7.4). In two arable clusters of 5 samples in one hectare pHs were 5.5-6.5 and 6.3-6.7 and in a wood cluster was 4.9-5.5.

In Figure 6.5 subsoil pH shows the typical pattern with parity at topsoil pH 7.5 widening to 0.6 higher subsoil pH at topsoil 6.0 on heavy soils, but a lesser difference on loamier subsoils. There is significant uncertainty in the fitted equation and allowance for subsoil OM% does not improve it.

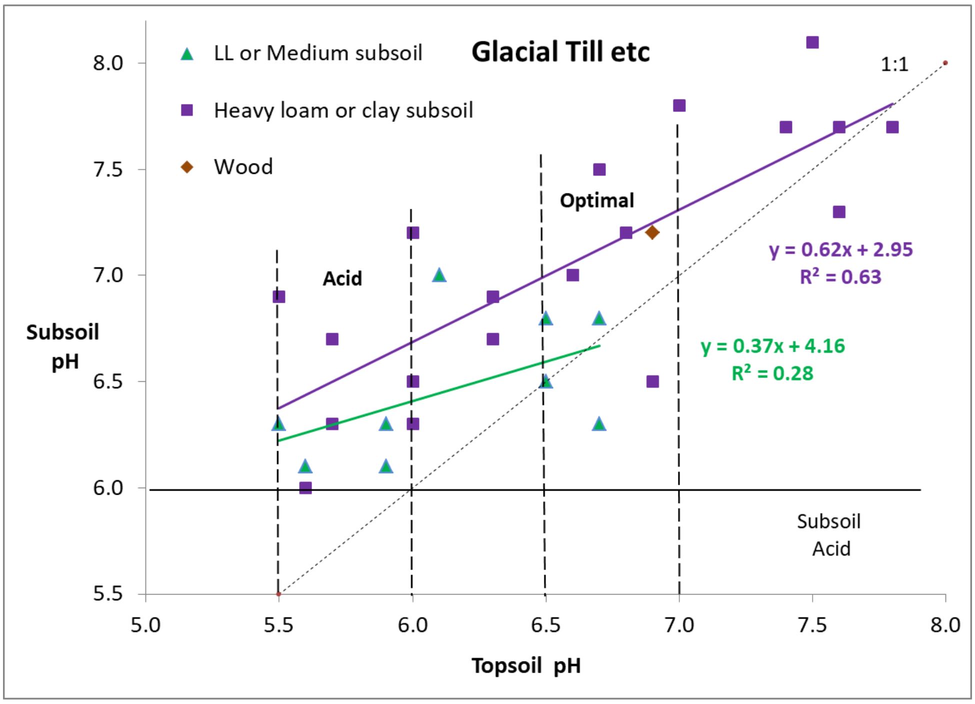


Figure 6.5: Soils on Glacial Till: pH in topsoil and subsoil

Agronomic, natural alkalinity: this data shows topsoil pH is locally highly variable and 63% of explained by pH of upper subsoil. 20% of topsoils and 30% of subsoils have pH >7.4 similar to other solid geological clays apart from Oxford and Rhaetic Clays which are predominantly alkaline (reference Table 2.6). Deeper soil profile data of these soils on Till shows calcareous material starting at depths varying from 20 to 80cm, though locally not within 120cm. This indicates highly variable degrees of decalcification of the Till probably linked to localised variation its original chalk/limestone content. Accordingly *spot pH testing or testing with ground-truth zoning topsoil is imperative on such soils*.

Testing *subsoil* for pH is advisable if topsoil is pH <5.5.

Organic Matter

Median topsoil OM in this data set was 5.4% (Good) with 17% of samples low and 38% >6% OM. Split by textural class, medians are light loams (4.0%), medium (3.4%) and heavy loam or clay (6.0%). On the cluster area (arable) the OM 10-90% range was 4.6-8.1%

According to the OM Index, median clay:SOC ratio was 9 and structural rating good (B) though data covered the whole range A to D.

Figure 6.6 shows subsoil OM poorly correlated with topsoil OM and is relatively higher in clay than loamier upper subsoils. We do not know whether there is a history of ploughing down manures on the heavier soils but certainly good OM levels have been attained here. The median subsoil OM was 2.4% with very few cases <1.5%. Where topsoil is >6% about 3% is likely in subsoil. For the light to medium subsoils if the high subsoil point is omitted {3.1,2.5} the line gives a useable fit (Table 6.3).

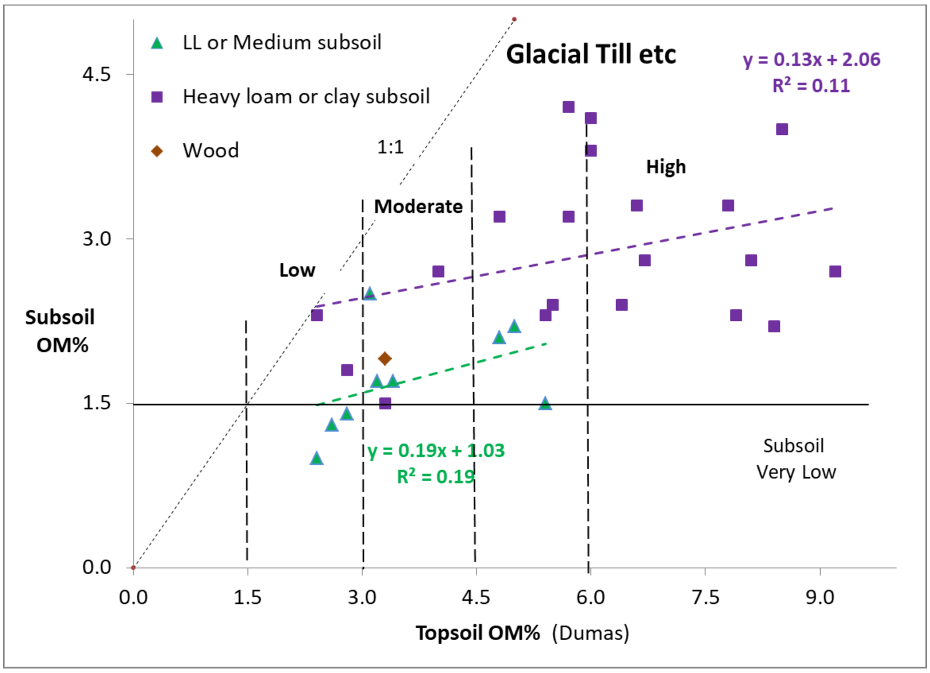


Figure 6.6: Region C, soils on Glacial deposits: organic matter in topsoil and subsoil

Table 6.3 : best fit regressions. Soils on Glacial Deposits

Equation (see Appendix 6)		r^2
Light-medium subsoil:	Subsoil P = Topsoil P x 0.34 + 2.8	0.32
Heavier subsoil:	Subsoil P = 3.5 x e (Topsoil P x 0.029)	0.51
	Subsoil P = Topsoil P x 0.10 + Subsoil OM%* x 1.8 + 0.49	0.35
Subsoil sandy to medium:	Subsoil K = Topsoil K x 0.78	0.80
Heavier subsoil:	Subsoil K = Topsoil K x 0.38 + 39	0.74
	Subsoil K = Subsoil pH x 42 - 185	0.40
	Topsoil K = Subsoil pH x 95 - 482	0.40
Heavier subsoil (up to 150 mg/l in topsoil):	Subsoil Mg = Topsoil Mg x 0.95	
Lighter subsoil :	Subsoil pH = topsoil pH x 0.37 + 4.16	0.28
Heavier subsoil:	Subsoil pH = topsoil pH x 0.62 + 2.95	0.64
Lighter subsoil :	Subsoil OM = topsoil OM x 0.24 + 0.72	0.50

* capped at 6%

7. Soils on Oxford Clay

This set comprises 67 sampling points from Quainton to Twyford in Oxfordshire. Most were sampled at a density of about 1 per 3 ha.

'Oxford Clay' is subdivided in modern BGS maps into Kellways, West Walton, Weymouth, Stewartby and Peterborough formations. The former three are calcareous mudstone or siltstones, the latter mudstones with shelly layers.

Similar soils occur in an arc from the Dorset coast to Humberside, and are usually mapped under Denchworth association on the SSEW sheets.

Land Use and Soils

43 sampling points were arable, 4 in grassed margins, 14 grassland and 6 in woodland.

3% of topsoils were hand-textured as medium clay loam, 23% as heavy (silty) clay loam with the remainder as clays. 98% of subsoils were clay textured; there was some variation in stoniness (0-10%). Colour was mottled greyish (olive) brown. 70% were WC IV.

26% of samples were taken by corer method. Median start depth of subsoil sampling was 25cm by corer and 30cm by auger method.

Table 7.1: Nutrient summary - arable soils on 'Oxford' clays

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	mean	median	10-90%	mean	median	10-90%	**0**	**1**	**2**	**3**	**4**	**5**
Phosphorus	22	**20**	10-36	7.5	**6.0**	3-13	*9*	*14*	*47*	*30*		
Potassium	247	**228**	163-345	175	**153**	110-258		*2*	*21+37*	*35*	*5*	
Magnesium	185	**182**	102-275	228	**218**	112-366			*9*	*40*	*30*	*21*
K:Mg ratio	1.5	**1.4**	0.9-2.1	0.9	**0.8**	0.5-1.3						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	7.0	**6.8**	6.3-7.8	7.4	**7.6**	6.6-8.1		*5*	*16*	*40*	*14*	*26*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	4.4	**4.4**	3.4-5.5	2.0	**2.2**	1.2-3.5		*2*	*51*	*40*	*7*	
clay:SOC	16	**16**	12-21		**Index**	**D-A**	*75*	*23*	*2*	*-*	arable	
Grass	12	**11**	8-17		**"**	**"**	*33*	*34*	*22*	*11*	grass	

Table 7.2: Nutrient medians in field margins (4), grassland (14) and woodland (6)

	Topsoil			Upper Subsoil		
	Margin	Grass	Wood	Margin	Grass	Wood
Phosphorus	13	3.5	13	6	2.0	3.8
Potassium	323	157	183	272	153	140
Magnesium	265	218	123	322	309	177
K:Mg ratio	1.2	0.8	1.4	0.8	0.5	1.0
pH	7.0	6.6	7.0	7.7	7.5	6.6
OM %	5.2	6.6	4.6	2.9	2.6	2.0

Phosphorus

On arable samples the median (20 mg/l) was target index; 23% of samples were below target and 30% above. Topsoil P was positively correlated with organic matter and weakly negatively related to texture class, stones and pH (Appendix 7). The nine data with heavy loam topsoil had higher median P than the clay topsoils (26 versus 18 mg/l). In a cluster of ten samples P ranged 10-19 mg/l (auger method).

Slightly lower P was found on the field margins and woodland and was very low on the permanent grassland (all cases except two were index 0).

Subsoil P on arable sites averaged 6 mg/l (mid index 0) and was extremely low on grassland. Arable and grass data fit to a very similar line in Figure 7.1 (as does the woodland) and whole data was used to produce regression equations.

When topsoil was index 1, subsoil was <8 mg/l (index 0), and when topsoil was target subsoil still likely to be index 0. At high P index the subsoil P was extremely variable, possibly due to variable in degrees of carry down of organic matter. Subsoil P was equally influenced by topsoil P and subsoil OM% P with each 1% increase in subsoil OM% corresponding to +Δ2.6 mg P/l (Table 7.3). Sampling method was less influential but as an approximation was 0.7 mg/l lower than fitted line when sampled by auger and 2 mg/l greater by corer (where sample start depth tended to be higher).

Subsoil pH had no statistical influence on P, however the tendency to high pH on this data might explain why subsoil P is lower in relation to topsoil P than found on other soil types.

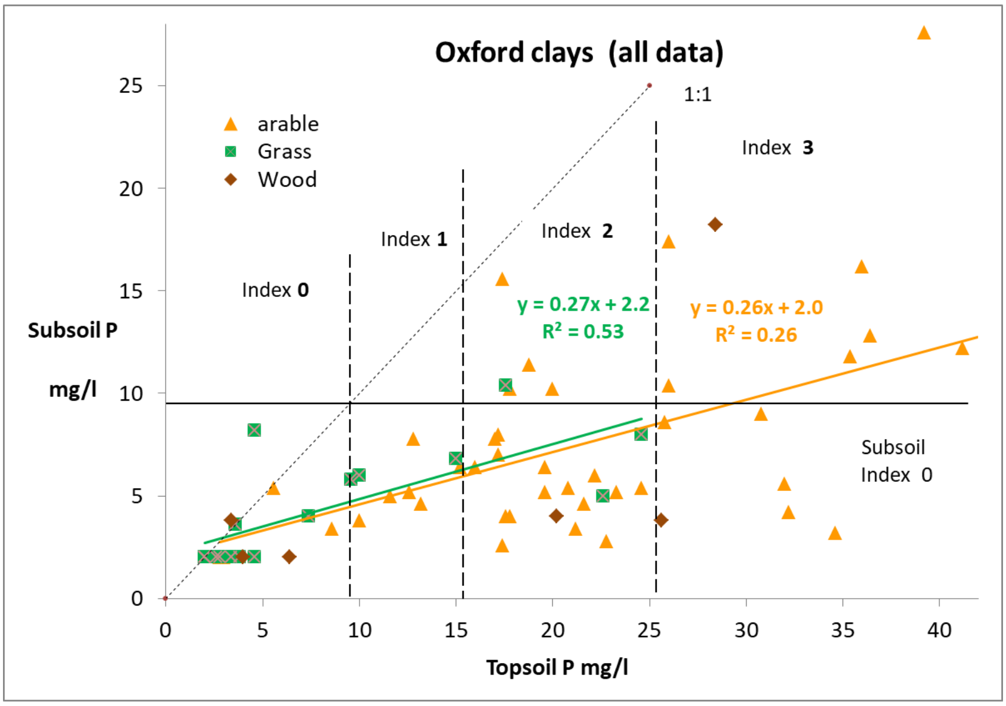


Figure 7.1: heavy soils on Oxford Clays: Phosphorus in topsoil and subsoil

Potassium

Topsoil K levels in arable soils were good - median index 2+ (218 mg/l) with 40% index 3 or 4 and only 2% below target. On the set aside grass margins K levels were somewhat higher and permanent grassland significantly lower with 21% below target index (though sampled to greater depth than normal). In the cluster of ten, K ranged 293-374 mg/l (±12%).

On arable data topsoil K was positively correlated with topsoil P, topsoil OM and weakly with texture and negatively correlated with pH and stoniness. Median topsoil K was 205 mg/l on heavy loam topsoils versus 232 mg/l on clay topsoils.

Subsoil K shows strong linear relationship with topsoil K (Figure 7.2). Both arable and grass data have a similar intercept (37 mg/l subsoil K at theoretical zero topsoil K), however the slope is greater under grassland (and set aside margins). It is possible that under grass there is a lower proportion of uptake from the subsoil than under arable conditions or more available K due to higher subsoil OM%.

When arable and grass data were combined regression analysis showed subsoil K to be influenced weakly by sampling method and more strongly by subsoil OM with each 1% increase in subsoil OM% corresponding to +Δ19 mg K/l. The fitted regression equation (Table 7.3) is almost identical to clays on Charmouth mudstone (Table 3.2).

The distinct intercept again points to a proportion of the measured exchangeable K in the subsoil clay not being plant available, possibly 50 mg K/l.

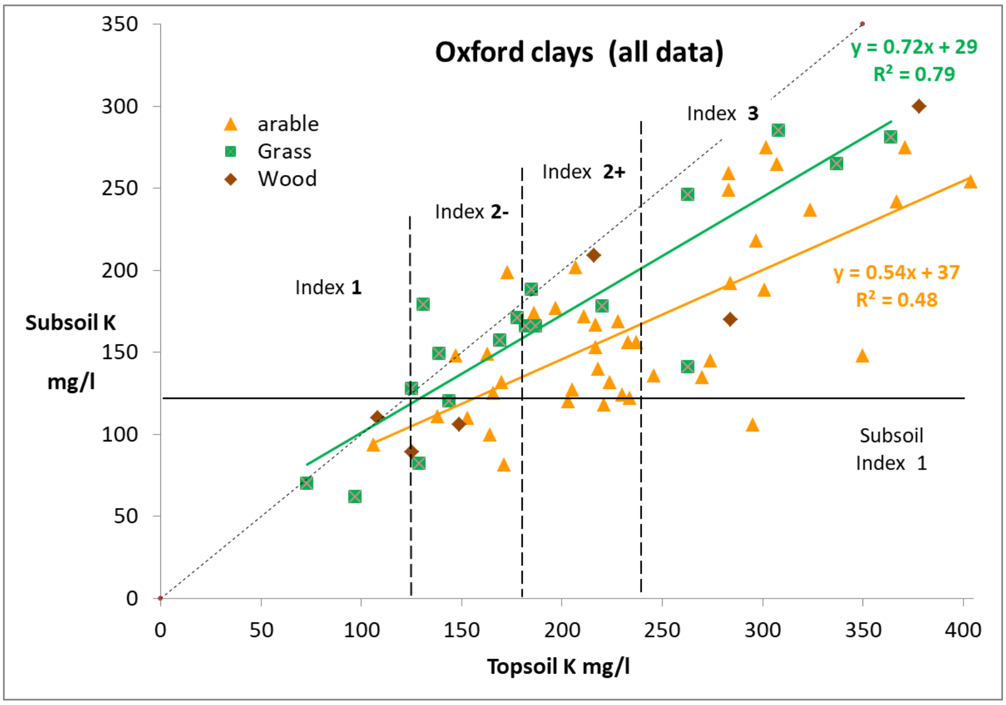


Figure 7.2: heavy soils on Oxford Clays: potassium in topsoil and subsoil.
One arable point excluded (626 mg/l K in topsoil)

Figure 7.3 illustrates that subsoil pH explains 26% of the variance in subsoil K. For each unit increase in pH, subsoil K increases +Δ45 mg/l. Topsoil K increases by 53 mg/l (r^2 = 0.22) on arable (but no relationship on grass). This suggests that the more alkaline clays have higher potash supply than decalcified variants, as is found on Glacial Till soils.

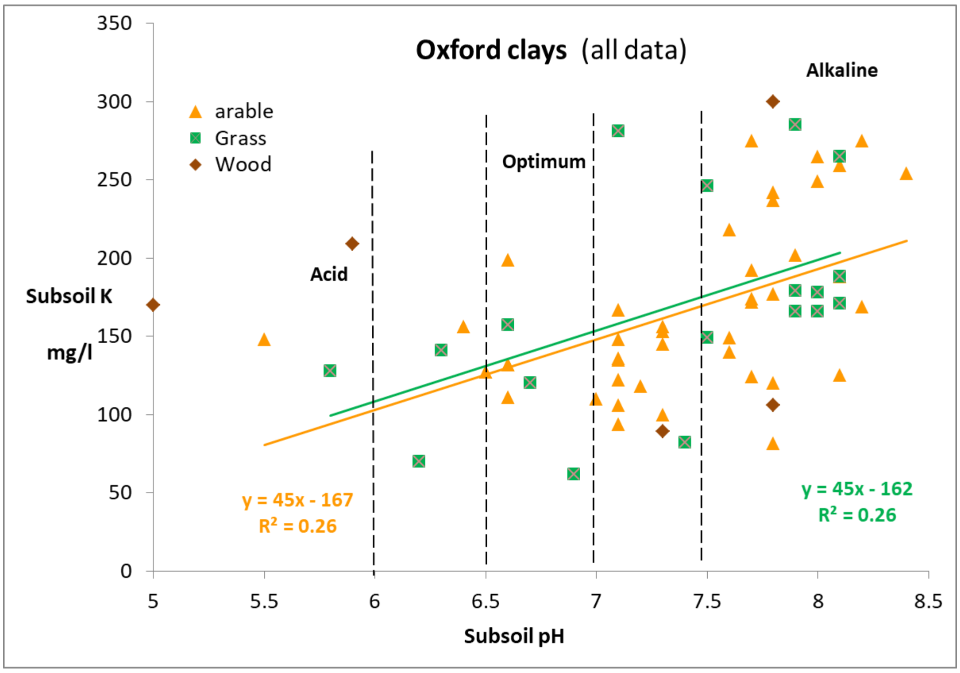


Figure 7.3: Region C, heavy soils on Oxford Clays: Subsoil pH and potassium

Agronomic: these soils generally are adequately supplied in K although some grass fields were below target index. Potassium status may vary according to the geological member and subsoil pH (decalcification is greatest on Peterborough Member which also has the lowest K). However significant within-field variation can occur.

- At topsoil index 1 subsoil will be lower index 1 (<90 mg/l) which might be deficient.
- at topsoil index 2- subsoil K is 2- or 1+, and unlikely to be a problem.
- at topsoil index 2+ subsoil K is at least 2-.
- a topsoil index 3 subsoil will vary from 2- to 3.

Magnesium

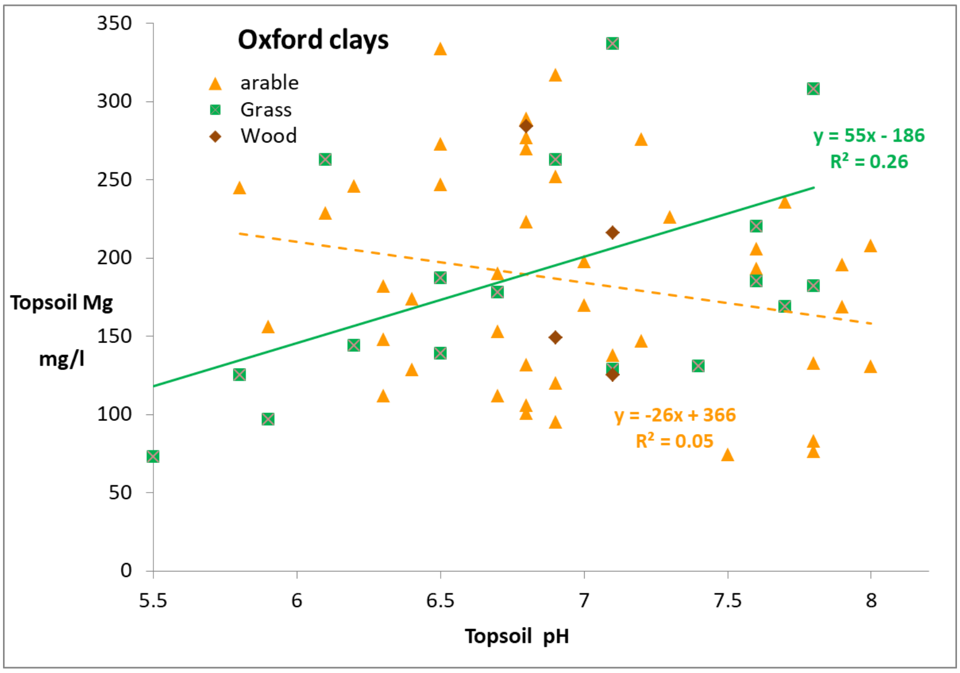


Figure 7.4: heavy soils on Oxford Clays: topsoil pH and magnesium

On arable land topsoil Mg was median index 4 (182 mg/l) with none at low index and 21% at index 5. Grassland tended to be higher (median 218 mg/l) but none above index 5. The general range, 100-300 mg/l, was wide and not obviously affected by heavy loam versus clay topsoil nor by soil pH (Figure 7.4). In the cluster Mg varied from 193-270 mg/l (±17%).

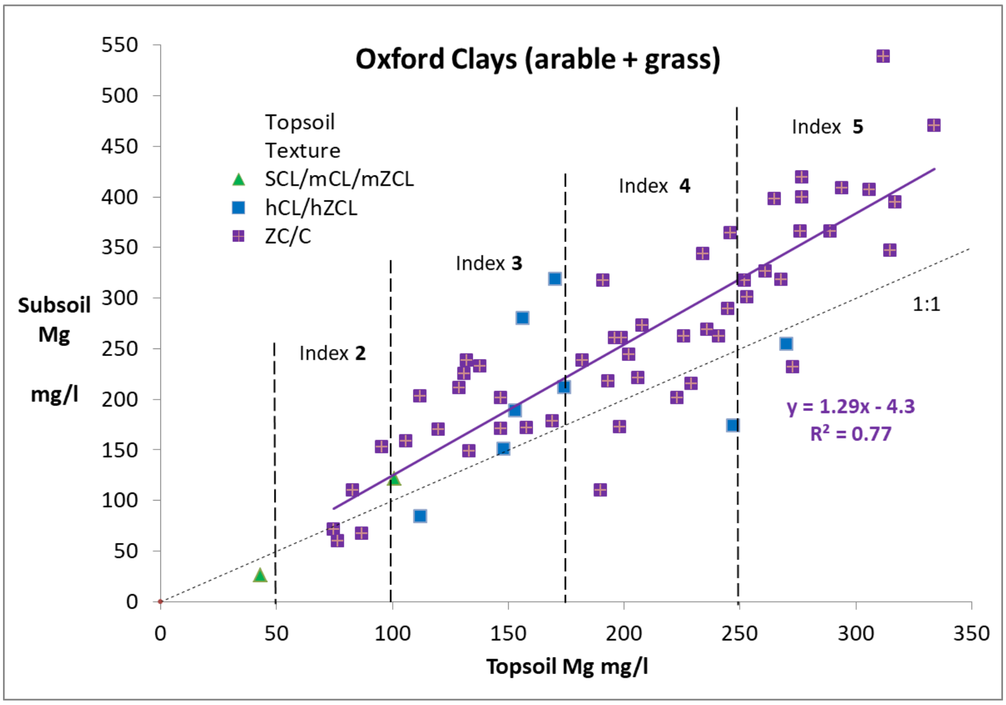


Figure 7.5: heavy soils on Oxford Clays : magnesium in topsoil and subsoil

Subsoil Mg was greater than topsoil Mg and strongly correlated with insignificant intercept (Figure 7.5). There was no obvious difference due to topsoil texture. The fitted equation (1.26x) was identical to Charmouth Mudstone, though the latter had a high representation of index 6 (>350 mg/l) unlike the Oxford Clays here.

When split according to geological classification, the Peterborough Member tended to lower magnesium in topsoil and subsoil compared to the younger 'Oxford' clays (ref. Table 2.5).

Average K:Mg ratio was above 1 in topsoil and about 0.8 in subsoil. In the arable data no topsoils and only 17% of subsoils were K:Mg (mg/l:mg/l) <0.5; a somewhat greater proportion on under grassland (12% and 47%).

No samples exceeded Mg index 5 and soils higher in Mg were also higher in K. Accordingly, Mg induced K deficiency seems less likely to be less of a problem on Oxford Clays than older clay formations further north.

pH

There was large range of pH. In arable data median topsoil was 6.8 and 21% were below target pH (6.5) but few (5%) < pH 6; 26% were > pH 7.4. pH on the grassland, excluding set aside margins, was very slightly lower (median 6.6) but only 3 cases < pH 6.0.

Of the arable subsoils only 7% were below pH 6.5 and more than half > pH 7.4.

Subsoil pH was higher than topsoil pH in almost every case (Figure 7.6). Arable and grass data fit similar lines: at topsoil pH 6.0 the subsoil is about 0.7 higher than topsoil and at pH 8.0, subsoil and topsoil pH converge (higher than found in other data sets, 7.0-7.5).

Woodland pH varies from 4.1 to 7.5 with poor relationship of topsoil to subsoil.

On the arable data topsoil pH had a weak negative correlation with topsoil OM% (each 1% OM increase associated with 0.27 less pH) and pH on average was 0.37 higher on clay than heavy loam topsoil.

Subsoil pH was negatively related to subsoil stone class and subsoil OM%. For fitting arable and grass data were combined. Sampling method was insignificant but organic matter was (each 1% of subsoil OM corresponding to a 0.24 decline in pH). Stoniness was associated with a small decrease in pH (0.13 for each 10% stones).

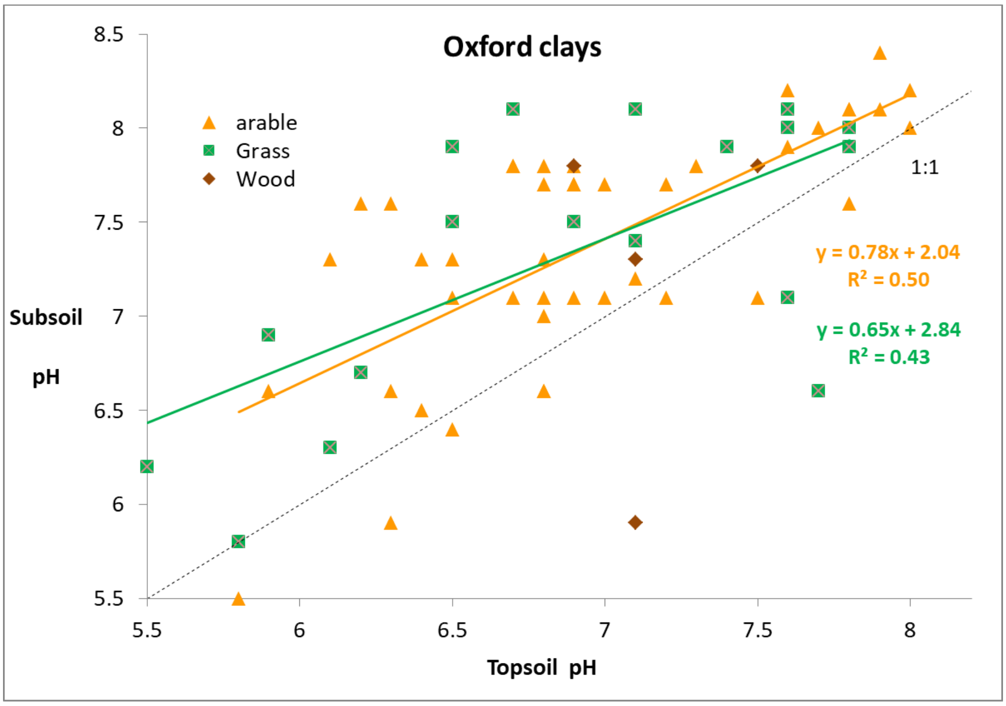


Figure 7.6: Heavy soils on Oxford Clays: pH in topsoil and subsoil
2 data on woodland not shown (pH 4:1,4.1 and 6.8, 5.0.

Agronomic alkalinity: most of the soils measured as alkaline (pH>7.4) were not detected as calcareous in the field HCl test, indicating that only small amounts of $CaCO_3$ were present, nevertheless this is probably is natural rather than due to liming. According to BGS the parent materials are inherently calcareous and this data shows at least 75% of upper subsoils of pH >7.4 except on the Peterborough member (reference Table 2.6). The West Walton formation sits just beneath Corallian limestone deposits so might be expected to be more calcareous than the older members.

It seems that variable degrees of decalcification have been occurring in soils formed on these Oxfordian clays. The lower pHs found on the Peterborough Member may be due to less $CaCO_3$ in original parent material or perhaps more mixing of superficial clayey head with the original mudstone (42% of upper subsoils contained significant stones compared to 13% of the Weymouth samples).

Agronomic: spot pH testing is important on these clays in order to find areas that have become decalcified in the topsoil and now require lime application. In a cluster of ten samples pH varied 6.7-7.9.

pH testing of subsoil is not necessary except for environmental purposes (e.g. woodland).

Organic Matter

Topsoil OM averaged 4.4% on arable land, 5.2% on grass margins and 6.6% on other grass; only one sample was <3%. The cluster ranged 3.5-5.1% (±20%). In arable samples the median clay:SOC ratio was 16 and grassland 11. Accordingly 75% of arable topsoils are classed degraded with the rest are moderate. 34% of grassland is classed degraded with all four classes represented. Certainly the 25% of all arable and grass soils <4.0% OM certainly does warrant improvement in OM status

OM in woodland was highly variable and one cluster varied from 3-14%.

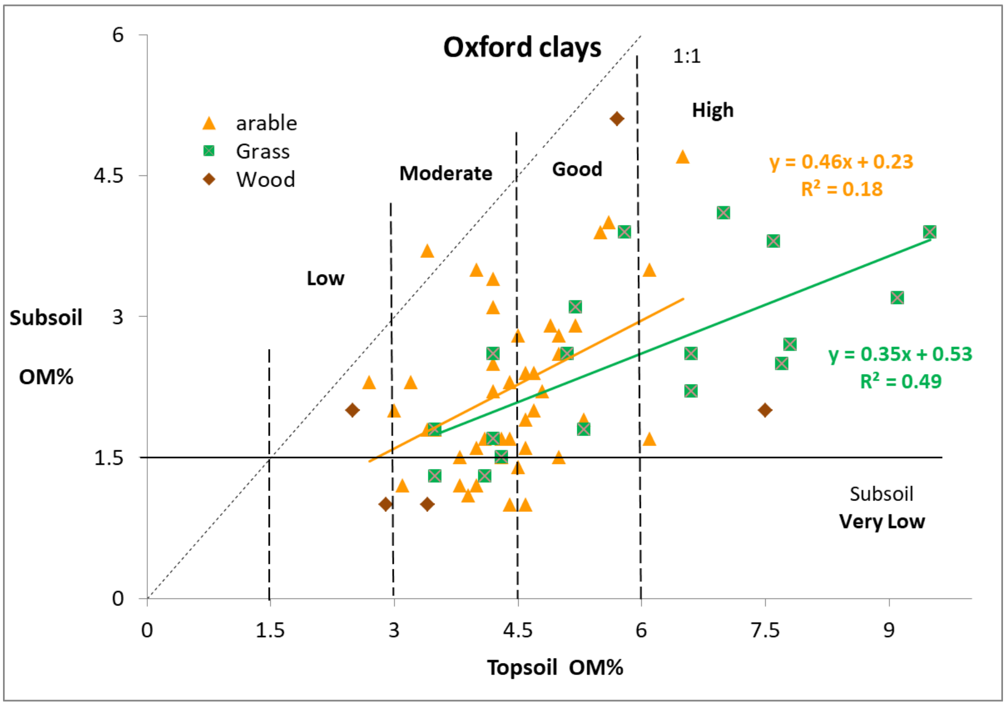


Figure 7.7: Region C, heavy soils on Oxford Clays: Organic Matter in topsoil and subsoil One woodland site not shown {14%,3%}

Median OM of subsoil was 2.2% under arable and 2.6% under grass, about 0.5x topsoil OM.

Figure 7.7 shows a weak relationship with topsoil OM on arable sites. To produce a useable fit, samples >9% OM and woodland were excluded and the arable sample where subsoil exceeded topsoil (unduly influenced by River Terrace Drift). r^2 is still poor (0.29).

Compared to auger sampling, the corer method averaged 1.8% OM greater in topsoil and 0.92% greater in subsoil, attributable to slightly deeper sampling by the auger.

On these soils, "good" topsoil OM of > 4.5% ensures >1.5% in the subsoil, moderate topsoil 1-3% in the subsoil. For topsoil >9% OM (under grass), >3% subsoil OM is expected.

The unpredictability of subsoil OM is more than mere sampling method influence and indicates variable degree of carry-down of OM from topsoil.

Table 7.3 : best fit regressions. Soils on Oxford Clays

Equation (see Appendix 7)			r^2
Subsoil P	=	Topsoil P x 0.26 + 2.0	0.37
	=	Topsoil P x 0.25 + Subsoil OM% x 2.62 - 3.84	0.64
Subsoil K	=	Topsoil K x 0.58 + 37	0.58
	=	Topsoil K x 0.57 + Subsoil OM% x 19.1 - 4	0.67
	=	Subsoil pH x 45 - 165	0.26
Topsoil Mg	=	Topsoil pH x 186 - Topsoil OM% x 48 + 1295	0.46
Subsoil Mg	=	Topsoil Mg x 1.26	0.74
Subsoil pH	=	Topsoil pH x 0.72 + 2.36	0.48
	=	Topsoil pH x 0.70 - Subsoil OM% x 0.24 + 3.05	0.59
Subsoil OM%	=	Topsoil OM% x 0.41 + 0.32 *	0.29

* Corer would tend to subsoil OM% 0.35 greater and auger 0.10% less than the fit.

8. Soils on Kimmeridge and Ampthill Clay

This set comprises 23 sampling points between Aylesbury and Quainton in Oxfordshire. Most were tested at a density of about 1 per 3 ha.

Kimmeridge deposits are the youngest Jurassic Clay and overlain by Ampthill Clay which though classed 'Oxfordian' is often associated with the Kimmeridge Clay. Both are calcareous mudstone or siltstones. On three places superficial Head was mapped but these samples did not have obviously different texture, pH or nutrients and so are included.

Similar soils occur in an arc from the Dorset coast to Humberside, and are usually mapped under Denchworth association on the SSEW sheets.

Land Use and Soils

10 sampling points were arable, 11 grassland and 2 in woodland. Median start depth of subsoil sampling was 25cm (10-90% range 20-28cm).

44% of topsoils hand-textured as heavy (silty) clay loam and 56% as clays. Nearly all subsoils were clay textured with few or no stones and WC IV. Colour was mottled greyish olive brown. 17% of samples were taken by corer method.

Table 8.1: Nutrient summary - arable soils on Kimmeridge and Ampthill clays

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	mean	median	10-90%	mean	median	10-90%	**0**	**1**	**2**	**3**	**4**	**5**
Phosphorus	25	**18**	12-27	9.3	**8.2**	4.2-15	*10*	*20*	*50*	*10*		*10*
Potassium	258	**227**	143-429	222	**188**	142-319			*30+30*	*20*	*20*	
Magnesium	256	**262**	176-340	273	**279**	159-344				*10*	*30*	*60*
K:Mg ratio	1.1	**0.9**	0.6-1.6	1.2	**0.8**	0.5-1.2						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	7.3	**7.2**	6.6-8.2	7.8	**7.9**	7.4-8.0				*40*	*20*	*40*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	4.7	**5.0**	3.3-6.0	2.5	**2.7**	2.2-3.9		*10*	*30*	*50*	*10*	
clay:SOC	16	**15**	11-21		**Index**	**D-A**	*70*	*20*	*10*	-		

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	mean	median	10-90%	mean	median	10-90%	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	34	**21**	5-84	13	**8.4**	2-37	*18*	*9*	*18*	*27*		*27*
Potassium	324	**335**	113-462	221	**164**	113-462		*27*	*18+0*	*9*		*56*
Magnesium	287	**262**	196-472	266	**285**	172-264					*36*	*64*
K:Mg ratio	1.2	**0.9**	0.4-2.0	0.9	**0.9**	0.4-1.6						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	6.8	**6.8**	6.2-7.6	7.6	**7.6**	7.1-8.1			*36*	*55*	*9*	
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	7.8	**7.8**	5.8-9.9	3.1	**2.7**	2.2-3.9				*18*	*64*	*18*
clay:SOC	8.0	**7.6**	8-18		**Index**	**D-A**	-	*18*	*9*	*73*		

Phosphorus

On arable the topsoil median (18 mg/l) was target index (2); 30% of samples were below target and 30% above.

On grassland the topsoil median (21 mg/l) was also target; 27% of samples were below target and 27% index 5, a vast range. Clearly the *mean* value (34 mg/l) is distorted and highly misleading in cases like this

Subsoil P medians were similar on arable and grass (8-9 mg/l upper index 0) but with wide range.

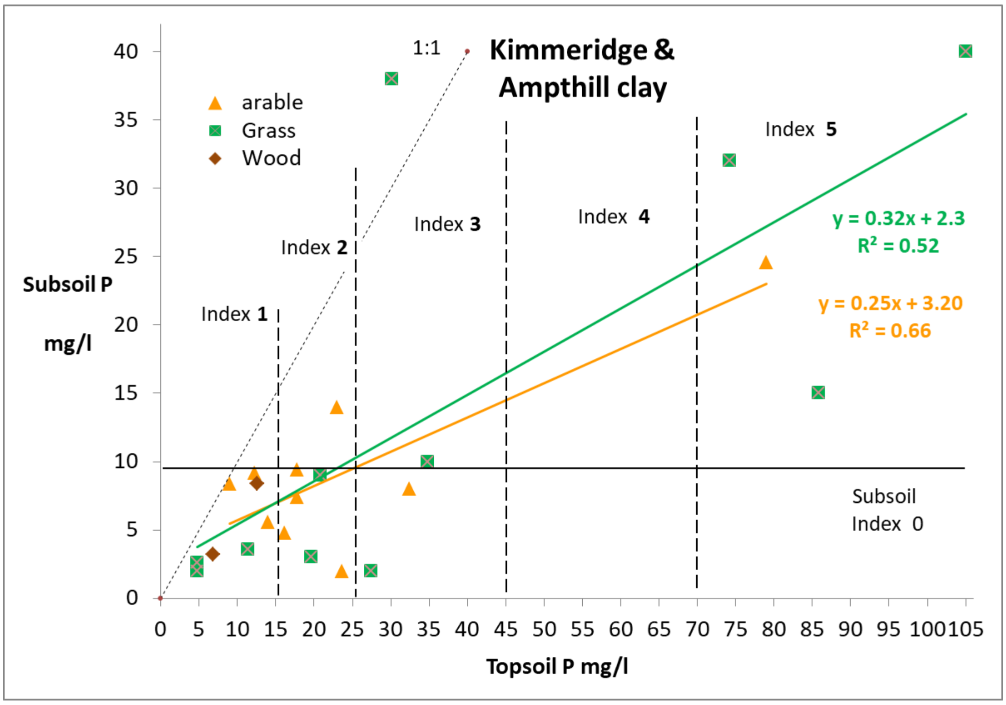


Figure 8.1: Kimmeridge and Ampthill Clays: Phosphorus in topsoil and subsoil

Figure 8.1 shows that where topsoil P was index 2 or less the subsoil was index 0 but at higher levels of topsoil P the subsoil P is highly unpredictable, presumably due to variable degrees of carry down of organic material from the topsoil. Almost certainly some fields have a history of heavy manuring. However, as a guide, at index 4 the subsoil P typically was a third of topsoil P.

Potassium

Topsoil K in arable soils was good - median index 2+ (227 mg/l) with 30% index 3 or 4 and none below target. Median grassland levels were somewhat higher but with a large range, one sample was >1000 mg K/l. The two samples of index 1 had heavy loam not clay topsoil.

Subsoil K median values were 164 and 188 mg/l respectively but with large range.

Subsoil K was related to topsoil K (Figure 8.2) and if the very high value is excluded, the arable and grass data fit a similar line with intercept of 66 mg/l subsoil K at theoretical zero K in topsoil (Table 8.2) – this is indication of significant unavailable extracted K, In clay subsoils under *heavy loam t*opsoil subsoil K might be proportionately greater than clay over clay but data set is too small to demonstrate this.

Unlike the Oxford Clays there was no relationship of subsoil pH to subsoil K.

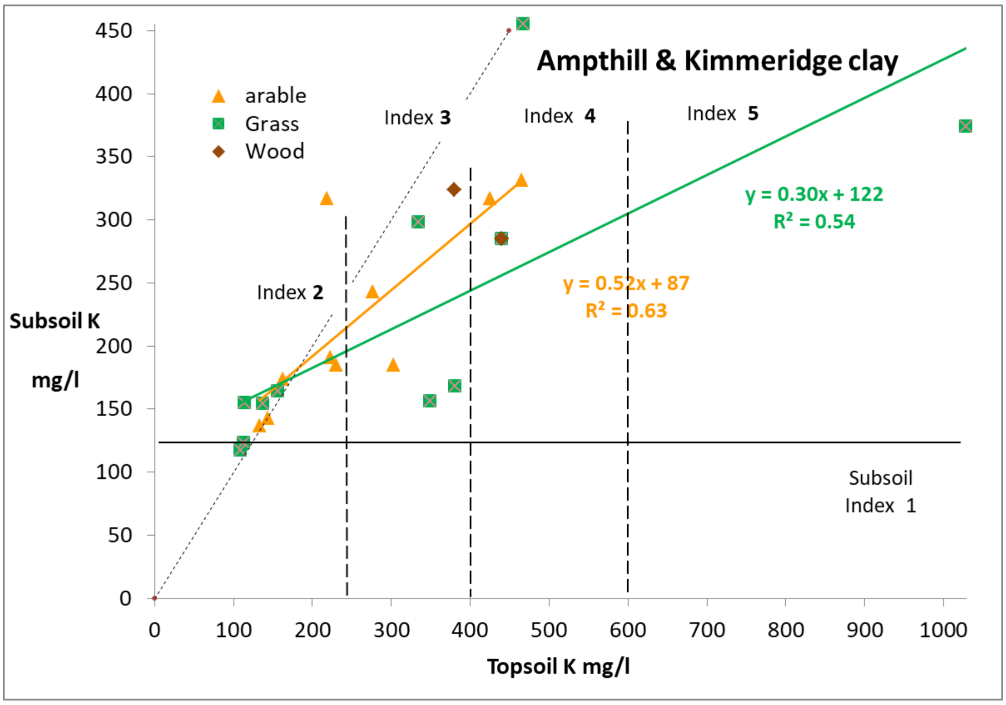


Figure 8.2: Kimmeridge and Ampthill Clays: potassium in topsoil and subsoil.

Provided topsoil K is index 2- or higher the subsoil K will be above index 1 and at topsoil 3 subsoil will be at least 150 mg/l, in some cases much higher (index 3).

Magnesium

On arable land median topsoil Mg was 182 mg/l (index 4) with none of low index and 21% at index 5. Grassland tended to be higher (median 218 mg/l) with 36% index 6. The main range, 100-350 mg/l, was not different on heavy loam versus clay topsoil but did decline with pH (Figure 8.3), each unit increase in pH corresponding to -Δ77 mg/l Mg. (This is logical since higher topsoil pH equates to more Ca causing more displacement of Mg by leaching).

Topsoil Mg was not related to texture class or OM. The very low Mg point on woodland was in Head with heavy loam subsoil.

Subsoil Mg was not related to subsoil pH. Figure 8.4 shows that it was similar to topsoil Mg: at high topsoil Mg subsoil Mg could be greater in arable and lower in grassland – the latter might be related to accumulation in topsoil due to heavy manuring or grazing. Overall regression gave a 1:1 fit (Table 8.2).

Median K levels in Ampthill and Kimmeridge Clay were 265 and 236 mg/l in topsoil and in subsoil of 285 and 262 respectively which are not significantly different to each other or to the older Oxfordian layers (see reference Table 2.5).

Median subsoil K was 191 and 160 mg/l respectively and K:Mg of 0.67 and 0.61. 15% of the topsoils and 20% of subsoils had a K:Mg ratio below 0.5.

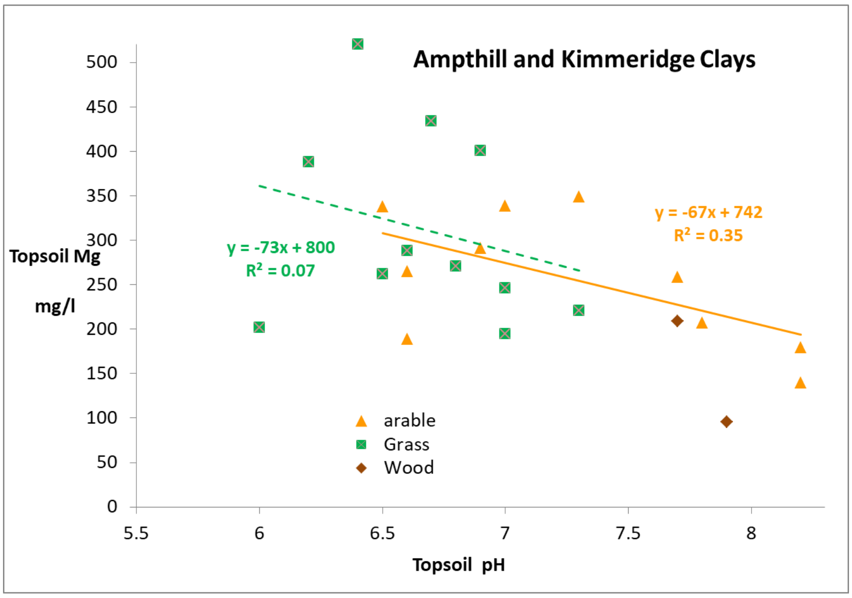


Figure 8.3: Ampthill and Kimmeridge Clays: topsoil magnesium versus topsoil pH

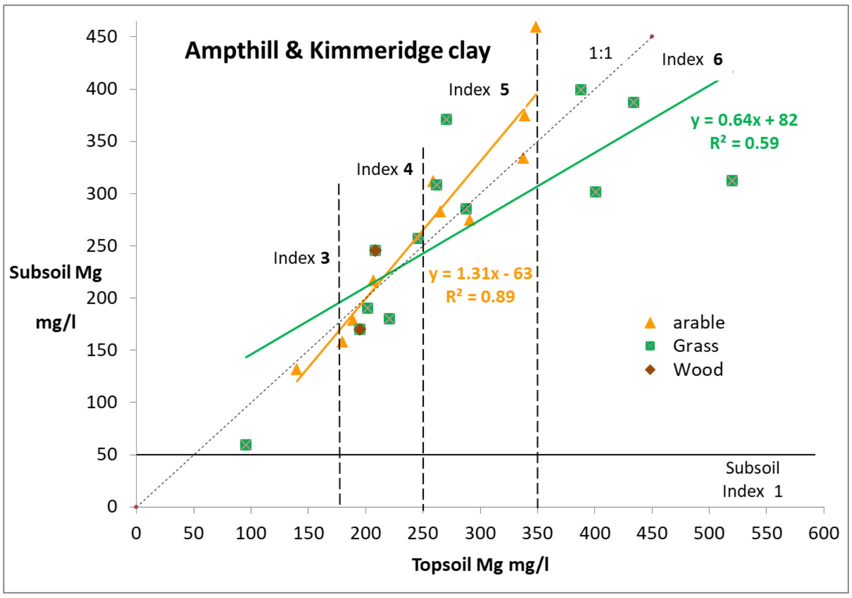


Figure 8.4: Ampthill and Kimmeridge Clays: magnesium in topsoil and subsoil

pH

Arable median was 7.2 with no samples below 6.5, grassland was 6.8 with no samples below 6.0. pHs were marginally lower on the Kimmeridge than Ampthill Clay.

Subsoil pH was always higher than topsoil and 80% of arable and 90% of grass were pH >7.4. Topsoil and subsoil pH converge at about 8.0 and at or below pH 6.5 the subsoil is 0.7 higher (Figure 8.5).

The regression equation is improved by inclusion of subsoil OM with each 1% OM associated with a 0.08 decrease in pH (Table 8.2).

The average subsoil pH was the same on Ampthill and Kimmeridge Clays (7.7 and 7.8) though in only 3 cases were the alkaline subsoils confirmed by visible reaction in the field HCl test indicating quite low levels of $CaCO_3$.

The lower topsoil pH on the Kimmeridge Clays is perhaps indicative that these are more susceptible to decalcification (or more affected by Drift admixture) than the Ampthill Clays which behaves like the Weymouth and other Oxfordian clays (reference Table 2.6).

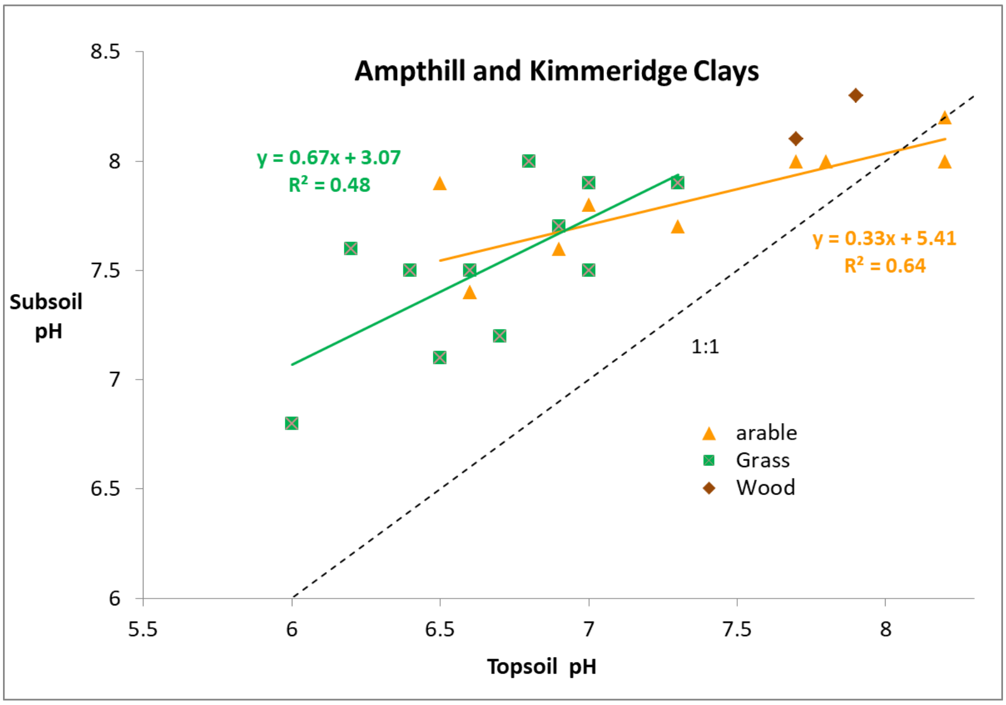


Figure 8.5: soils on Ampthill and Kimmeridge Clays: pH in topsoil and subsoil

Organic Matter

Topsoil OM was higher on grassland (median 7.8%) than arable (5.0%). Median clay:SOC ratio was 8 and 15 respectively. 70% of arable topsoils were judged degraded ((D) whereas 73% of the grassland was very good (A), 18% moderate (C) and none degraded.

Median OM in subsoil was 2.7% under both arable and grass implying that carry down of topsoil OM was limited despite high levels in topsoil. There poor relationship between topsoil and subsoil OM (Figure 8.6).

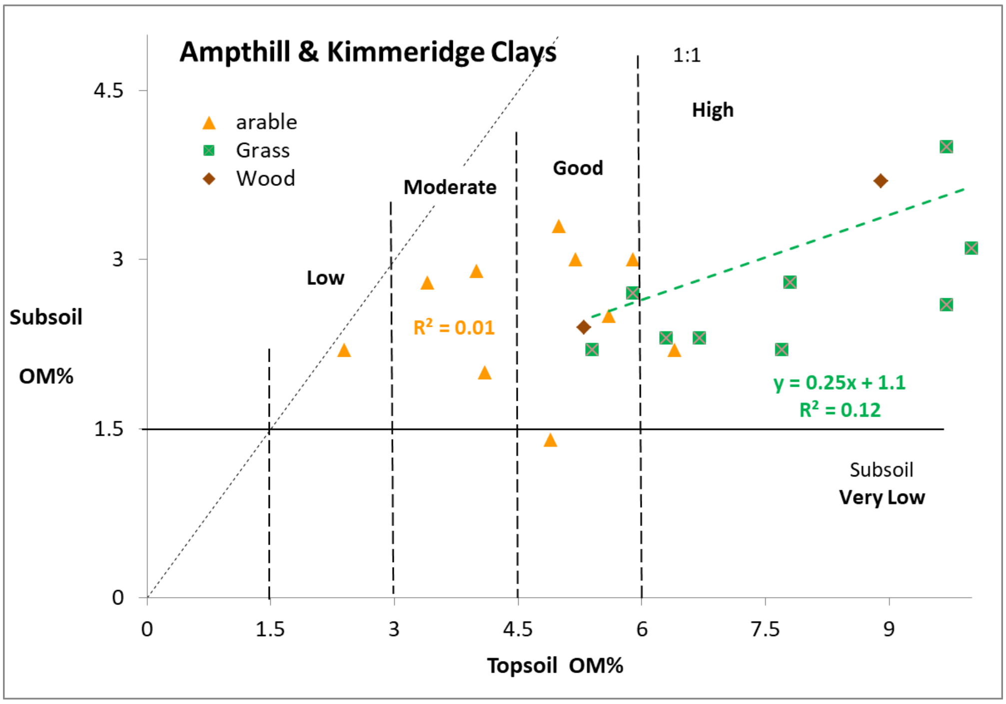


Figure 8.6: Ampthill and Kimmeridge Clay: Organic Matter in topsoil and subsoil

So according to this limited data subsoil OM < 1.5% is unlikely and > 3% is unlikely unlrdd the topsoil is organic.

Table 8.2: best fit multiple regressions. Soils on Ampthill & Kimmeridge Clays

Equation (see Appendix 8)	r^2
Subsoil P = Topsoil P x 0.30 + 2.4	0.58
Subsoil K = Topsoil K x 0.57 + 66	0.60
Topsoil Mg = - Topsoil pH x 77 + 618	0.25
Subsoil Mg = Topsoil Mg	0.78
Subsoil pH = Topsoil pH x 0.43 + 4.64	0.56
Subsoil pH = Topsoil pH x 0.40 - Subsoil OM x 0.08 + 5.11	0.62
Subsoil OM% = Topsoil OM% x 0.20 + 1.54 *	0.19

9. Soils on the Chilterns

This comprises data from Wendover to east of the Colne Valley. It is 57 samples, a sporadic representation of grassland, leys, arable and woodland sampled at variable density. In 65% of places the solid geology is white Chalk (Seaford, Lewis Nodular or Holywell Chalk), and 35% lies on the overlying Lambeth Deposits (Reading Beds), mainly at the south end.

Lambeth Beds are estuarine, variably sandy, silty, clayey or stony material. Both Chalk and Lambeth Beds soils are influenced by superficial Drift - various sand & gravels (Shepherds Hill, Gerards Cross and Winter Hill Gravels), Clay-with-Flints or Head. Shallow soils over Chalk are almost absent in this data set, though the lower subsoil was frequently calcareous.

Accordingly, there is a range of topsoil texture – 25% light loams, 44% medium 16% heavy loams and 16% clay and only 8% were calcareous. SSEW map as Sonning I or II, Batcombe and Charity II associations and the manuals describe the range of soils present but are unable to predict the soil at any given location. The continuous exposure of Lambeth Beds in the south is mapped Wickham IV association (though without clay upper subsoils found on London Clay in the same map unit). 50% of the data were well drained (WCI), the rest WC II to IV. The Clay-with-Flints varied from moderately to slowly permeable.

Similar soils extend from West Berkshire into North Hertfordshire including the Rothamstead research station. Clay-with-flints is widespread also in Hampshire, Dorset and Surrey.

Average start depth of subsoil sampling was 27cm and half samples were taken by corer and half by auger. Main data is table is 58% arable 42% grassland.

Table 9.1: Nutrient summary - Chiltern Soils – median values

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	main	10-90%	wood	main	10-90%	wood	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	**28**	13-74	14	**13**	4-43	10	*10*	*10*	*29*	*12*	*24*	*15*
Potassium	**126**	49-256	85	**86**	52-169	77	*15*	*30*	*28+12*	*13*		*2*
Magnesium	**49**	26-108	86	**51**	24-104	66	*10*	*43*	*33*	*12*	*2*	
K:Mg ratio	2.8	0.8-5.4	2.7	2.1	0.9-3.4	2.4						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.4**
pH	**7.0**	5.7-7.9	5.6	**7.2**	6.2-8.0	7.0	*2*	*18*	*14*	*17*	*20*	*29*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter % *	**3.8**	2.2-6.1	7.8	**1.4**	0.8-3.5	2.2		*25*	*43*	*20*	*12*	
clay:SOC	**10.5**	6-17			**Index**	**D-A**	*31*	*24*	*21*	*24*	arable	
"	**8.4**	5-16	5.2		**"**	**"**	*25*	*13*	*21*	*41*	grassland	

n = 33 arable plus 24 grass and 8 wood

Phosphorus

Median topsoil P was above target, 28 mg/l (index 3) – and arable samples (48 mg/l) were twice grassland (21 mg/l). Range was large. 20% of all samples were below target index (no arable samples) and 39% index 4 or 5. Topsoil textures varied across arable and grassland, and (combined data) shows higher P on light loams :

light loams (51mg/l) > medium soil (25 mg/l) , heavy loam or clay (30 mg/l)
n = 14, 25 and 22 respectively

The lines in Figure 9.1are forced through origin with no loss of r^2. On less stony soils subsoil P is 0.45x topsoil P over the whole range with no obvious change point above 35 mg/l (as found in Midlands data). However, where there is high topsoil P (index 3 or 4) subsoil P is highly variable, very low in some clay subsoils.

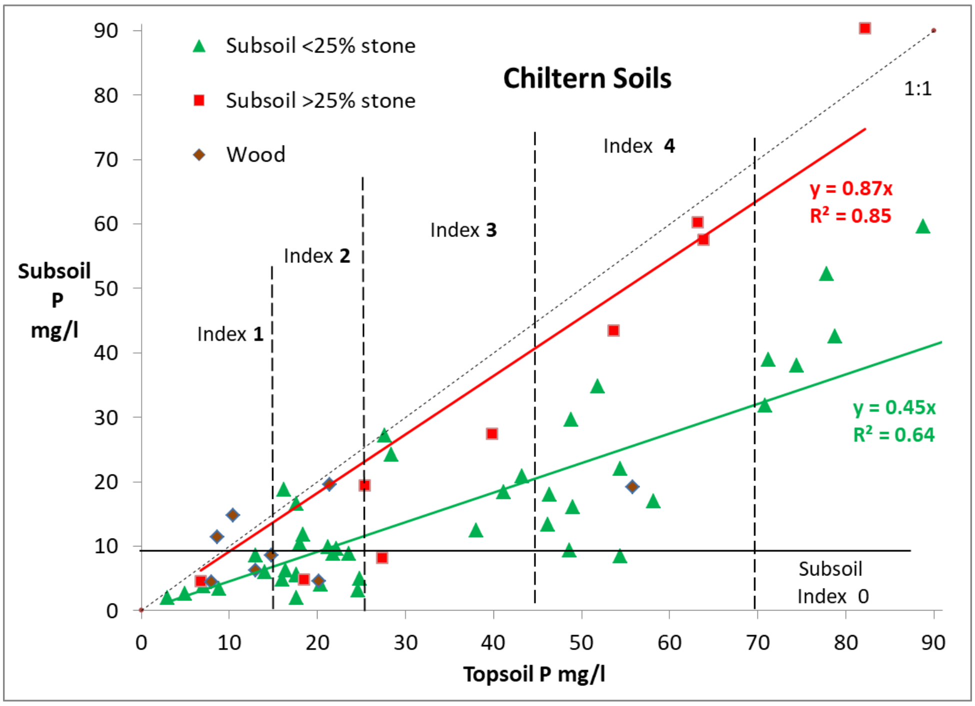


Figure 9.1: phosphorus in topsoil and subsoil

In very stony subsoils the subsoil P increases almost 1:1 with topsoil P (the lower values are clay with flints, the others stony medium or light loam). The higher P is probably because of higher subsoil organic matter in the stony subsoils, though there could be P leaching from topsoil where levels are very high.

Median **subsoil** P relates strongly to *subsoil* texture:-

light loams (27 mg/l) > medium soil (19 mg/l) > heavy loam (9 mg/l) > clay (6 mg/l)
n = 11, 16, 14 and 15 respectively.

Agronomic: high phosphorus levels seem common on Chilterns especially (but not only) on light textured or stony soils. The wide range of P levels suggests either soil analysis and RB209 recommendations have not been followed or they have failed to run-down high soil P.

- where topsoil is P index 2 subsoil is likely to be index 0 or 1;
- at topsoil index 3 subsoil is likely to be index 1 or 2 (0 or 1 if clay)
- at topsoil index 4 subsoil is likely to be index 2 or 3 (1 if clay).

Subsoil P is likely to be concentrated in stonier subsoils and lower on clay subsoils (Clay-with-Flints or Tertiary Clay).

Potassium

Median topsoil K was 126 mg/l (low end of index 2-) with 46% of arable samples and 44% of grassland below target. Topsoil texture does not have an obvious influence here (medians are light loams 147 mg/l, medium topsoil 114 and heavy loam or clay 139 mg/l).

Subsoil K relates to topsoil K. Subsoil stoniness had no influence on fitted line but subsoil texture was significant as shown in Figure 9.2. Subsoil K is proportionately less on light loams and to some extent on medium loam subsoils, suggesting that retention in lighter subsoil might be impeded when topsoil exceeds index 2-.

Heavy loam and clay subsoils show an intercept of 29 and 45 mg/l as found on other clays, but the proportionate increase, 0.5-0.6x topsoil K, is somewhat higher. So for a given topsoil K index, subsoil K is likely to be higher on Clay with Flints, Lambeth Beds than some other clay soils, though the latter usually have higher K release (reference Table 2.5).

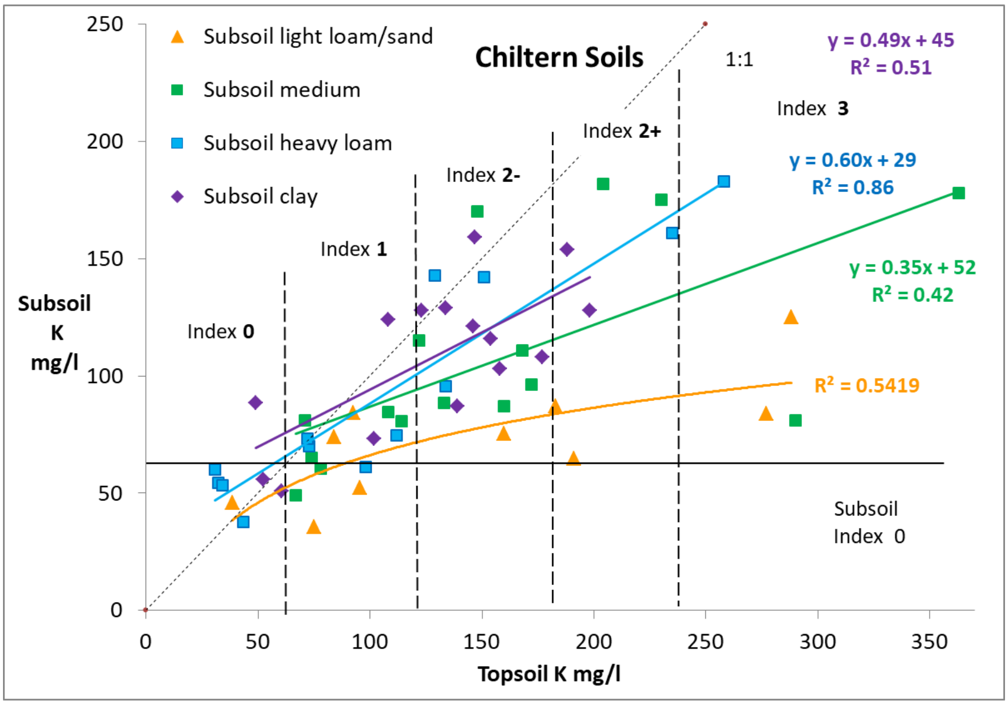


Figure 9.2: Chiltern Soils : potassium in topsoil and subsoil

Fitted equations for sandy to medium subsoil show no effect of stoniness although subsoil OM is relevant, each 1% OM associated with +Δ11 mg/l of subsoil K. On heavier subsoils OM had no influence but there is a small influence of stones (one class corresponding to 10% by volume, corresponding to +Δ5 mg/l subsoil K which is small).

Agronomic: in the Chilterns region topsoil K levels border on low in arable and grassland. Topsoil texture has little influence but subsoil texture is relevant with proportionately less subsoil K in sandy, light loamy and sometimes medium subsoils.

- Where topsoil is K index 1 subsoil will be lower index 1 (<90 mg/l) or 0.
- At topsoil index 2- subsoil will be 1 or 2-
- At topsoil index 2+ subsoil will be index 2- unless lighter textured.

Assuming 90 mg/l to be a safe subsoil minimum, topsoil index 2- should be sufficient except where the subsoil is light loam, sandy or stony (where even if >90 mg/l, the reduced soil volume means less potassium is accessible). In such cases topsoil K target ideally should be 180 mg/l, though this might incur some leaching loss.

Magnesium

The Chilterns is characterised by lower soil Mg levels than all other areas investigated. Median topsoil Mg was 49 mg/l (index 1); 43% of samples were index 1 and 10% index 0 (<25 mg/l); 14% were index 3 or 4. 74% of arable samples and 29% of grassland were below target (<51 mg/l).

Mg tended to increase with topsoil texture class but differences are quite small. Medians : light loams (43 mg/l) < medium soil (48 mg/l), heavy loam (51mg/l) < clay (62 mg/l) n = 14, 25, 9 and 8 respectively. The range in clay topsoils was 48-99 mg/l *

Subsoil Mg overall was similar to topsoil but a texture trend is clearer :

sands (21 mg/l), light loams (26) < medium soil (51), heavy loam (58), clay (56 mg/l).
n = 3, 8, 16, 14 and 10 respectively. Clay subsoils ranged from 30-166 mg/l *
* excluding one very high sample on Lambeth Beds clay.

Figure 9.3 shows that subsoil Mg is strongly related to topsoil Mg with the slope affected by subsoil texture. Where subsoil is light loam or sand, subsoil Mg is 0.64 x topsoil Mg, for medium or heavy loam textures subsoil Mg is slightly lower than topsoil or parity.

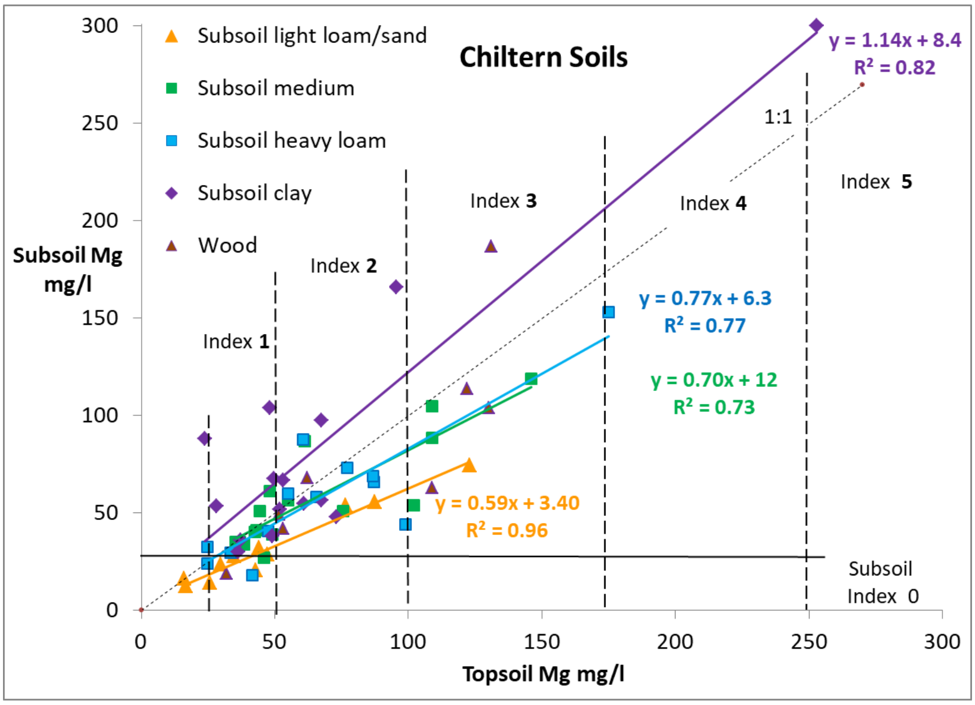


Figure 9.3, Chilterns : magnesium in topsoil and subsoil (1 point excluded {68,159}, sandy loam over clay. Lines were forced through origin.)

Where subsoil texture was clay, subsoil Mg was parity or higher than topsoil Mg. The data mapped on Lambeth Beds Clay varied from index 2 to 5. Clay-with-Flints subsoils was lower (index 1 or 2) suggesting these have different mineralogical composition to other clays, and possibly enhanced Mg leaching due to high pH.

Under woodland, Mg levels tended to be higher (30-130 mg/l). Subsoils follow the same fit as main data. Very low subsoil Mg, 19 mg/l, was found on Chalky Drift

Agronomic: in the Chilterns low Mg index is quite common across on all textures and some light loam topsoils were index 0. Subsoil Mg is lower than topsoil on lighter textures, parity in medium subsoils and higher in clay subsoils.

Soils of Mg index 0 should receive corrective treatment. Most cereals might be considered safe at index 1 but there are concerns that underlying sandy or light loam subsoils will be index 0. Magnesium application at index 1 is recommended for rape and legumes irrespective of soil texture. Under grassland the high prevalence of index 1 suggests some risk to grazing animals of Mg deficiency. Use of Magnesian limestone on acid soils makes sense (though it requires a long haul down the M1 from the East Midlands). Otherwise, judicious use of kieserite or Mg-containing wastes can be used to rectify low Mg levels.

Heavy loam and clayey subsoils are compared with other Clays in reference Table 2.6. The Chiltern clays tend to lower subsoil K (median 103 mg/l) than other clay formations, and much lower Mg (median 58 mg/l). Accordingly, K deficiency induced by high Mg should be rare. More likely Mg deficiency may be aggravated where soil K levels are good or high.

pH

Median topsoil pH was 7.0. 20% of all samples were acid (pH < 6.0) and 29% alkaline (pH >7.4). Of the arable samples 15% were suboptimal pH (6-6.4) and 15% acid.

Subsoil pH shows a typical pattern with parity at topsoil pH 7.5 widening to 0.5 higher at subsoil pH < 6.0. There is suggestion that subsoil pH is less in stony subsoils (Figure 9.4).

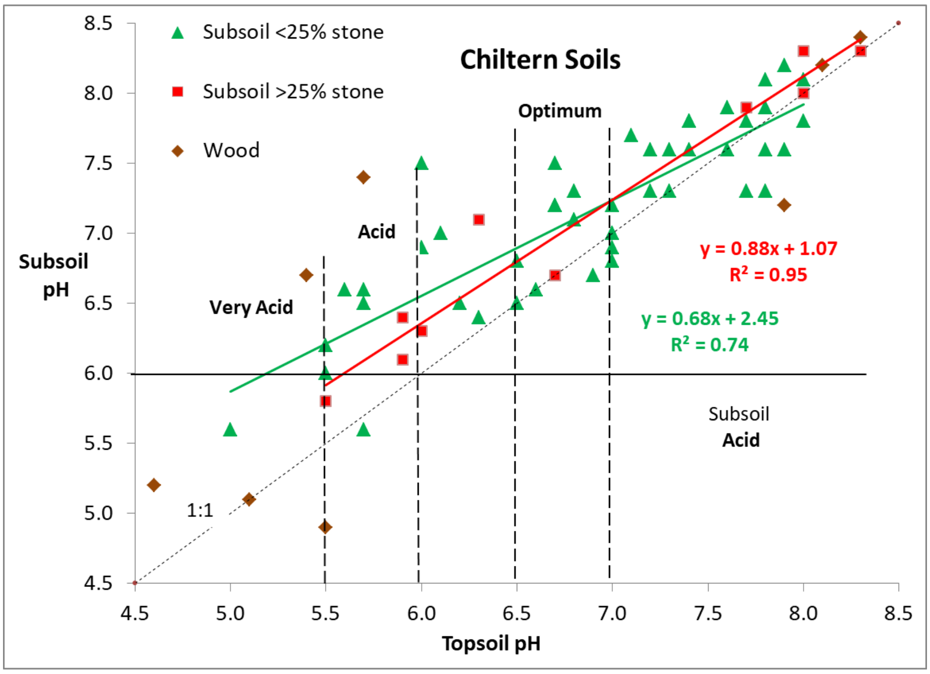


Figure 9.4: Region C, Chilterns soils: pH in topsoil and subsoil

In a woodland cluster of 5 points pH varied from 4.6-5.7 in topsoil and 4.9-6.7 in subsoil (due to variation in depth to chalk), and subsoil could be more acid than topsoil. In a nearby small arable cluster topsoil pH was 6.9-7.6.

Figure 9.5 examines the effect of subsoil texture on pH, and shows no consistent trend.

To find a best fit all data up to pH 7.4 was isolated. Equations are shown in Table 9.2 and improved by adjustment for subsoil OM (each % corresponding to 0.09 pH decrease) or subsoil stones (each 10% stones corresponding to a 0.07 pH decrease). OM and stoniness are related.

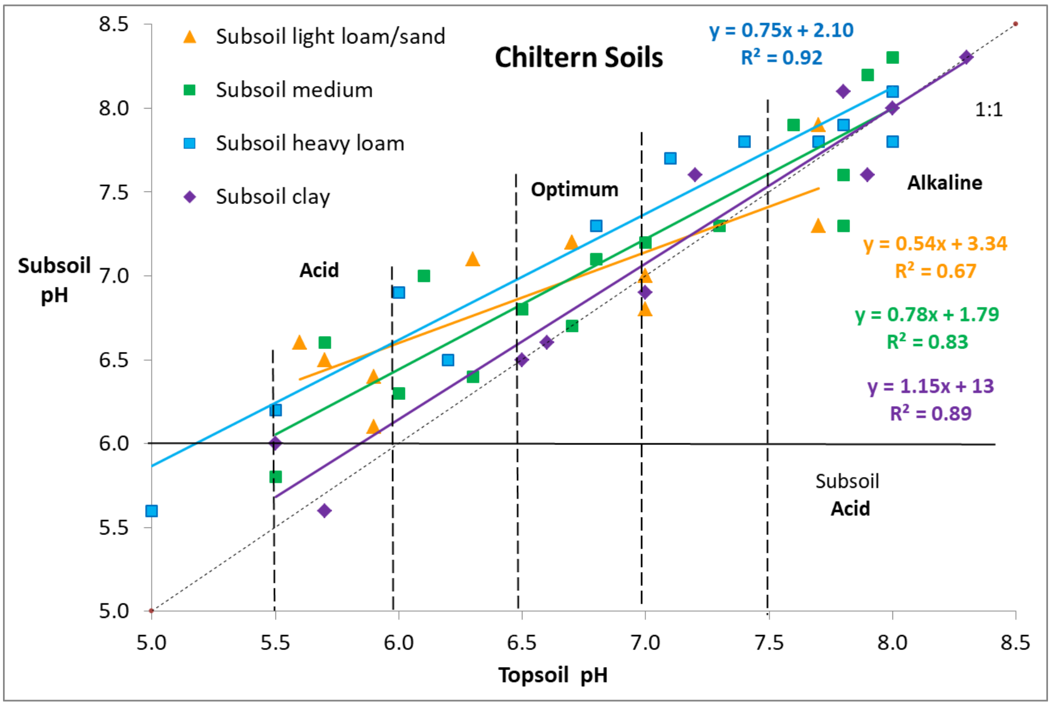


Figure 9.5; Chilterns soils: pH for different subsoil textures

Agronomic: in the Chilterns most topsoils are non-calcareous and there is a significant proportion of arable and grassland below target pH (6.5 or 6.0). Subsoil pH is higher than topsoil pH, though the difference is less on stony (and possibly clay) subsoils. Testing *subsoil* for pH is advisable if topsoil is 5.5 or less or < 6.0 with a stony or clay subsoil.

Some advisers (correctly) reduce RB209 lime recommendations for volumetric stone estimate in topsoil, however where topsoil pH is < 6.0 stony subsoils may benefit from a small additional amount ploughed under especially if going into responsive crops such as barley or legumes. The equation implies that at topsoil pH 5.8 pH is likely to be 6.3 in a stoneless subsoil but 6.1 if >25% stones.

Alkaline soils: 29% of the topsoils and 37% of upper subsoils had pH > 7.4 of which only 10% and 15% registered as calcareous according to the field HCl test, suggesting that very small amounts of $CaCO_3$ were sometimes present (possibly residual effects of past over-liming or decalcification), sufficient present to give an alkaline pH. Whenever topsoil gives a positive HCl test it is very unlikely to go acid in the foreseeable future. It is possible for an acid topsoil to develop over calcareous upper subsoil where cultivation never extends below top 20-25cm.

Organic Matter

The median topsoil OM for arable land was 3.5% (moderate) and 4.5% for grassland; overall 25% of samples were low and 12% above 6%. As expected there is trend with textural class

light loams (3.5%) < medium soil (3.8%) < heavy loam (4.1%) < clay (4.8%)
n = 14, 25 and 12 respectively.

In clusters on woodland and arable (disturbed), pH range was 4.6-5.7 and 6.9-7.6.

The median clay:SOC ratio was 10.5 for arable and 8.4 for grass, which is lower (better) than many of the other groups and there is a wide spread of SOM Index with 38% arable and 25% of grass topsoils classed as degraded (D) and 21 and 42% respectively classed very good (A). The latter occurred on a range of textures (SL – hZCL) although the degraded ones tended to be heavier (mCL to C).

The stoniness and good drainage of many Chiltern soils benefits ease of workability.

This data shows no trend of increasing topsoil OM with increased stoniness.

Subsoil OM on the Chiltern data tends to be lower than other areas (median 1.6%).

Figure 9.6 shows that subsoil OM is about 0.4x topsoil OM except on stony subsoils where subsoil can be as high as parity with topsoil (in some cases it was not possible to sample to full 50cm). The higher OM in stony upper subsoils was obvious during surveying and may be the result of concentration of organic (root) residues and earthworm burrows or greater rooting into the subsoil to compensate for a less soil in a stony top).

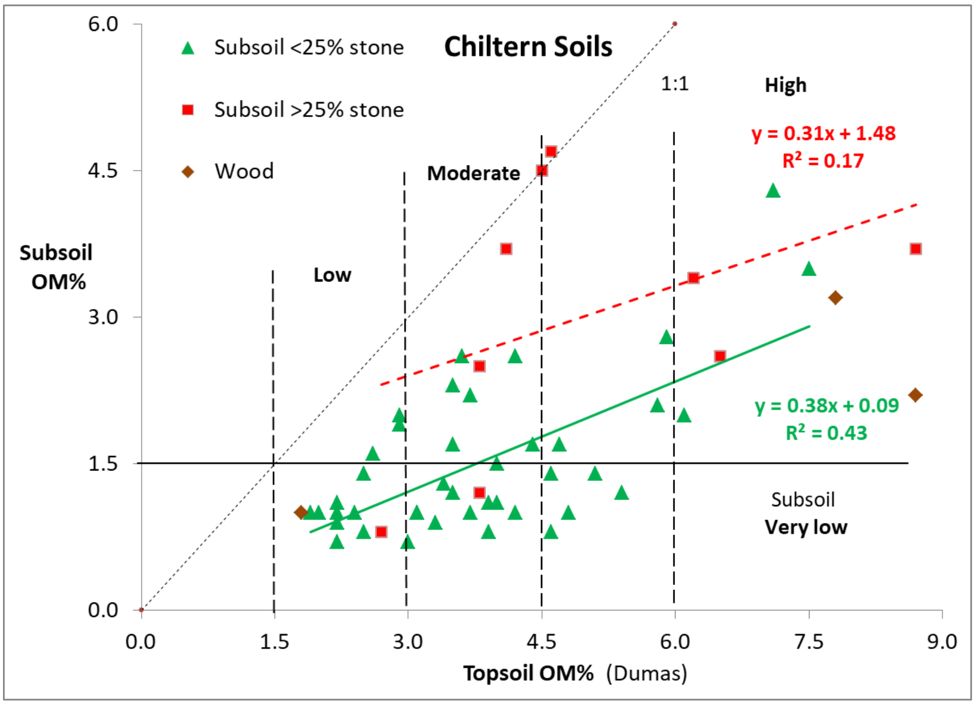


Figure 9.6: Chiltern soils: Organic Matter in topsoil and subsoil

The best fit equation shows that subsoil OM increases by 0.36 for each stone class so subsoil >25% stones would be expected to have 1.1% greater OM than stoneless subsoil.

Agronomic: organic matter levels in Chiltern topsoils varies from low to good, but the good drainage usually means the soils are easy to cultivate (especially where alkaline). The variation in OM levels is due to management and soil texture. Subsoil OM is about 0.4x topsoil OM% but only half the variation in subsoil OM is accounted for by topsoil OM% (with an adjustment for stones).

- where topsoil is low OM, subsoil is likely to be very low (<1.5%)
- where topsoil is moderate or good OM (3-6%) subsoil OM varies from very low to low (1-3%) and is difficult to predict more exactly.
- stony subsoils tend to higher OM% (or deepened topsoil), however in a carbon stock calculation when correction is made for stone content the total carbon might be no different to less stony soils of similar texture. This can be checked once the calculation method has been approved.

When subsoils are sampled for analysis, reasonable estimates should be made of stoniness (flints, pebbles or chalk). Corer or screw augers need to be used.

Table 9.2: best fit regressions. Chiltern soils

Equation (see Appendix 9)	r^2
Subsoil <25% stones: Subsoil P = Topsoil P x 0.45	0.64
Subsoil 25%+ stones: Subsoil P = Topsoil P x 0.87	0.85
Subsoil sandy to medium: Subsoil K = Topsoil K x 0.31 + 46	0.38
Subsoil K = Topsoil K x 0.31 + 10.5 x Subsoil OM%* + 26	0.47
Heavy loam subsoil : Subsoil K = Topsoil K x 0.60 + 29	0.86
Clay subsoil : Subsoil K = Topsoil K x 0.49 + 45	0.51
Heavier subsoil: Subsoil K = Topsoil K x 0.57 + stone class x 5 + 27	0.75
Subsoil sandy or light loam: Subsoil Mg = Topsoil Mg x 0.64	0.95
Subsoil medium or heavy loam: Subsoil Mg = Topsoil Mg x 0.85	0.72
Subsoil clay: Subsoil Mg = Topsoil Mg x 1.14 + 8	0.82
Subsoil pH = topsoil pH x 0.68 + 2.45	0.74
Subsoil pH = topsoil pH x 0.72 - subsoil OM%* x 0.09 + 2.34	0.75
Subsoil pH = topsoil pH x 0.72 - subsoil stone class x 0.07 + 2.17	0.75
Subsoil <25% stones: Subsoil OM = Topsoil OM x 0.40	0.42
General: Subsoil OM = topsoil OM x 0.37 + subsoil stone class x 0.36 -0.27	0.52

* capped at 6%

10. Soils on London Clay

This comprises data from Harefield into central London – the main data was 46 points in grassland sampled at 1 per ~3 ha plus; a further 40 points were in two clusters sampled at about 5 per ha on amenity grass and on a permanent grass field, plus nine samples taken under woodland. 11 profiles had disturbed topsoil.

Six of the samples were on *clayey* Lambeth Beds but most were on London Clay - a brown mottled or grey strongly-swelling clay which locally contains iron pyrites or is slightly calcareous. The overlying soils are mapped by SSEW as Wickham IV or Windsor association and are extensive in south Hertfordshire, Essex and the south Hampshire basin.

In this survey some profiles had medium loam topsoil passing to clay usually within 50cm depth while others were heavy loam or clay topsoil directly overlying clay. Accordingly Wetness Class assessment varied, 10% WCII, 42% WCIII and 48% WC IV.

Average start depth of subsoil sample was 25cm. The majority were taken by corer.

Table 10.1: Nutrient summary - grassland on London Clay – median values

	Topsoil			Upper Subsoil			Arable topsoil frequency *% in Index*					
	main	10-90%	cluster	main	10-90%	cluster	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	**16**	5-34	33	**5.6**	2-13	7.9	*26*	*19*	*30*	*16*	*7*	*2*
Potassium	**158**	65-334	169	**141**	92-247	180	*9*	*21*	*30+21*	*14*	*3*	*2*
Magnesium	**245**	149-430	540	**426**	198-638	729				*21*	*33*	*46*
K:Mg ratio	0.6	0.4-1.4	0.3	0.4	0.2-0.7	0.2						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.5**
pH	**6.6**	5.7-7.4	6.7	**7.2**	6.1-8.0	7.4	*7*	*14*	*19*	*35*	*16*	*9*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	**6.4**	4.6-10	9.1	**2.1**	1.6-3.2	2.6			*9*	*26*	*53*	*12*
clay:SOC	**6.5**	5-14	5.9		**Index**	**D-A**	*12*	*12*	*9*	*67*		

n = 44 and 20 respectively

Table 10.2: Nutrient summary - woodland and amenity on London Clay

	Topsoil			Upper Subsoil		
	wood	10-90%	amenity	wood	10-90%	amenity
Phosphorus	18	7-28	3.2	8.4	4-21	<2.5
Potassium	353	144-600	113	247	144-321	85
Magnesium	347	185-765	232	550	309-751	340
K:Mg ratio	0.8	0.4-2.2	0.6	0.4	0.3-1.0	0.3
pH	7.5	5.6-8.0	5.5	7.8	7.1-8.2	5.8
OM %	5.6	3.2-15	6.2	2.8	1.2-7.1	2.5
clay:SOC	12	4-20	6.1			

n = 9 and 22 respectively

Phosphorus

The main grass data shows wide variation in P levels, median was 16 (low index 2) and 45% of samples were below target, though based on a sample depth of 20 cm rather than the normal 7.5 or 15cm for grassland. The amenity cluster had extremely low P levels (median lower index 0) and several topsoil samples were below NRM detection limit (2.5 mg/) which are entered as 2.0. Across various woodlands the 10-90% range was 7-28 mg/l (index 0 to 3-).

Figure 10.1 indicates that on the main data, subsoil P rises very gradually in response to topsoil P. Under grassland at topsoil P < 35 mg/l (mid index 3) heavier subsoils are likely to be index 0, medium subsoils may rise more rapidly but are likely to be index 0 if topsoil is index 2 or lower (<26 mg P/l).

P in woodland subsoils rose more sharply with topsoil P. Two thirds were disturbed land although subsoil was London Clay.

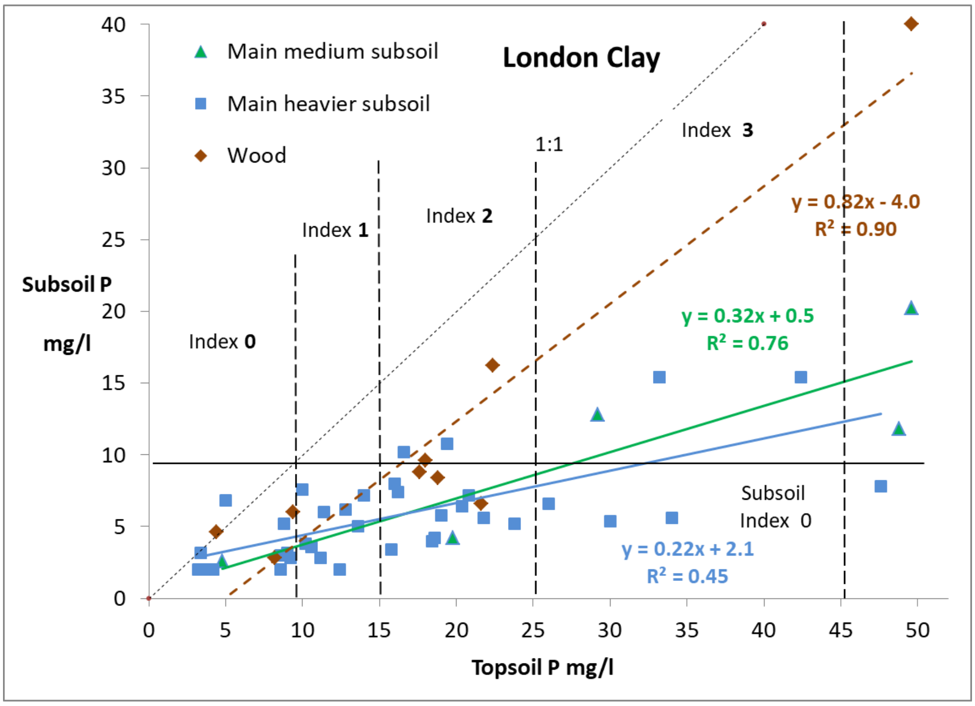


Figure 10.1: London Clay main grassland data and woodland : phosphorous in topsoil and subsoil. One data point {92,74 mg/l} is excluded (grass covered with compost).

The cluster data is shown on Figure 10.2. Nearly all samples were taken by corer to standard depths 0-20 and 25-50cm. The amenity data shows that at topsoil index 0 subsoil will be lower index 0. The other cluster on an organic heavy clay loam over clay soil indicates a significant range of P values within the same field (10-90% range was 21-43 mg P/l). Subsoil P varies proportionately to topsoil P though the latter accounts for less than 50% of the variation.

To derive the best fit equation, main data with heavier subsoil and cluster data was combined and main data with medium subsoil was combined with amenity (usually medium textured subsoil).

Equations are in Table 10.3. The slope is 0.2x for clay subsoils and 0.3 for medium subsoils. Inclusion of subsoil OM% improves r^2 somewhat with each 1% increase in SOM corresponding to $+\Delta 0.9$ mg/l subsoil P.

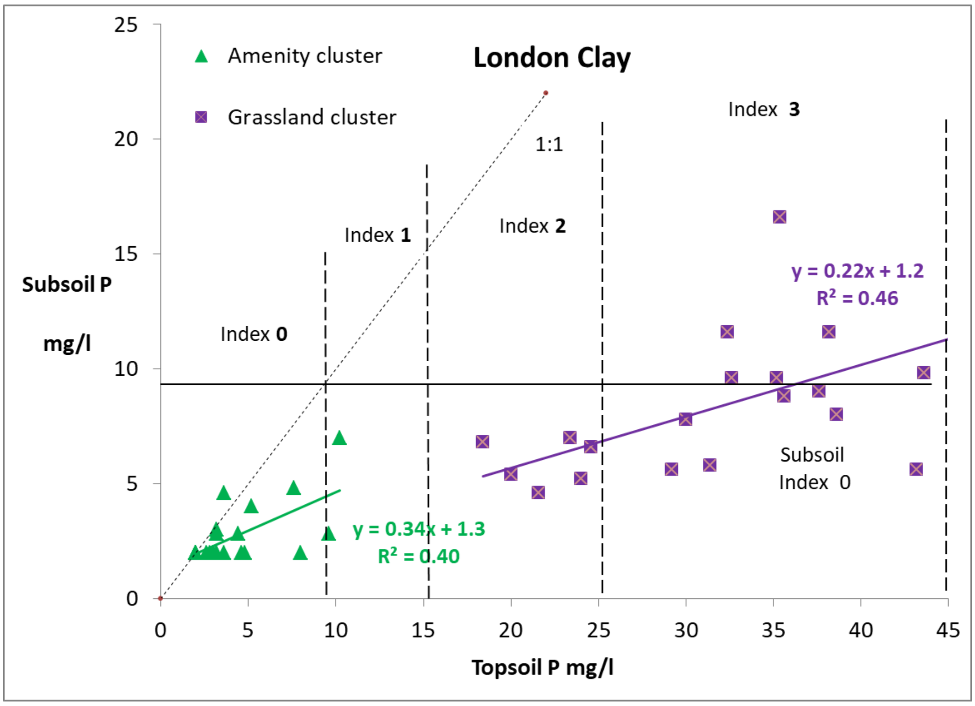


Figure 10.2: London Clay cluster samples: phosphorous in topsoil and subsoil. (One data point {64,17 mg/l} not shown).

The agronomic conclusion that on grassland when topsoil (0-20cm) is <35 mg/l, subsoil P is unlikely to exceed index 0 in clay textured or heavy loam upper subsoils.

Potassium

In the main grass data median topsoil K was158 mg/l (index 2-); 30% were below target index and 19% index 3 or more. The grass cluster had a similar median (169 mg/l). Potassium on the amenity cluster was lower, and in woodland tended to be high.

Figure 10.3 shows significant variability in topsoil K within clusters on the same grass field or in adjoining amenity areas. The former had a 10-90% range of 144-243 mg/l despite very similar soil type. Possibly there was history of uneven manuring or grazing.

In the main data topsoil K is influenced by topsoil texture class :

medium 130 mg/l   <   heavy loam 160 mg/l   <<   clay 241 mg/l
n = 18,20 and 4 respectively

Subsoil K tended to be lower than topsoil K except on the grassland cluster field.

Subsoil K correlated with topsoil K. On the main grassland the minority of samples with medium subsoil were too few to demonstrate that they behaved significantly differently to the main data with heavy loam (loam over clay) or clay subsoils. The fitted line has an intercept of 57 mg/l subsoil K at theoretical zero topsoil K.

The amenity cluster, though generally lower in K, follows a similar line (Figure 10.4).

However the grassland cluster was unusual in exhibiting an almost 1:1 subsoil: topsoil relationship. One possible reason is the high organic matter in the topsoil in this field, which might result in greater movement of K into the subsoil.

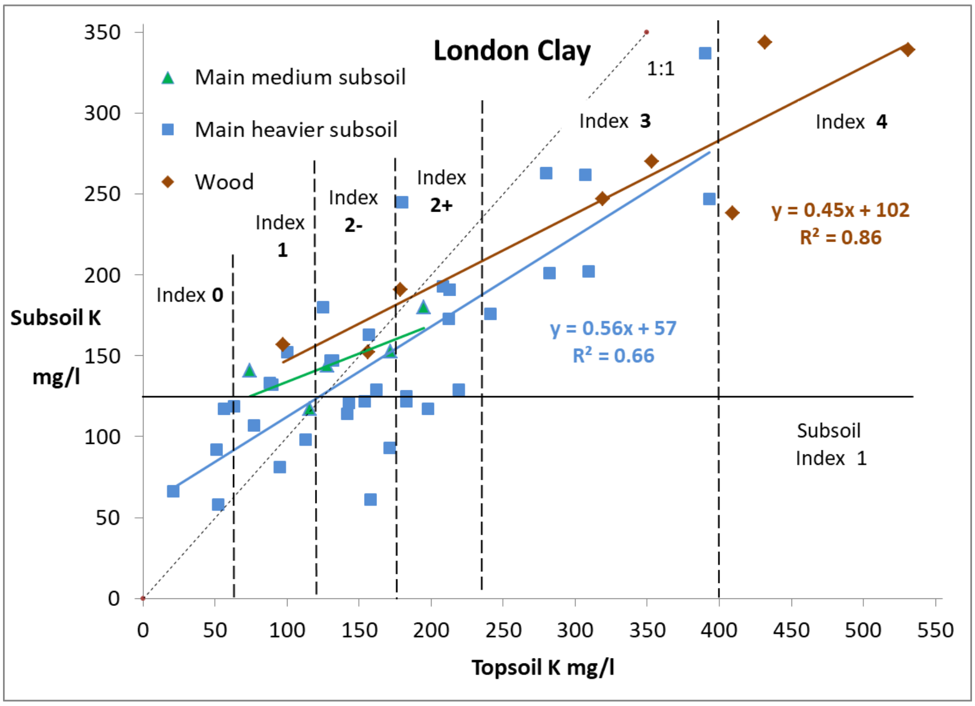


Figure 10.3 : London Clay main grassland data and woodland : potassium in topsoil and subsoil. (One high point for woodland {877,450} not shown).

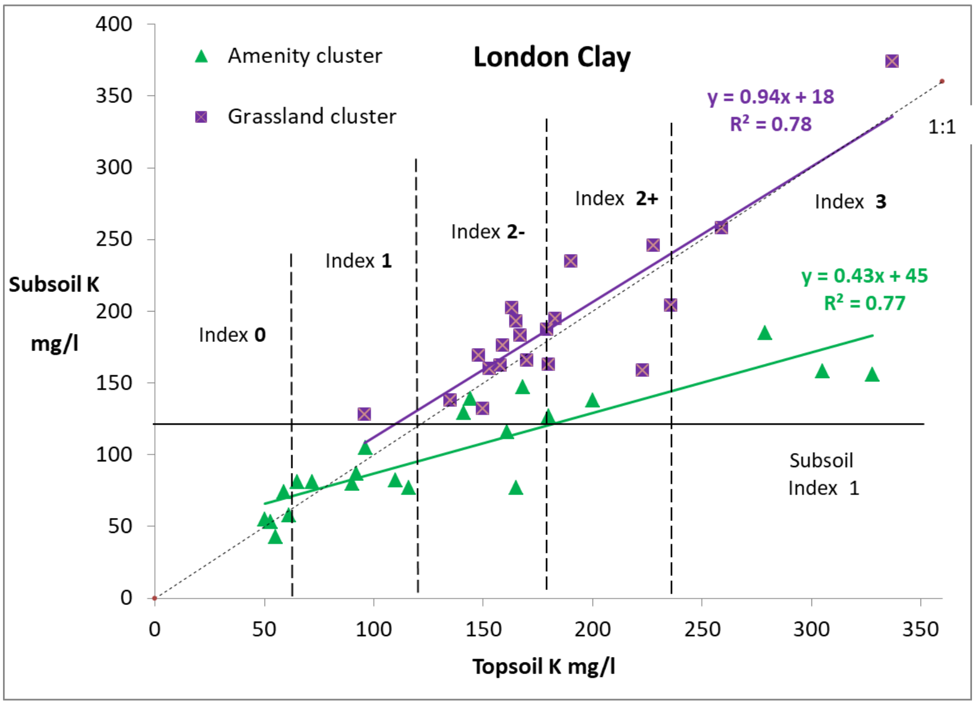


Figure 10.4: London Clay clusters : potassium in topsoil and subsoil.

For assessment of texture influence the grassland cluster was excluded and the main data and amenity cluster combined. *Topsoil* K increased with textural class; medians were

medium loams 116 mg/l < heavy loams 171 mg/l < clays 241 mg/l
(n = 37, 21 and 5 respectively)

Figure 10.5 shows that *subsoil* texture also has a slight influence: the intercept is similar for heavy loam and clay subsoils but lower for medium subsoils (as normally found). There was no influence of subsoil OM. Fitted equations gave intercept of 37 mg/l K for medium subsoils and 51 mg/l for heavier subsoils (Table 10.3).

There was no relationship of subsoil K to subsoil pH on any of the data sets.

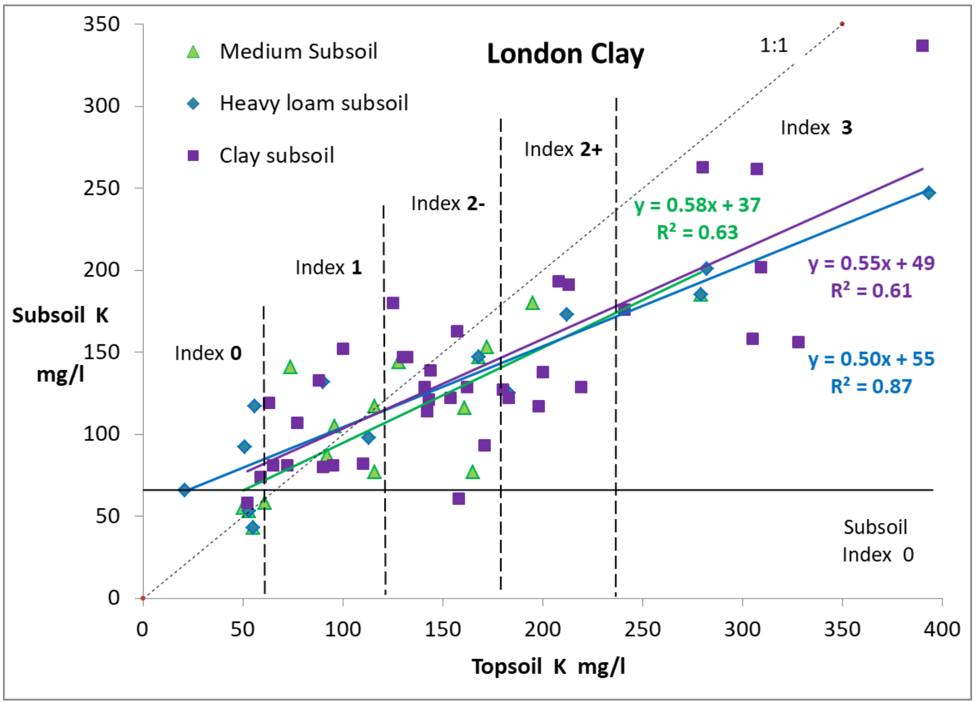


Figure 10.5: London Clay: potassium in topsoil and subsoil.

Agronomic: grassland soils on London Clay (sampled to 20cm) have K levels varying from index 1 to 3 due partly to textural variation of topsoil and (mainly) due to different management (some grassland was "rough" and likely unfertilised).

Where topsoil was index 2+ the subsoil is likely to be 2- * ; at topsoil index 2- subsoil is in 2-/1+ region and at topsoil is index 1 subsoil is parity. Index 0 in topsoil was rare but possible and in such cases the subsoil K was somewhat higher.

The unavailable measured potassium in the London Clay is likely to exceed 60 mg/l.

* although where topsoil OM% is very high the subsoil K may be similar to topsoil

Magnesium

Magnesium levels are very high on this data - median levels in topsoil were 232 mg/l for the amenity cluster, 245 mg/l (index 4) for main grassland rising to 347 mg/l under woodland and 539 mg/l (index 6) on the grassland cluster with organic topsoil. There was variation in the grass cluster (10-90% range 427-651 mg/l) though no points were below index 3 and 46% were index 5 or above. On the amenity cluster the lowest value was 99 mg/l.

Subsoil Mg levels are even higher than topsoil in all data sets; the main data median is 426 mg/l (index 6). The relationship of subsoil to topsoil Mg was similar in all grass data sets, and so these are combined and shown in Figure 10.6. All lines are forced through origin with little loss of r^2. The medium subsoil fits to the same line as clay subsoil, the heavy loam (or medium over clay) upper subsoils have a steeper slope which is difficult to explain. The simplest relation is the subsoil Mg is 1.45x topsoil Mg, which is similar to other data sets on clays. There is no relationship of subsoil Mg and pH (nor topsoil Mg and pH).

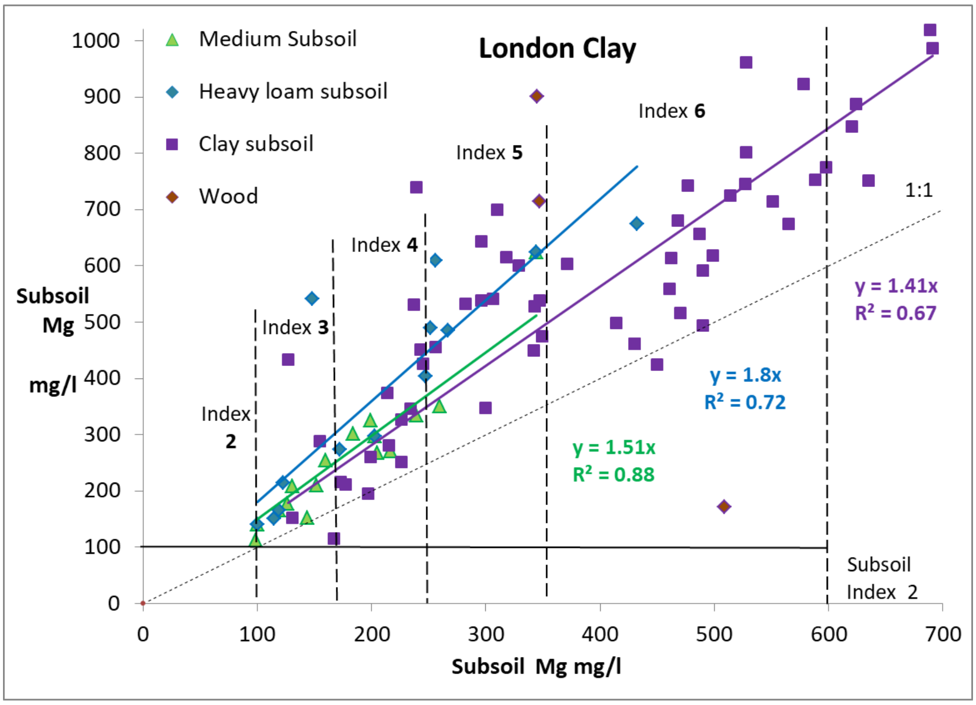


Figure 10.6 : London Clay : magnesium in topsoil and subsoil

For comparison with other geological clays only 1 in 3 of the cluster points were included and disturbed profiles excluded to get a more representative balanced data set. As shown in reference Table 2.6 the subsoil median, 462 mg/l is higher than all the other clays listed and the subsoil K:Mg ratio lowest (0.3). We cannot be sure the extent that the high magnesium is due to clay mineralogy or the high prevalence of (grazed) grassland. Some data on arable soils formed on London Clay is worth investigation.

pH

In the main data median topsoil pH was 6.6. 21% of samples were < pH 6.0. The grass cluster median was pH 6.7 (10-90% 6.4-7.1) with no acid samples whereas the amenity cluster was mainly acid (and pH might be even lower if sampled to standard 7.5cm depth). Woodland was alkaline (median pH 7.5) because six of the nine profiles were disturbed and contained some chalk (presumably added).

Subsoil pH was always greater than topsoil pH. The main data shows convergence at pH 8 with subsoil >0.5 units higher at topsoil pH < 6.0 (Figure 10.7).

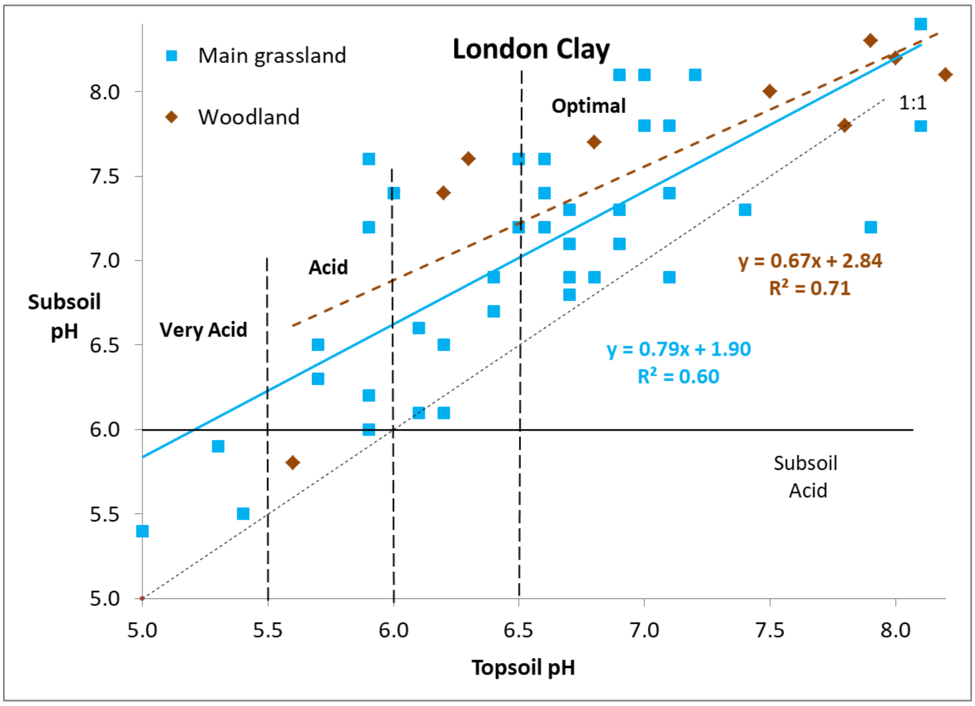


Figure 10.7: London Clay main grass data and woodland : pH of topsoil and subsoil.

In the grassland cluster (Figure 10.8) the subsoil pH was consistently 0.7 higher and up to 7.7 although no $CaCO_3$ was present in field observations. In the amenity cluster, at topsoil <5.5 the subsoil pH was somewhat unpredictable – varying between parity (as acid as) topsoil to 1.0 units higher.

Equations fitted (Table 10.3) show a large negative influence of subsoil OM% on subsoil pH, which might be coincidental in that the more acid samples tend to have lower OM%.

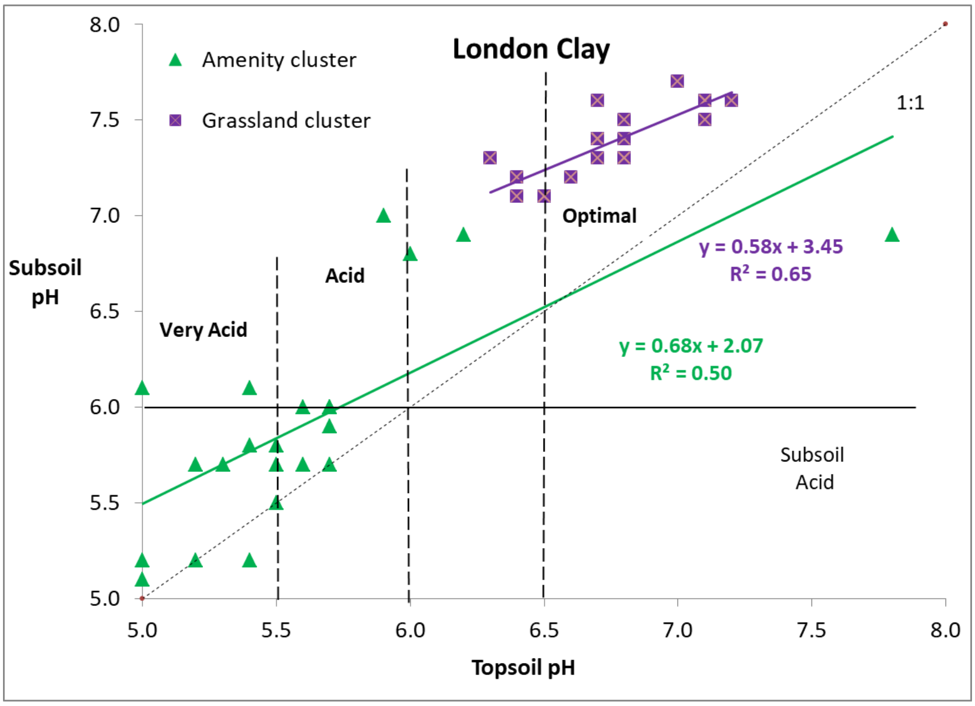


Figure 10.8 London Clay cluster data: pH of topsoil and subsoil.

The main agronomic point is that where topsoil pH is 5.5 or lower (to 20cm) it is important to test subsoil pH as well to ascertain how much lime it needs.

On London Clay the few calcareous profiles were stony, contained chalk and very likely are disturbed. Excluding these (in the balanced data set) only 2% of topsoils were pH >7.4 and 22% of subsoils indicating that London Clay is less likely to be alkaline that many of the older clay formations (reference Table 2.6).

Organic Matter

The main grass cluster had median topsoil OM of 6.4% (high by SSEW system), the amenity field slightly lower (5.6%) and the grass cluster field high (9.1% with 10-90% range of 7.5-9.8%). Levels on woodland sites were extremely variable (median 5.6%).

Clay:SOC ratio averaged 6 on main grassland and 67% of data would be classed "very good" structural condition (A) with the remainder spread over the other 3 classes. On both clusters clay:SOC was about 6 and almost all points are in the A category.

Subsoil OM% on the main data median was 2.1%; the grass cluster 2.6% and amenity cluster 2.8%. On the main data subsoil OM was unrelated to topsoil OM (Figure 10.9) and rarely exceeded 3% even where topsoil was organic (>10% OM).

On the woodland the subsoil OM is proportionate to topsoil though with wide scatter from the fitted line.

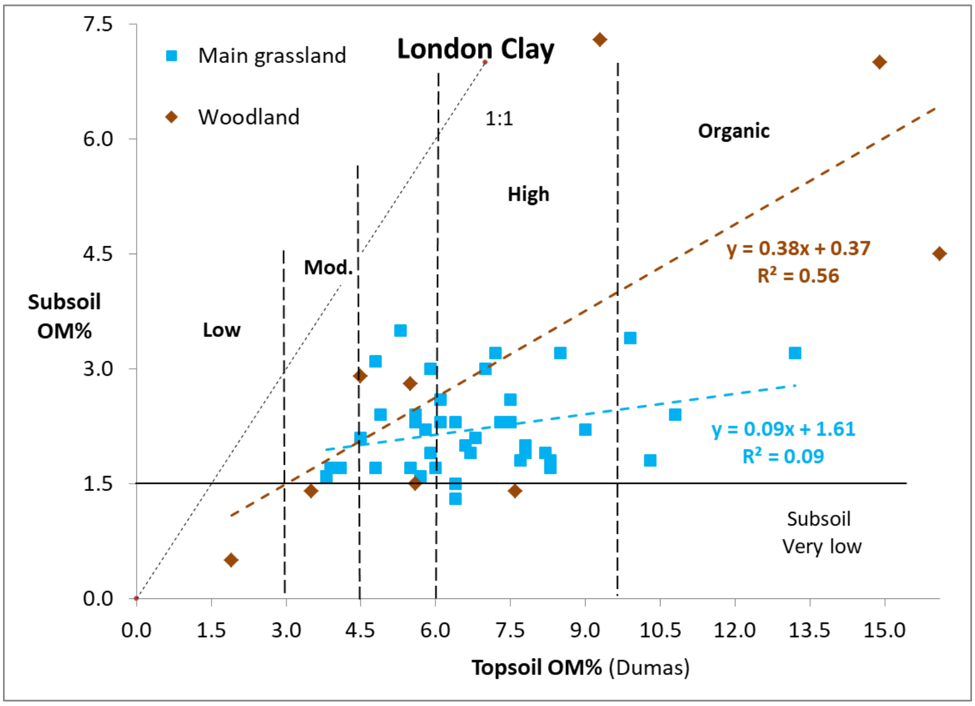


Figure 10.9: London Clay: main data and woodland: OM in topsoil and subsoil

On the cluster data (Figure 10.10), subsoil OM was related to topsoil OM, but proportionately higher on the amenity site. This indicates more transfer of organic matter into loamy compared to clay subsoils.

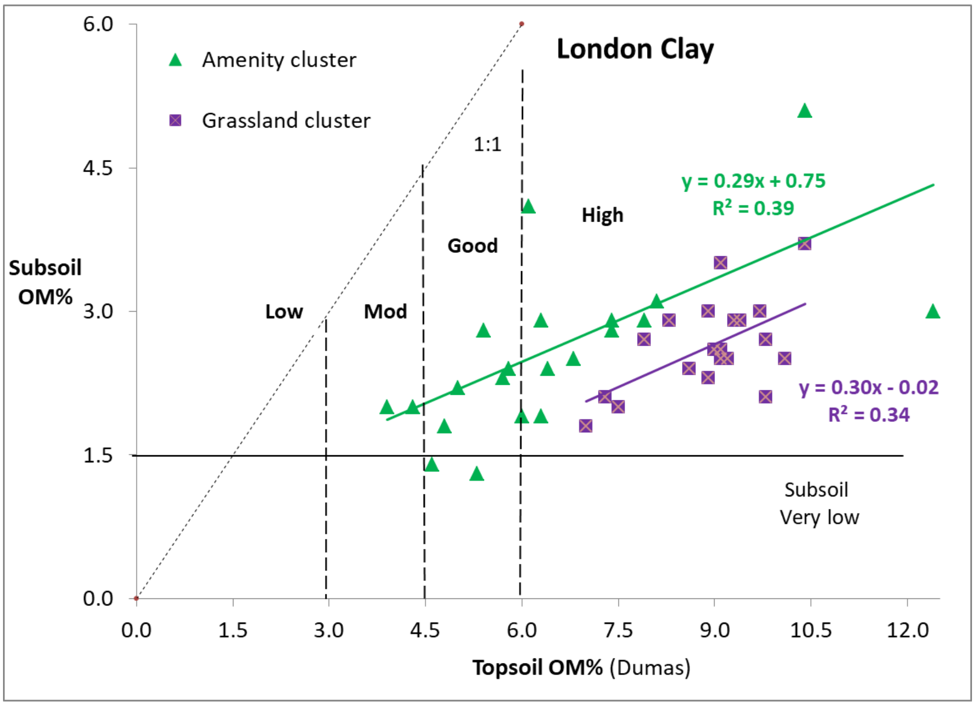


Figure 10.10: Region C, London Clay: cluster data: Organic Matter in topsoil and subsoil

Agronomic: in grassland on London Clay topsoil OM% levels are good and normally in range 4.5% to 10%. Subsoil OM% is difficult to predict from topsoil OM% but usually lies between 1.5 and 3.0%. The proportionate increase of subsoil OM with increasing topsoil OM% is no more than 0.3 and probably greater in medium than clay subsoils.

Table 10.3: best fit regressions. Grassland soils on London Clay

Equation (see Appendix 10)	r^2
Medium or heavy loam subsoil	
Subsoil P = Topsoil P x 0.30 + 1.4	0.86
Subsoil P = Topsoil P x 0.30 + Subsoil OM x 0.87 - 0.73	0.88
Clay subsoil	
Subsoil P = Topsoil P x 0.20 + 2.3	0.50
Subsoil P = Topsoil P x 0.20 + Subsoil OM x 0.86 + 0.21	0.53
Medium subsoil	
Subsoil K = Topsoil K x 0.58 + 37	0.63
Heavy loam or clay subsoil	
Subsoil K = Topsoil K x 0.53 + 51	0.68
Subsoil Mg = Topsoil Mg x 1.45	0.75
Heavy loam or clay subsoils	
Subsoil pH = Topsoil pH x 0.90 + 1.08	0.68
Subsoil pH = Topsoil pH x 0.82 - Subsoil OM x 0.32 + 2.38	0.75
Subsoil OM% = Topsoil OM% x 0.30 (+ 0.75 if medium textured)	0.36

11. Soils on Alluvium

This comprises 21 data from along the whole transept. Alluvium occurs in narrow strips adjoining rivers across all solid geologies. 3 data were arable, 7 in woods and 11 under grassland. Arable use is possible where good drainage has minimised risk of high groundwater.

Soil associations were Fladbury 1 and 3, Bishampton, Wickham 2 and Denchworth associations (in the latter two SSEW maps do not map the alluvium separately).

15 of the samples had heavy loam or clay topsoils and 1 was loamy peat. Most subsoils were heavy. 62% were judged WC IV and 31% WC III.

Average start depth of subsoil sampling was 25cm and half samples were taken by corer and half by auger. Arable and grassland data combined in table 11.1

Table 11.1: Nutrient summary - Soils on Alluvium – median values

	Topsoil			Upper Subsoil			Topsoil frequency *% in Index*					
	main	10-90%	wood	main	10-90%	wood	**0**	**1**	**2**	**3**	**4**	**5+**
Phosphorus	**14**	6-20	13	**6**	3-10	13	*36*	*21*	*22*	*21*		
Potassium	**128**	67-195	112	**108**	68-189	78	*7*	*36*	*29+21*	*7*		
Magnesium	**190**	72-319	113	**171**	57-323	161		*7*	*14*	*21*	*21*	*36*
K:Mg ratio	0.7	0.4-1.1	1.1	0.7	0.2-2.2	0.8						
							<5.5	**5.5-5.9**	**6-6.4**	**6.5-6.9**	**7-7.5**	**>7.4**
pH	**6.6**	5.7-7.8	7.0	**7.3**	6.11-7.8	7.0	*7*	*21*	*14*	*21*	*7*	*29*
Organic							**<1.5**	**1.5-2.9**	**3-4.4**	**4.5-6**	**6-9**	**10%+**
Matter %	**7.1**	4.2-13	8.9	**3.6**	1.5-6.3	7.0			*14*	*14*	*43*	*29*
Clay:SOC	**8.6**	4-18	5.0		**Index**	**D-A**	*21*	*7*	*29*	*43*		

n = 14 and 7 respectively

Phosphorus

Median topsoil P on grass/arable data was 14 mg/l (index 1); 21% of samples were index 1 and 36% index 0 (sampled to 20cm+). Some arable samples were above target index.

Subsoil P was usually index 0. Figure 11.1 shows that on grass/arable data subsoil P correlates weakly with topsoil P and was unlikely to be > 9 mg/l unless topsoil P exceeded 30 mg/l. On only one datum did subsoil P exceed topsoil P, for reasons that are unclear.

The woodland data shows high P levels in subsoil, about 0.65 x topsoil P which corresponds to proportionately greater organic matter in woodland subsoils. Average P levels in woodland were comparable or greater than grassland.

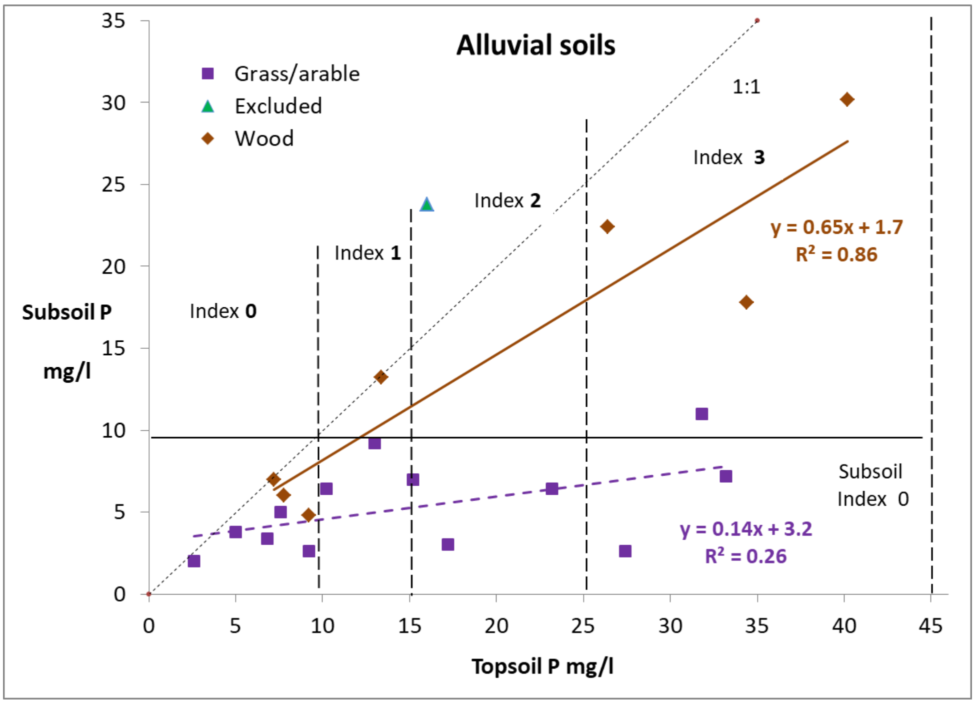


Figure 11.1: Soils on Alluvium : phosphorus in topsoil and subsoil

Potassium

Median topsoil K was 128 mg/l (low end of index 2-) and 43% of grass/arable samples were below target index. Median level was higher on clay topsoil (188 mg/l) than on heavy loam (92) or medium topsoil (106 mg/l). n = 7, 5 and 2.

Subsoil texture was predominantly clay and Figure 11.2 shows that subsoil K relates to topsoil K similarly to other clay data sets: subsoil K equals topsoil K at index 1 and the line gives an intercept of 40 mg/l.

However under woodland there is little correlation; the datum with subsoil K more than double the topsoil was loamy peat overlying organic clay. Overall K levels in woodland are slightly but not significantly lower than in grassland.

Topsoil K correlated with topsoil pH: each unit rise Δ46 mg/l topsoil K (r^2 = 0.57)

Subsoil K correlated with subsoil pH: each unit rise Δ37 mg/l topsoil K (r^2 = 0.39)

The strongest correlation is topsoil K and *subsoil* pH: each unit rise Δ62 mg/l topsoil K (Figure 11.3). This reinforces a strong influence of parent material with the main shift occurring between pH 7 and 8 reflecting absence or persistence of $CaCO_3$ in the upper subsoil.

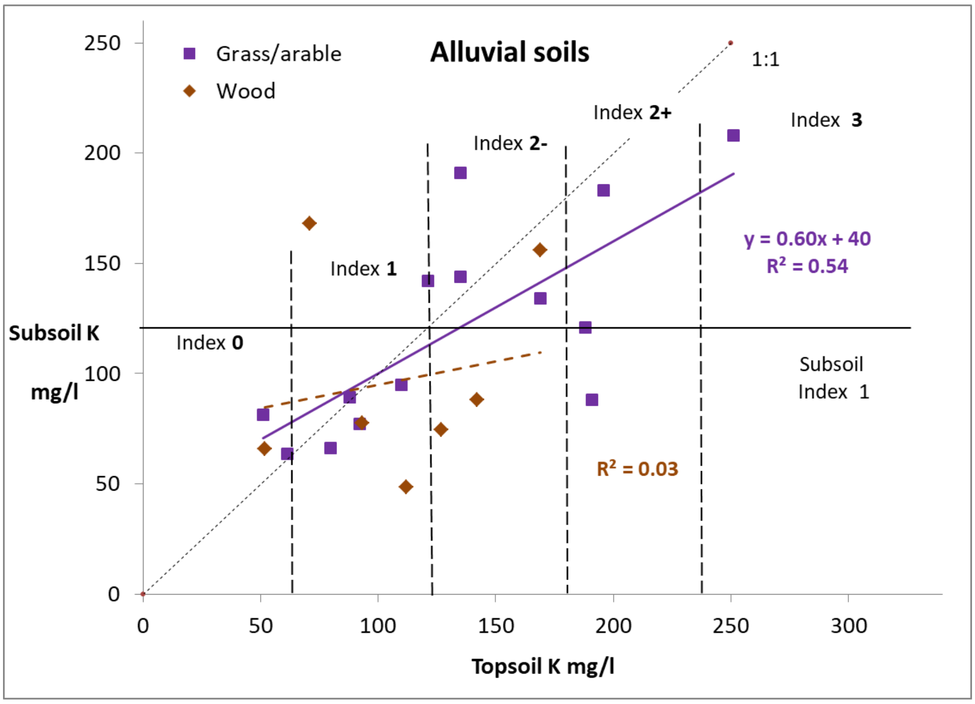


Figure 11.2: Soils on Alluvium : potassium in topsoil and subsoil

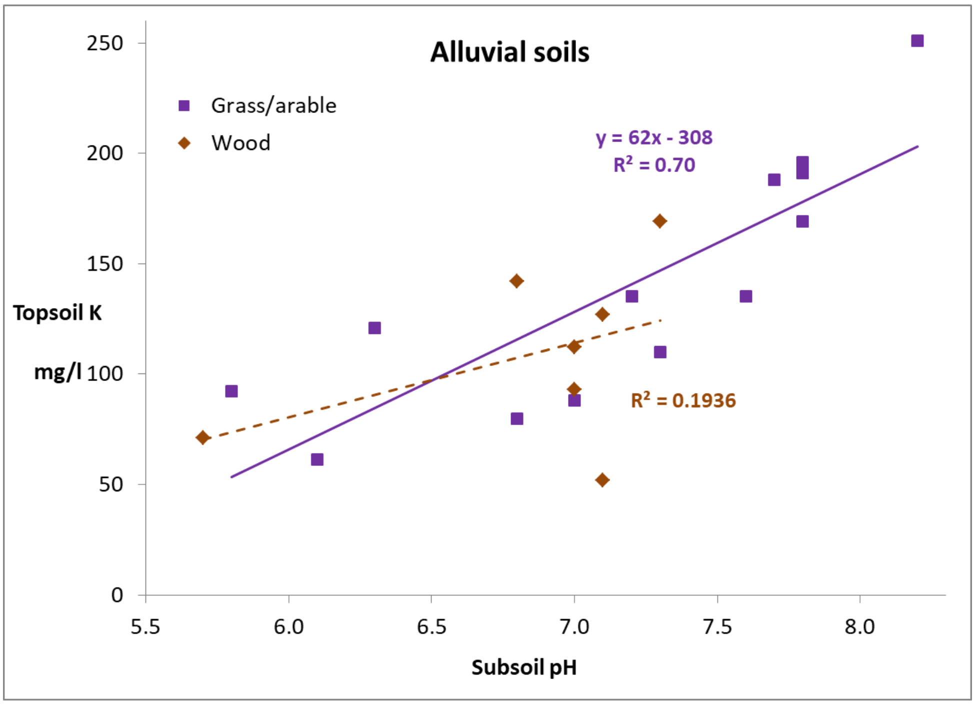


Figure 11.3: soils Region C soils on clayey Alluvium : potassium in topsoil and pH of subsoil (sample with light loam subsoil excluded {51,81}).

Agronomic: if topsoil K is index 2- subsoil is likely >100 mg/l and at index 3 will be index 2. There is no indication that alluvial soils behave differently to other soils of similar texture.

Magnesium

Median topsoil Mg was 190 mg/l (index 4) but with wide range. Lower levels tended to be on medium loams and higher ones on clay-textured topsoils.

Subsoil Mg is strongly correlated with topsoil Mg, being somewhat lower than topsoil at low topsoil Mg and vice versa at high topsoil Mg. Woodland shows a similar pattern apart from the anomalous peat over clay profile {71,222}. Subsoil Mg levels in seem related to the underlying geology (reference Table 2.5). This is to be expected if the alluvium was derived from local material. The average subsoil Mg in Alluvium grouped by solid geology is :

Chalk 36 mg/l (3), < Rutland and Whitby Mudstone 75 (3) < Dyrham Siltstone 166 (6) < Peterborough Mudstone 240 (3), Kimmeridge Clay 259 (1), Weymouth Mudstone 393 (2)
n in ( )

K:Mg ratios were <0.5 in 30% of the grass/arable topsoils and subsoils and these alluvial soils may be susceptible to Mg-induced K deficiency but though less risk than alluvial soils of the Midlands which have extremely high Mg levels (NW Report).

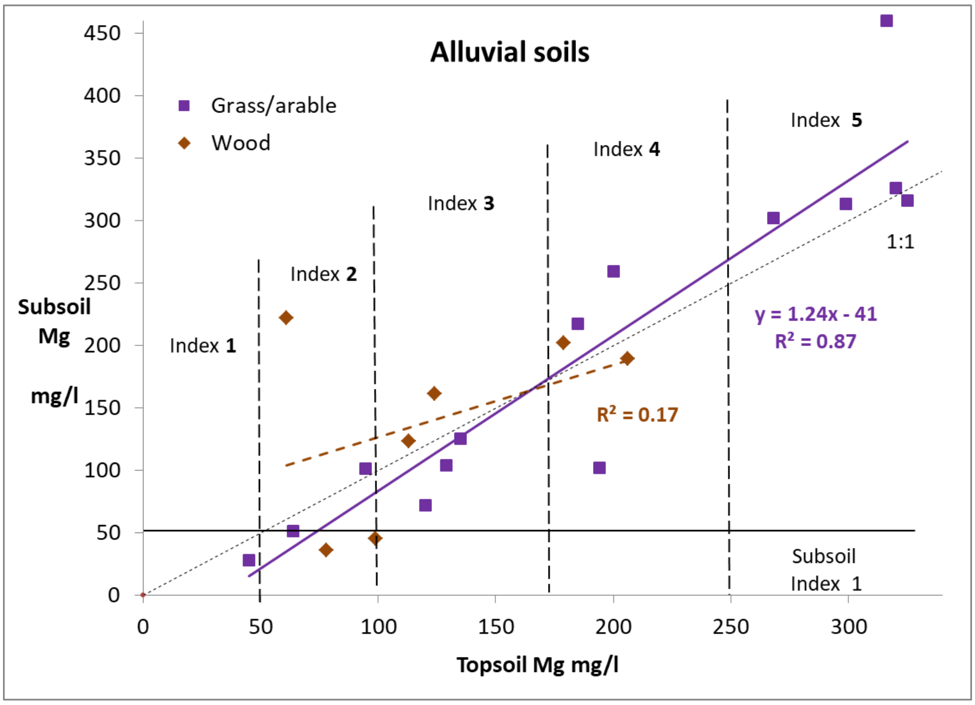


Figure 11.4:soils on Alluvium: Magnesium in topsoil and subsoil

pH

Median pH of topsoil was 6.6 with wide range; 29% of grass/arable samples were acid (pH < 6.0) and 29% alkaline (pH >7.4).

Subsoil pH (Figure 11.5) shows the typical pattern of parity at topsoil pH 7.5, widening to 0.7 greater subsoil pH at topsoil < 6.0. Only 50% of variance is explained by the equation and is not improved by factoring in subsoil or topsoil OM%. 50% of subsoils were alkaline (pH >7.4) though only 29% registered as calcareous by the field method (HCl).

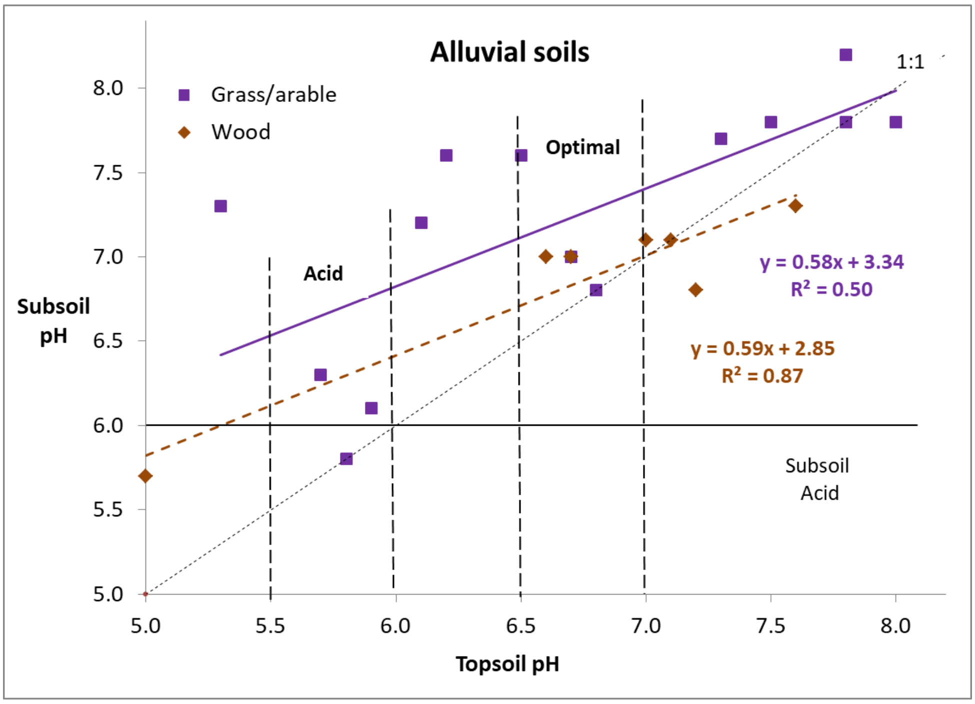


Figure 11.5: soils on Alluvium: pH in topsoil and subsoil.

pH in woodland subsoils seems closer to topsoil pH than grass/arable data, a trend also found in other data sets.

Agronomic: alluvial soils seem no different in their pH behaviour to the surrounding non-alluvial soils and likely to be of similar pH though not always.

Organic Matter

Median topsoil OM on Alluvium is higher than other soil types both under grass/arable (7.1%) and woodland (9.1%). This is as expected because of increased wetness. OM in the topsoil ranged from 4-40%. Clay:SOC ratio averaged 8.5 and so 70% of the samples were classed as good or very good structural condition and 21% as degraded.

Subsoil OM is also higher than in other clays (median 3.6%) and related to topsoil OM. At topsoil OM 6% subsoil is 0.5x topsoil on grass or woodland, but as topsoil OM increases, the subsoil OM increases by greater proportion under wood. On grass/arable sites with organic topsoil (10%+) subsoil OM is unlikely to exceed 6% though difficult to predict more precisely.

Sampling method and specification of depth is very important when sampling high organic matter soils.

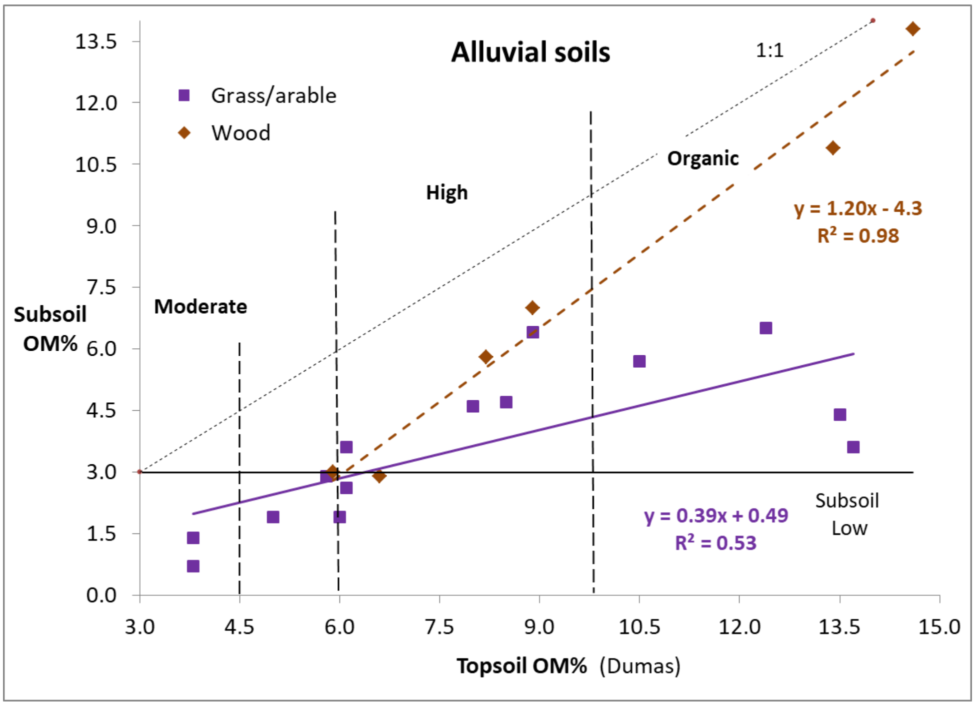


Figure 11.6: soils on Alluvium: organic matter in topsoil and subsoil. (1 woodland point excluded {41,15}).

Table 11.2: best fit regressions. Alluvial soils (mainly heavy)

Equation (see Appendix 11)		r^2
Grass/arable	Subsoil P = Topsoil P x 0.14 + 3.2	0.26
Woodland:	Subsoil P = Topsoil P x 0.65 + 1.7	0.86
Grass/arable	Subsoil K = Topsoil K x 0.60 + 40	0.54
Heavy subsoil	Topsoil K = Subsoil pH x 62 - 308	0.70
Grass/arable	Subsoil Mg = Topsoil Mg x 1.24 - 41	0.87
Grass/arable	Subsoil pH = topsoil pH x 0.58 + 3.34	0.58
Woodland	Subsoil pH = topsoil pH x 0.59 + 2.85	0.87
Grass/arable	Subsoil OM = Topsoil OM x 0.39 + 0.49	0.53
Woodland <15% OM	Subsoil OM = Topsoil OM x 1.2 - 0.43	

12. Phosphorus overview

Region C: South-Central England

Phosphorus in topsoil

On arable land the representative average for the whole region was 22 mg P/l (index 2), however *40% of samples were below target index,* spread across all geological groups except the Chilterns. 31% of samples were above index 2 (66% in the Chilterns) with a few very high P values in most data sets, skewing the means so averages are cited as median values in this summary. The PAAG 2019 laboratory survey found less to be deficient (22%), though sampled to 15cm rather than the full 20-30cm depth of topsoil in this study.

On grassland the median P was lower than arable at 14 mg/l (index 1) with *51% of samples below target,* again measured on a deeper sample (20cm+) than is usually taken (7.5 or 15cm). PAAG (2019) reported 34% of grassland as deficient.

Topsoil P could vary significantly within cluster samples (4-5 per hectare); examples of 10-90% range of 8-13 mg/l in an arable field and 21-43 mg/l in a grass field. On no data group did P correlate with topsoil pH and there was unclear influence of clay mineralogy, though P seems to be lower on the Charmouth (Lias) Mudstone and iron-rich soils (Table 12.1).

Table 12.1: Geological grouping and phosphorus status (median values in mg/l)

	Arable data				Grassland data					
(BGS maps)	topsoil	subsoil	<Ind.2	>Ind 2	topsoil	subsoil	<Ind.2	>Ind.2	n	n
Charmouth Mudstone	**13** (1)	6	81%	4%	**10** (1)	5.0	100%	-	*56*	*4*
Whitby Mudstone	**28** (3)	26	20%	60%	**6** (0)	2.5	20%	60%	*6*	*3*
Horsehay Sand	**13** (1)	12	75%	-	**17** (2)	16	-	-	*4*	*2*
Limestone & Clay	**-**	-	-	-	**8.6** (0)	4.2	64%	-		*11*
Glacial Deposits	**20** (2)	7	32%	43%	**5** (0)	4.0	88%	12%	*29*	*6*
Oxfordian Clays	**20** (2)	6	23%	30%	**4** (0)	3.8	83%	-	*43*	*18*
Ampthill & Kimmeridge	**18** (2)	8.2	30%	20%	**21** (2)	8.4	27%	54%	*10*	*11*
Chilterns	**45** (4)	15	-	66%	**21** (2)	10	29%	38%	*32*	*24*
London Clay	**-**	-	-	-	**16** (2)	5.5	45%	25%		*43*
Alluvium	**27** (3)	6	33%	67%	**13** (1)	5.0	63%	-	*3*	*11*
Weighted median	**22 (2)**	8.7	40%	31%	**14** (1)	6.2	52%	21%	*183*	*134*

Topsoil texture was influential On Oxford Clays and the Chilterns with a decrease of 7 mg P/l per texture category. All data (including clusters) is compared in Table 12.2 and shows that compared to other textures clays have 9mg/l less P in topsoil, and most likely to be index 1 even on arable land. Woodland was marginally lower in P than grassland (median 13 mg/l).

Table 12.2 Region C: Topsoil Texture and phosphorus, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	28 (39)	7 (24)	18	*13*	*9*	*2*
2	SCL, mCL, mZCL	23 (35)	17 (19)	8 (14)	*24*	*36*	*9*
3	hCL, hZCL	23 (30)	20 (26)	15 (20)	*44*	*75*	*28*
4	C, ZC	15 (18)	11 (15)	7 (10)	*104*	*32*	*10*
	Overall	**18** (24)	**16** (22)	**13** (17)	*185*	*152*	*49*

3 > 4 P(T<=t) two-tail = 0.002, 0.008 and 0.022

arable data 1 versus 2 is not statistically significant (P = 0.57)

On heavy loam and clay topsoils there was a relationship of organic matter with P, each 1% OM (up to 10%) corresponding to +Δ1.9 mg/l topsoil P but with large uncertainty in factor (0.6-3.3); see Appendix AG) This trend might be linked to clays tending to lower OM% than heavy loam topsoils (see OM overview).

Phosphorus in subsoil

Subsoil P averaged 8.7 mg/l arable and 6.2 mg/l grass. Alkaline / lime rich (clay) subsoils were nearly always <5 mg/l. On arable land, light loam topsoil was associated with much higher subsoil P and across all land uses clay topsoil was associated with lower subsoil P than medium or heavy loam topsoils (Table 12.3).

Table 12.3 Region C: *Topsoil* texture and Subsoil phosphorus, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, fSL, SZL	25 (26)	7 (13)	11	*13*	*11*	*2*
2	SCL, mCL, mZCL	9 (20)	6 (8)	6 (11)	*24*	*39*	*9*
3	hCL, hZCL	8 (13)	6 (10)	8 (10)	*40*	*73*	*28*
4	C, ZC	6 (7)	5 (7)	5 (6)	*104*	*32*	*10*
	Overall	**7** (11)	**6** (9)	**7** (10)	*181*	*155*	*49*

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.

Table 12.4 Region C: *Subsoil* texture and Subsoil phosphorus, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
0	LS,S	23 (24)	26	-	*4*	*1*	-
1	SL, SZL	21 (25)	7 (12)	14	*10*	*7*	*1*
2	SCL, mCL, mZCL	16 (26)	8 (11)	13 (12)	*14*	*17*	*3*
3	hCL, hZCL	13 (29)	6 (11)	7 (12)	*13*	*28*	*18*
4	C, ZC	6 (7)	5 (8)	6 (7)	*146*	*100*	*28*
	Overall	**7** (11)	**6** (9)	**6** (9)	*185*	*153*	*50*

3 > 4 highly significant. On arable data 2 versus 3 is not statistically significant (P = 0.77)

Arranging data by *subsoil* texture (Table 12.4) gives clearer trend: on all land uses, *clay* subsoils have much lower P than other textures and on arable land the median sequence below is representative (some very high data muddies statistical verification).

Sandy, light loamy (21 mg/l) > medium (16) > heavy loam* (13) >> clay (6 mg/l)

* or medium over clay upper subsoil.

On arable land, light loam and medium subsoils are likely to be index 2, heavy loams index 1 and clays index 0. Under woodland, lighter subsoils are higher P than medium than heavier loam subsoils, though insufficient data here to prove the latter difference.

Prediction of subsoil P

For each geological group the subsoil P correlates with topsoil P (r^2 0.3 – 0.8). Various fits were attempted, summarised in Table 12.5. Standard errors are quite high. For heavy subsoils the ratio of subsoil P to topsoil P is 0.25-0.37x plus an intercept 1.4-2.9 or in other cases simply 0.45-0.47x.

In some (but not all) groups, subsoil organic matter has an influence of Δ0.9–2.9 mg P / l per 1% OM (capped at 6%). Likely causes are more carry-down of P in organic material by earthworms, deeper rooting (residues and exudates) or shallower start depth of subsoil sampling (sampling method). P is almost certainly lower in the 40-50cm zone than in the subsoil above. Corer versus auger could vary subsoil P by $\pm$1 mg/l P.

In lighter or stony subsoils, P could be as high as 0.9x topsoil P though not in all groups.

Table 12.5: Predicted subsoil phosphorus at six levels of topsoil P (mg/l)

Soil Group	m	c	**10**	**15**	**20**	**25**	**30**	**35**	error
Glacial light-medium	0.34	2.8	6.2	7.9	9.6	11	13	15	
Horsehay Sand	1.07		10.7	16.1	21.4	27	32	37	
Chiltern stony	0.87		8.7	13.1	17.4	22	26	30	
Charmouth Clay	0.46		4.6	6.9	9.2	12	14	16	2.1
Limestone and clay	0.47		4.7	7.1	9.4	12	14	16	
Glacial Till *			4.7	5.4	6.2	7.2	8.3	10	2.3
Oxford Clay	0.26	2.9	5.5	6.8	8.1	9	11	12	3.8
Kimmeridge Clay	0.32	2.4	5.6	7.2	8.8	10	12	14	7.6
Chiltern heavier	0.45		4.5	6.8	9.0	11	14	16	
London Clay grass	0.30	1.4	4.4	5.9	7.4	9	10	12	2.6
Alluvial Clay grass	0.14	3.2	4.6	5.3	6.0	7	7	8	
Woodland heavier	0.42	2.1	6.3	8.4	11	13	15	-	4.9

Subsoil P = Topsoil P x m + c * subsoil P = 3.5 x $e^{\text{Topsoil P} \times 0.0288}$

Where subsoil is clay :

- when topsoil is index 0 (<10 mg/l), subsoil P is usually in range 3-8 mg/l.
- when topsoil is low end of index 1 (10 mg/l), subsoil P is likely 4.5-6 mg/l
- when topsoil is mid index 2 (20 mg/l) subsoil is 7-10 mg/l
- when topsoil is 30 mg/l subsoil P is 10-15 mg/l (index 1).

Grassland subsoils are more likely to be at the lower end of the above ranges, and if the topsoil sample is only taken to 7.5cm the topsoil P will be higher and so grossly overestimate subsoil P using the equations.

There is no obvious distinction between the different geological clays in regard to phosphorus, though in clearly calcareous clay subsoils P is frequently < 5 mg/l.

So if topsoil is index 0-2 the heavy upper subsoil will be index 0; at low index 3 (26-35 mg/l P) subsoil will be index 1, however exceptions are quite common.

In light, medium or stony subsoils :

- when topsoil is low end of index 1 (10 mg/l), subsoil P is most likely to be 6-10 mg/l
- when topsoil is mid index 2 (20 mg/l) subsoil is 10-20 mg/l
- when topsoil is 30 mg/l subsoil P will be 15-30 mg/l (index 2).
- subsoils with 25%+ stone are likely to be at the upper end of these ranges.

So when topsoil is index 2 a lighter or stony subsoil is likely to be at least index 1.

- on any texture when topsoil is very high index (5) subsoil P is typically 0.46x topsoil P, but in some clay subsoils the increase in P is more limited (< 0.3x).

Only half the variation in subsoil P can be explained by topsoil P and texture, and there is wide uncertainty about the extent to which high topsoil P contributes to raised subsoil P, on clays especially. On all research projects and crop trials is worth sampling and analysing subsoil as well as topsoil and to strictly specified depths (0-20, 20-40 and 40-50cm as indicated in NW report).

Woodland

Median P in topsoil was 13 mg/l and in subsoil 7 mg/l. There was high variation in clusters within the same wood (as might be expected from the heterogeneity of rooting density and undergrowth). Some woods were quite fertile suggesting they are not ancient but have been planted on land that was farmed at some point in history.

Subsoil P is less variable than topsoil P and not well correlated to at the normal end (index 0 – 2) though it seems that topsoil and subsoil converge at about 5 mg/l. For heavy loam and clay subsoils combined the equation is in Table 12.5 ($r^2 = 0.63$).

These are not dissimilar to fits on arable and grass samples.

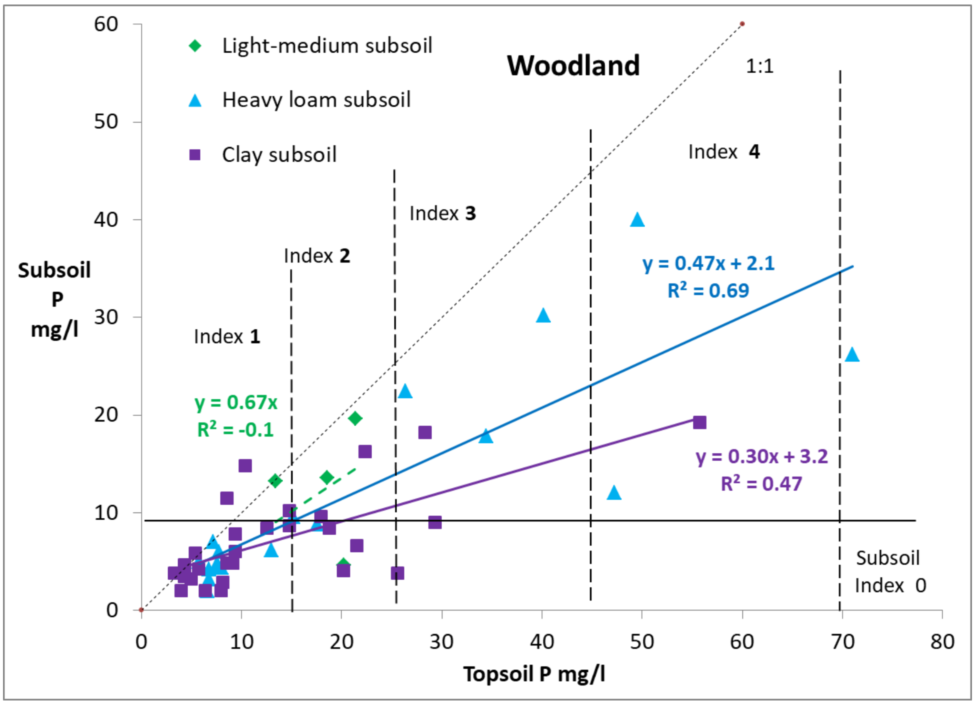


Figure 12.1 Region C Woodland : phosphorus in topsoil and subsoil

Agronomic aspects

Despite progress in promoting use of RB209 recommendations of phosphate over the past two decades, the large range of P levels found in this survey, in arable and grassland, suggests limited efficacy in evening up soil fertility and optimising use of phosphorus inputs (fertiliser and manures). The causes are fertiliser over- or under application and manure over-application in relation to crop demand. Despite the clear influence of soil texture on phosphorus availability, excessive available P can be found both on light and heavy soils.

At index 3 RB209 recommends no phosphate on most crops, although it is unclear whether this applies to midpoint of index 3 or anywhere in the index. The author's nutrient balance research suggests a safe rundown* over 3-4 years at midpoint index 3 is -75 kg P_2O_5/year which usually exceeds offtake and so no phosphate need be applied.

Table 12.6: Revised build/run-down in phosphorous recommendations kg/ha P_2O_5/year - arable, grass and forage (not vegetable crops).

Soil P level	**6** mg/l	**13** mg/l	**20** mg/l	**25** mg/l	**30**mg/l	**35**mg/l	**45**mg/l
Soil Type	**0**	mid **1**	mid **2**			mid **3**	
Sandy soils Light loam or stony	+60	+30	-	-30	- 55 [1]	-80 [1]	-125
Other soils	**+60/100**	**+30/50**	**-**	**-30**	**- 55 [1]**	**-80 [1]**	**-125**
Clayey soils	+100	+30/50	+10	-20	- 45 [1]	-70 [1]	-125

[1] provided soil result is not exaggerated

The latter option in Table 12.6 could be used for heavy loam and clay topsoils, combining the faster build option in RB209 and a slightly more cautious run-down at lower index 3. There is no reason why the larger builds should also be used on non-clayey soils since target is unlikely to be attained within 4 years, except on sandy or stony topsoils.

The current target index of mid 2 for arable and grassland should **not** be reduced for several reasons:

- Short range variation in soil P implies patches are likely to be 15% lower than the analysed value of a one per hectare or zonal composite sample, even if texture is uniform. Under grassland the variation may be 25% (see Section 18).
- Index 2 is a realistic target on clay soils provided organic matter levels are good.
- Clay *subsoils* tend to lower available P (and is more difficult to access by roots) than medium or light subsoils. P encourages deep rooting, likely to improve soil structure.
- Up to 35 mg/l topsoil P it is very likely that the upper subsoil P, averaged 25-50cm, is <16 mg/l P and in clays is likely to be very much lower at 40-50cm depth, with low risk of phosphorous transfer into drains except when topsoil is cracked..
- In medium, light or stony subsoils P tends to be higher but these are less likely to have under-drains (very rare on Chilterns soils).

- When topsoil lies within the lower half of index 3 there need be no restriction on applying small amounts of phosphate fertiliser in higher response situations such as maize, intensive grassland, late-winter or spring sown cereals sown into a poor seedbed etc.

13. Potassium overview

Region C: South-Central England

Topsoil K

The average for arable land is above target index at 186 mg K/l (index 2+). *20% of samples were below target index* (similar to 21% PAAG, 2019 survey). 31% of samples were index 3 or higher. Table 13.1 shows that topsoil K was highest in soils on Charmouth (Lias) Mudstone, Oxfordian Clays and Kimmeridge Clay (median ~225 mg/l), intermediate on Glacial deposits (140 mg/l) and Whitby Mudstone and least on the Chilterns (126 mg/l).

Grassland averaged 163 mg K/l (index 2-) *with 32% of samples below target index* (slightly less than 44% *in* PAAG survey, despite being sampled to 20cm+ depth). Levels were very high on Kimmeridge/Ampthill Clay (>300 mg/l), moderate on Oxfordian clays, clay-limestone and London Clay (150-230 mg/l), and low on the Chilterns (122 mg/l) and Whitby Mudstone, Glacial sandy deposits or clayey alluvium averaged index 1 (60-120 mg/l). 20% of grassland samples were index 3 or higher.

Topsoil K varied up to ± 25% within large clusters; examples of 10-90% ranges of 172-305 mg/l (arable field) and 144-243 mg/l (grass field) though smaller clusters were ± 15%.

Table 13.1 Geological grouping and potassium status (median values in mg/l)

	Arable data				Grassland data					
(BGS maps)	topsoil	subsoil	<Ind.2	>Ind 2	topsoil	subsoil	<Ind.2	>Ind.2	n	n
Charmouth Mudstone	**225** (2+)	160	4%	42%	**75** (1)	62	80%	-	*56*	*5*
Whitby Mudstone	**129** (2-)	117	60%	-	**73** (1)	52	67%	-	*6*	*3*
Horsehay Sand	**32** (0)	18	100%	-	**156** (2-)	65	-	-	*4*	*2*
Limestone & Clay	**-**	-	-	-	**228** (2+)	207	-	27%		*11*
Glacial Deposits	**136** (2-)	96	38%	21%	**88** (1)	55	17%	17%	*29*	*6*
Oxfordian Clays	**228** (2+)	153	2%	40%	**157** (2-)	153	22%	22%	*43*	*18*
Ampthill & Kimmeridge	**227** (2+)	188	-	40%	**335** (3)	164	27%	65%	*10*	*11*
Chilterns	**126** (2-)	84	48%	15%	**122** (2-)	89	46%	17%	*32*	*24*
London Clay	**-**	-	-	-	**158** (2-)	141	30%	19%		*43*
Alluvium	**191** (2+)	142	-	33%	**110** (1)	95	55%	-	*3*	*11*
Weighted median	**186** (2+)	132	20%	31%	**161** (2-)	127	32%	20%		

Topsoil texture has major influence on K levels (Table 13.2). Despite some very high values skewing the means, the differences are highly significant between medium and heavy loam textures on grass or arable and between heavy loam and clay on the arable data.

Table 13.2 Region C: Topsoil Texture and potassium, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	93 (124)	136 (194)	143	*13*	*9*	*2*
2	SCL, mCL, mZCL	130 (136)	128 (128)	127 (118)	*24*	*36*	*9*
3	hCL, hZCL	174 (179)	167 (201)	162 (232)	*44*	*75*	*28*
4	C, ZC	227 (234)	186 (218)	157 (204)	*104*	*32*	*10*
	Overall	**192** (200)	**158** (185)	**153** (208)	*185*	*152*	*49*

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 ZC = silty clay, C = clay.

P(T<=t) two-tail Arable Class 1 < 2 0.70, 2 < 3 0.01, 3 < 4 0.001
Grass 1 > 2 0.26 2 < 3 0.002 3 < 4 0.64

The arable median sequence gives a fair representation :
light loam (93 mg/l) , medium (130) < heavy loam (174) < clay (227 mg/l)

Grassland and woodland show a similar pattern. The less marked increase between heavy loams and clays might be due to the difficulty of distinguishing these by hand-texturing in cases where organic matter is very high.

The texture differences on arable land were greater than in the Midlands Triassic data set (medians 122,132,167 and 183 mg K/l respectively). The Midlands (red) clays were generally lower in K than the Southern region clays and the Carboniferous clays of the NE Midlands were very much lower.

On the southern data, potassium increases by ~40 mg/l for each 9% increase in clay content. RB209 recommendations aim to converge on 150 mg/l (mid index 2-) and are clearly failing. Probably there is some effect of leaching on the lighter textures and potassium release on heavier soils. RB209 revisions are proposed below.

On heavy loam topsoil, index 0 (< 60 mg/l) was never found and 16% were index 1. On clay topsoils only 5% were index 1.

Subsoil K

Median subsoil K was 134 mg/l on arable sites and 129 mg/l under grass (Table 13.1). It was lower in woodland (106 mg/). In heavy loam or clay subsoils <60 mg/l K (index 0) was very rare (1 instance on arable and 8 on grassland).

In three groups (Glacial Till, Oxford Clays and alluvial clays) K was strongly correlated with pH: 1.0 unit rise in subsoil pH corresponding to +Δ40 mg/l subsoil K and also +Δ50-90 mg/l in *topsoil K*. *Topsoil* pH had a less clear effect probably because it can vary according to recent liming practice. The effect of subsoil pH was most marked as it climbed from 7 to 8.0+ probably corresponding to $CaCO_3$ in the upper subsoil (though frequently too small to detected by field HCl test). This indicates that the persistence even of small amounts of natural lime enhances (or preserves) the potassium-supplying power of clay soils. This may also be related to mineralogy of parent material (reference Table 2.5) as well as topsoil texture. Where topsoil and (upper subsoil) was affected by thin Drift (even if clay textured) potassium analysis tended to be lower.

Subsoil K varies with topsoil texture in a similar way to topsoil K as shown in Table 13.3 There is a typical increase of 30 mg/l per topsoil texture class.

Table 13.3 Region C: Topsoil Texture and <u>subsoil</u> potassium, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	74 (70)	84 (157)	122	*13*	*9*	*2*
2	SCL, mCL, mZCL	86 (91)	115 (112)	81 (93)	*24*	*36*	*9*
3	hCL, hZCL	113 (127)	160 (175)	106 (144)	*44*	*75*	*28*
4	C, ZC	160 (177)	170 (182)	161 (197)	*104*	*32*	*10*
	Overall	**134** (146)	**147** (159)	**106** (143)	*185*	*152*	*49*

For textures see table 13.2

When *subsoil* texture class is compared (Table 13.4); despite some high values skewing the means, there is evidence of a real differences (P(T<=t)$_{\text{two tail}}$ of ~0.2). The median sequence is representative suggesting an increase of ~30 mg/l per subsoil texture class

light loam subsoil (63) < medium (83) < heavy loam* (117) < clay (143 mg/l)

* includes duplex upper subsoils (medium loam over clay)

Table 13.4 Region C: *Subsoil* texture and Subsoil potassium, medians (means)

Class	Subsoil texture	Arable	Grass	Wood	*n*	*n*	*n*
0	LS,S	50 (59)	84	-	*4*	*1*	-
1	SL, SZL	63 (57)	61 (143)	86	*10*	*7*	*1*
2	SCL, mCL, mZCL	83 (80)	117 (121)	72 (73)	*14*	*17*	*3*
3	hCL, hZCL, SC	117 (138)	121 (146)	117 (150)	*13*	*28*	*18*
4	C, ZC	143 (161)	159 (171)	125 (162)	*146*	*100*	*28*
	Overall	**134** (146)	**147** (159)	**108** (151)	*185*	*153*	*50*

P(T<=t) two-tail On arable data Class 0 < 1 0.99 , 1 < 2 0.15 , 2 < 3 0.01 , 3 < 4 0.22
On grassland 2 < 3 0.20 , 3 < 4 0.20

Extremely low K was found on ferruginous loamy fine sandy subsoils (<15 mg/l).

Woodland

The median value in topsoil 106 mg/l represents a very large range (Figure 13.1). Most of the high points are woods in disturbed topsoil over London Clay.

Topsoil and subsoil K are well correlated and follow similar trend to the arable and grass with topsoil and subsoil converging at about 90 mg/l. It is possible that clay subsoils accumulate more K heavy loam subsoils, but combining these gives similar fit to arable grass.

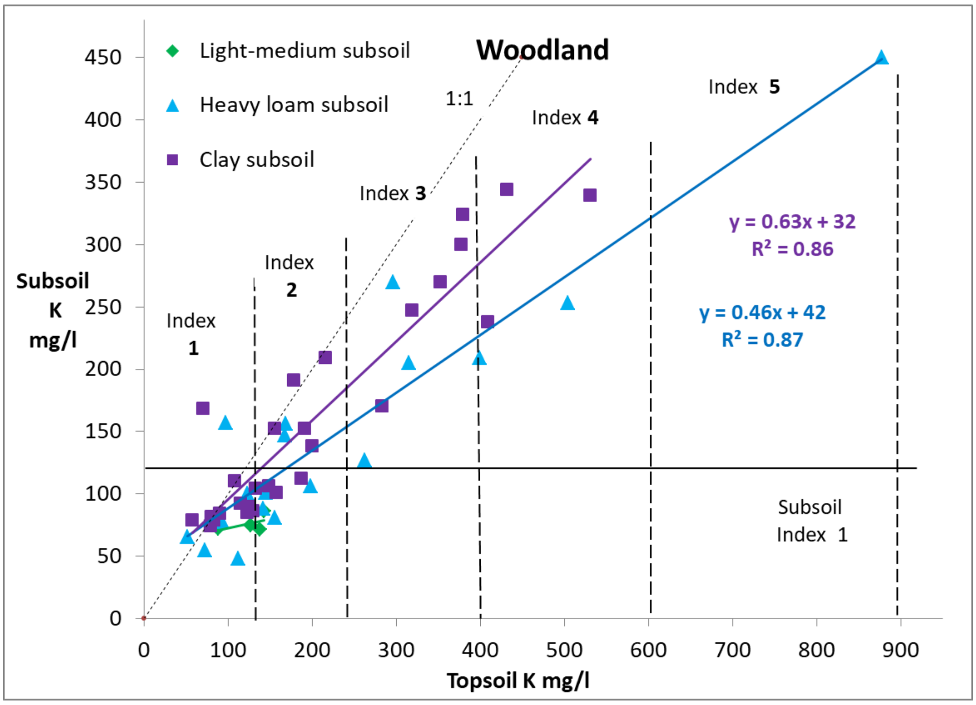


Figure 13.1 Region C : Woodland potassium in topsoil and subsoil

Prediction of subsoil K

The equations indicate that for heavy subsoils the slope (ratio subsoil K to topsoil K) is 0.4-0.6 x plus an intercept of 37-50 mg/l subsoil K at theoretical zero topsoil K, which might correspond to the unavailable but extractable K in heavy soils, a phenomenon well known from classical grassland exhaustion experiments. The Midlands report on Triassic clay subsoils found an intercept of 45 mg/l. Predictions are compared in the table 13.5 and have a standard error of ± 30 mg/l K.

A general purpose equation for heavy loam or clays topsoils (Appendix G)

Arable Subsoil K = Topsoil K x 0.57 + 40 $r^2 = 0.56$
Woodland Subsoil K = Topsoil K x 0.52 + 44 $r^2 = 0.82$.

Equation fitted to arable soils with light loam or stony medium subsoils (Appendix G)

Arable Subsoil K = Topsoil K x 0.42 + 19 $r^2 = 0.82$

Subsoil organic matter has an influence of Δ18 mg K / l per 1% OM (capped at 6%) on Charmouth Mudstone and Oxford Clays but not on other data sets. Stoniness had minimal effect on Chiltern soils (+Δ5 mg/l per stone category).

Table 13.5 : Predicted subsoil potassium at six levels of topsoil K (mg/l)

	m	c	**90**	**120**	**180**	**240**	**300**	**360**	error
Glacial light-medium	0.78		70	93	140	187	233		
Horsehay Sand	0.37	10	43	54	77	99	121		
Chiltern stony	0.31	36	64	73	92	110	129	148	34
Charmouth Clays	0.62	32	88	106	144	181	218	255	33
Limestone-&-clay	0.77	29	98	121	168	214			54
Glacial Till	0.38	39	73	85	107	130	153	176	32
Oxfordian Clay	0.58	37	89	107	141	176	211	246	39
Kimmeridge Clay	0.57	66	117	134	169	203	237	271	60
Chiltern heavy loam	0.60	29	94	101	137	173	209	245	20
Chiltern clay	0.49	45	89	104	133	163	192		20
London Clay med.	0.58	37	89	107	141	176	211	246	
London Clay grass	0.53	51	99	115	146	178	210	242	34
Alluvium grass	0.60	40	94	112	148	184	220	256	
Woodland heavier	0.52	44	91	106	134	169	200	231	40

Subsoil K = Topsoil K x m + c

Agronomic aspects

For all clays he fitted equations indicate that

- topsoil at mid index 1 (90 mg/l) subsoil is likely to be parity
- topsoil at bottom of index 2 (120 mg/l) subsoil is ~110 mg/l
- topsoil at upper end of index 2- (180mg/l) subsoil K will be 145 mg/l (index 2-)
- topsoil at upper end of index 2+ will be 175 mg/l.

- topsoil at mid-index 3, subsoil will be >200 mg/l.

These relationships are very similar to the Midlands Triassic clay soils.

Taking 90 mg/l as a minimum safe level for subsoil K (if topsoil dries) if index is 2- then subsoil will be adequate (despite the error around the fitted equations).

For **medium and light subsoils** data is fewer. The intercept is lower and ratio of subsoil K : topsoil K is proportionately less than heavier soils (though data is somewhat sparse). To ensure > 90 mg/l, the subsoil K topsoil should be at least mid-index 2- (150 mg/l) with 180 mg/l a better target.

Moreover, short range variation in soil K implies patches are likely to be 15% lower than the analysed value of a one per hectare or zonal composite sample, even if texture is uniform (20% under grassland, see Section 18).

All soils at index 3 have less surplus of topsoil K. When potash inputs are not applied light-medium soils are likely to run-down faster than heavier soils which have a greater buffer of subsoil K (crop roots can utilise K from subsoil as well as topsoil).

RB209 modifications: in the heavier soils which dominate this region potassium supply from topsoil and subsoil is likely to be adequate but there is a wide disparity of K status which could be addressed by simple modifications to RB209. Guidance on potassium releasing clays might be modified based on data in this and the NW and NE reports:

A. Potassium releasing clays

- Chalky Boulder Clay (calcareous Glacial Till)
- Gault Clay, Kimmeridge Clay, Oxford Clay, Lias and Rhaetic clay and associated Alluvium. *Clay topsoil* and subsoil.

B. Intermediate potassium supply

- above Clays with loamier, siltier or stony topsoil.
- shallow clays on limestone
- decalcified Glacial Till or Alluvium (natural pH < 7.0)
- Triassic (red) Clays (clay upper subsoil)
- London Clay, Weald Clay

C. Poor potassium supply

- Carboniferous Clay
- Clay-with-Flints

RB209 says the best way to estimate annual free release of potassium is by keeping a nutrient balance (Principles p25) and release (free potash) can be 50 K_2O kg/ha/year.

An alternative way to handle this is by modifying the build/rundowns in RB209.

- when soils come back index 2+ or 3 it is likely that potash release is occurring
- if a soil returns 2- (target) then release may be insignificant (even if a clay).
- if a soil drifts down below target then there may be some leaching loss.

At index 3 RB209 recommends no potassium on most crops though it is unclear whether this applies to midpoint of index 3 or anywhere in the index. The author's nutrient balance research on non-clay soils suggests a safe rundown* over 3-4 years at midpoint of -125 kg/ha K_2O/year and so no potash is needed except on very high offtake crops such as maize, whole crop or fodder root crops.

Table 13.4 Revised build/run-down in potassium recommendations kg/ha K_2O/year, arable soils

Soil K level	**45** mg/l	**90** mg/l	**120**mg/l	**150**mg/l	**210**mg/l	**240**mg/l	**280**mg/l	**320**mg/l
Soil Type	**0**	mid **1**		mid **2-**	mid **2+**			**mid 3**
Sandy soils	+50	+25	+10	-	-20	-50	-65 [1]	-100
Light loam or stony	+60	+40	+25	+10	-20	-50 [1]	-75 [1]	-100
Other soils	**+60/100**	**+30/50**	**+15/30**	**-**	**-30**	**-60 [1]**	**-90 [1]**	**-125**
Clayey soils	+100	+ 50	+25	-10	-45	-80 [1]	-110 [1]	-150

[1] provided soil result is not exaggerated.

- On sandy soils the expectation is that some leaching may occur but index 1 shouldl be maintained. Where more than 50 kg/ha is required the application is best split between seedbed and spring topdressing.
- Chalky soils should be treated as light loam; shallow soils on limestone as Other.
- Clayey soils are assumed to provide some 'free' potash. Non-releasing clays (eg Carboniferous) should use Other category. On very high K-releasing clays a further 20 kg/ha/yr can be deducted on fields which have historically held high K levels.
- Where Mg exceeds 300 mg/l this may depress potash uptake and the soil should be maintained at K index 2+ by adding 30 kg/ha to the values in table.
- For land in vegetable rotations add 40 kg/ha in order to maintain index 2+.

If index 1 is found this is indicative that the clay is not releasing in the first place. Although the subsoil K is likely to be index 1 and higher than medium or lighter subsoils, a large proportion of K in the clay may not be crop available and it must not be thought safe to leave heavy soils at index 1 in order to save fertiliser.

in most but not all Southern clays K:Mg ratio was >0.5:1 (see next section) but caution should be exercised in run-downing down surplus K where Mg index is high. At Mg index 6 the target K index should be 2+ (210 mg/l).

Inclusion of the options above into RB209 should even out the large disparity in K status apparent from this data. Other points are:

- For additional safeguard in rundowns, topsoil should be sampled to 20cm depth in arable, forage crops and conserved grassland.
- When sampling zonally for potassium, if practicable, areas of different topsoil texture class (clay content) should be delineated as well as calcareous versus non-calcareous.
- Although subsoil K with texture accounts for 65-75% of the variation in subsoil K, significant variance can still occur. It is possible that carry-down of organic matter by earthworms, ploughing under of manure may be important. In potash response trials it is prudent to measure subsoil K also as well as noting the texture of topsoil *and subsoil*.

Footnote: analytical issues

All measurements in this study were by the same laboratory. In other laboratories it is possible that preparation of the soil sample may systematically affect the K result in two ways:

a) speed of drying which influences collapse of clay minerals trapping some K.

b) degree of grinding which affects the extent to which small soft stones are included <2mm and the density of the volume of soil scooped out for analysis.

PAAG could do some inter laboratory cross-checks on partially moist (6mm sieved) soils, with the weight of soil in scoop recorded to aid comparison (it varies 0.9 - 1.3 g/cm^3 according to soil OM and texture).

14. Magnesium overview

Region C: South-Central England

Topsoil Magnesium

Weighted median Mg of balanced data was 179 mg/l arable and 181 mg/l grass (index 4) but with wide range: 18% of arable samples and 10% of grassland were below target (<50 mg/l), largely in the Chilterns, while 27% of arable samples and 31% of grassland were >250 mg/l (Mg index 5+), higher than the PAAG (2019) national average of 12%. 6% of all data was index 6+ (mainly on Charmouth Mudstone and London Clay grassland).

Grassland, where grazed and/or heavily manured, would be expected to be higher in Mg than arable land due to input from animal (feeds).

Table 14.1 : Geological grouping and magnesium status (median values in mg/l)

	Arable				Grassland					
(BGS maps)	topsoil	subsoil	<Ind.2	>Ind 4	topsoil	subsoil	<Ind.2	>Ind.4	n	n
Charmouth Mudstone	**308** (5)	327	2%	55%	**174** (3)	179	-	-	*56*	*5*
Whitby Mudstone	**70** (2)	64	-	-	**135** (3)	212	-	-	*6*	*3*
Horsehay Sand*	**29** (1)	19	50%	-	**108** (3)	39	-	-	*4*	*2*
Limestone & Clay	**-**	-	-	-	**103** (3)	98	9%	9%		*11*
Glacial Deposits	**90** (2)	81	14%	7%	**90** (2)	55	60%	-	*29*	*6*
Oxfordian Clays	**182** (4)	218	-	21%	**218** (4)	309	6%	50%	*43*	*18*
Ampthill & Kimmeridge	**262** (5)	279	-	60%	**262** (5)	285	-	65%	*10*	*11*
Chilterns	**45** (1)	39	81%	-	**68** (2)	67	29%	-	*32*	*24*
London Clay	**-**	-	-	-	**245** (4)	426	-	46%		*43*
Alluvium	**194** (4)	104	-	33%	**185** (4)	217	9%	36%	*3*	*11*
Weighted median	**179 (4)**	190	18%	27%	**181** (4)	255	10%	30%	*183*	*134*

Mg in cluster samples varied ±20% from the average value.

The effect of soil texture is examined by pooling all data, including large clusters, in Table 14.2. Grassland tends to magnesium levels ~60 mg/l higher than arable soil or woodland.

Table 14.2 Region C: Topsoil Texture and <u>subsoil</u> magnesium, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	33 (40)	68 (83)	95	*13*	*9*	*2*
2	SCL, mCL, mZCL	47 (62)	126 (146)	99 (120)	*24*	*36*	*9*
3	hCL, hZCL	118 (160)	271 (307)	129 (165)	*44*	*75*	*28*
4	C, ZC	209 (251)	253 (250)	201 (332)	*104*	*32*	*10*
	Overall	**140** (190)	**202** (238)	**138** (188)	*185*	*152*	*49*

For texture names see below Table 14.3

P(T<=t) two-tail On arable data Class 2 >1 0.04 , Grass data 1 < 2 0.00. Other are all very highly significant except heavy loam to clay on grassland.

Topsoil texture is hugely significant in arable, grass and wood data. The median ranking for arable data is representative :

light loam (33 mg/l) < medium loam (47) < heavier loam (118) < clay (209 mg/l)

On arable land index <2 is very likely on light loam topsoils, common on medium topsoils but very unlikely on heavy loams or clays which are typically index 3 and 4 respectively, though 18 & 27% respectively were index 5 and 5% & 8% index 6.

On grassland index < 2 was found in a few cases. Mg is typically index 2 on light loams and 3 on medium loams. Index 4 is typical for heavy loams and index 5 for clays, though 8 & 20% respectively were index 5, 8% & 13% index 6 or 7.

Woodland was typically Mg index 2 on light loams, 3 on heavy loams and 4 on clays.

Subsoil Mg

Subsoil Mg is correlated with *topsoil* texture as shown in Table 14.3. Subsoil Mg is less on light loam topsoils (usually <25 mg/l, index 0) and on clays is higher than topsoil. Under heavy loam topsoil, subsoil Mg tends to be index 3 on arable or woodland but index 5 under grassland. Under clay topsoil the subsoil is most likely to be Mg index 5.

Table 14.3 Region C: Topsoil Texture and <u>subsoil</u> magnesium, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	24 (30)	46 (68)	184	*13*	*9*	*2*
2	SCL, mCL, mZCL	51 (56)	177 (207)	86 (111)	*24*	*36*	*9*
3	hCL, hZCL	108 (168)	371 (402)	130 (190)	*44*	*75*	*28*
4	C, ZC	262 (313)	302 (318)	270 (358)	*104*	*32*	*10*
	Overall	**159** (225)	**261** (312)	**148** (210)	*185*	*152*	*49*

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
ZC = silty clay, C = clay.

When the data is partitioned by *subsoil* texture (Table 14.4) there is even sharper separation. Medium subsoils have significantly higher Mg than light loam subsoils with +Δ20 mg/l under arable and +Δ50 mg/l under grassland. Medium to heavy loam is a further +Δ400 mg/l but the sharpest difference is heavy loam to clay, >Δ100 mg/l on arable and >Δ200 mg/l under grass. This may correspond to a doubling in clay content (some geological clays are > 60% clay). The representative median sequence for arable subsoils :

light loams (and sand) (21 mg/l) < medium (37) < heavy loam (91) << clay (214)

Table 14.4 Region C: *Subsoil* texture and Subsoil magnesium, medians (means)

Class	**Subsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
0	LS,S	21 (27)	46	-	*4*	*1*	*-*
1	SL, SZL	21 (22)	30 (51)	25	*10*	*7*	*1*
2	SCL, mCL, mZCL	37 (45)	82 (117)	36 (35)	*14*	*17*	*3*
3	hCL, hZCL	91 (170)	103 (179)	140 (141)	*13*	*28*	*18*
4	C, ZC	214 (264)	337 (404)	183 (280)	*146*	*100*	*28*
	Overall	**159** (225)	**261** (312)	**150** (210)	*185*	*153*	*50*

$P(T<=t)_{\text{two-tail}}$ On arable data Class 1 < 2 0.002, Grassland Class 1 < 2 0.002. All others are highly significant.

Medium loam arable subsoils tend to index 1 under arable and 2 under grass. It is evident that admixture of loam reduces the very high Mg inherent in clay-textured upper subsoils, but not all types of clay are the same as shown in Table 2.6.

Table 2.6 : Geological member and magnesium and potassium status

Geological Grouping	Topsoil Mg mg/l		Subsoil Mg mg/l		Subsoil K mg/l		*Sub*	*n*
(BGS maps)	median	25-75%	median	25-75%	median	25-75%	*K:Mg*	*(grass)*
Rhaetic Clay / limestone	**138**	128-151	**164**	130-209	**208**		*1.3*	*4 (4)*
Charmouth Mudstone	**280**	165-452	**324**	211-586	**156**	128-220	*0.5*	*62 (6)*
Whitby Mudstone	**83**	67-113	**80**	58-141	**87**	52-112	*1.1*	*8 (3)*
Horsehay Sand *	**34**	27-78	**21**	19-29	**32**	15-43	*1.5*	*6 (2)*
Dyrham Siltstone ^	**154**	125-184	**175**	133-199	**72**	66-85	*0.4^*	*6 (2)^*
Jurassic clay / limeston*	**96**	57-123	**69**	31-113	**201**	113-439	*2.9*	*7 (7)*
Glacial Till	**111**	90-125	**92**	81-115	**106**	93-143	*1.2*	*25 (6)*
Peterborough Member	**155**	112-233	**202**	153-242	**134**	120-150	*0.7*	*32 (3)*
Stewartby Mudstone	**265**	241-284	**359**	306-402	**246**	230-257	*0.7*	*4 (1)*
Weymouth Mudstone	**226**	193-261	**262**	225-344	**188**	169-254	*0.7*	*21(11)*
West Walton Formation	**206**	152-259	**237**	166-331	**173**	164-179	*0.7*	*4 (3)*
Ampthill Clay	**265**	234-344	**285**	237-312	**191**	162-317	*0.7*	*15 (7)*
Kimmeridge Clay	**236**	197-321	**262**	181-361	**160**	146-180	*0.6*	*6 (4)*
Chilterns – clayey	**55**	42-73	**58**	41-88	**103**	70-129	*1.8*	*29 (15)*
Chilterns–other subsoil*	**46**	38-76	**40**	28-56	**84**	67-107	*2.1*	*27 (9)*
London Clay	**256**	202-402	**485**	277-613	**132**	108-137	*0.27*	*63 (60)*

Only cases with heavy loam or clay upper subsoil are included, except *.
^ Alluvium on Dyrham Siltstone and includes 4 wood samples so may not be representative

The magnesium-supplying power of the clay appears to increase in sequence :

Clay-with-Flints < Jurassic limestone-&-clay, Glacial Till , Whitby Mudstone < (Dyrham siltstone), Rhaetic clay-limestone < Oxford Clay, Kimmeridge Clay < London Clay and Charmouth Mudstone (Lias).

In some but not all clay groups Mg increased with decreasing pH (-Δ80 to -Δ190 mg/l per unit pH increase). It might be expected that Mg is less in *calcareous* (or well limed) clays because raised soluble calcium displaces more exchangeable magnesium into the drainage water (the pH effect on Mg is commonly seen on Chalk soils).

The Midlands report (Triassic data) found red Glacial Till subsoils tended to higher values (~200 mg/l Mg) than the Southern Tills here. Red mudstones (~250 mg/l) were similar to most of the Southern Clays, although Red Dolomitic or alluvial clays were much higher in Mg. Carboniferous clay subsoils (NE report) were typically 200 mg/l under arable and 300 mg/l under grass.

NB the rankings in Table 2.6 may be biased by the higher number of grassland data in some sets

Subsoil Mg strongly correlates with topsoil Mg. More than 75% of the variation in subsoil Mg could be explained by topsoil Mg modified for textural class :.

- In clay subsoils Mg is 1.1 – 1.4x greater than topsoil Mg.

- In medium subsoil Mg tends to parity (1x) or slightly less (0.85x) than topsoil Mg, significantly less where stony or very calcareous.
- Light loam, sandy or stony subsoils have lower Mg than topsoil (about 0.65x).

Subsoil OM% had a significant positive influence in the Charmouth Mudstone and Alluvium but not the other data.

Woodland

The median topsoil Mg under wood was 148 mg/l (index 3) but, as Figure 14.1 shows, there is a tail of very high samples up to index 8 (mainly in disturbed topsoil over London Clay).

Mg in subsoil was rarely lower than in topsoil which was typically 1.2x in clay subsoils or parity where heavy loam (or medium-over-clay) subsoil. In few cases was topsoil much lower than subsoil (below 1:1 line). Despite some high acidity (leaching) the topsoil usually maintained itself at > 80% of subsoil Mg implying that the *topsoil* is continuing to release magnesium, supplemented by returns from leaf fall.

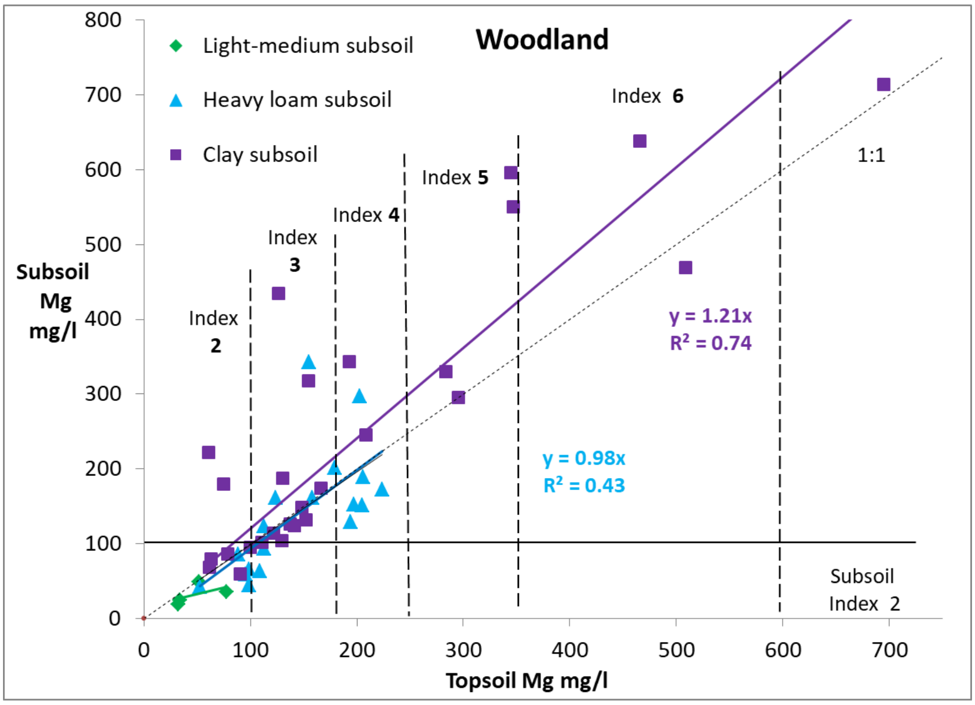


Figure 14.1 Region C Woodland: magnesium in topsoil and subsoil. (One point omitted {1043,901})

Relevance to RB209

On arable land

- Index 0 is likely on sands, index 1 on light loams and medium textures 2 ^
- On heavy loam or clay topsoils Mg is index 3^ to 6 and relates to mineralogy.

^ *one index lower when overlying gravel, limestone, (Chalk), or Clay-with-flints*

Low topsoil Mg (< 50 mg/l) is usually limited to sandy / light loamy soils plus medium textures on the soil types indicated ^.

Mg level is determined by leaching counteracted by Mg-release from clay minerals. Lighter textures tend to lower release and higher leaching for any given Mg level. Highly alkaline topsoil may encourages leaching.

On grassland Mg levels are higher, especially long-term or grazed/manured grassland. Woodland behaves similar to arable land.

Treating low Mg soils: there is debate as to the responsiveness of crops to Mg fertiliser at index 1, with oilseed rape, legumes and spring barley often cited as more responsive. This data shows that Mg status of the subsoil is likely to be equal or better than topsoil *unless subsoil is sandy, light loamy or stony, chalk or limestone,* in which case the subsoil is liable to be worse than topsoil posing increased risk of Mg deficiency if the topsoil dries out.

High Mg raises concerns firstly about Mg induced K deficiency. K:Mg ratio tends to be lower in subsoil than topsoil. However, in most Clay data sets K:Mg (mg/l:mg/l) median was above the commonly cited threshold of 0.5 (Mg is twice K) in both horizons, although there were numerous instances of much lower ratio, especially on grassland.

Secondly, there are concerns that high Mg that could contribute to instability of the clay-organic colloids and topsoil structure. More than 20% Mg on the exchange complex is sometimes stated as cause for concern. However table 14.4 indicates this threshold cannot be crossed on medium soils until Mg index hits 6 on medium soils or high end of 6 on clays. Index 6/7 was not found consistently except in certain fields on London Clay or Charmouth Mudstone.

Table 14.4: measured soil Mg in mg/ (index) and % CEC occupancy

CEC meq/100g	100- (3)	175- (4)	250- (5)	350- (6)	600- (7)
10 light	11%	20%	29%	-	-
20 medium	6%	10%	14%	20%	34%
30 heavy	4%	7%	10%	13%	23%

* from CEC calculation used by NRM which assumes that 76% of Ca and 71% of the exchangeable K or Mg are actually extracted. This ignores scoop density which can be up to 1.2 g/cm^3 on loamier soils. CEC is quoted on a gravimetric not volumetric basis. Therefore on loamy or sandy samples the % Mg values err on the low side.

If CEC is measured, 20% saturation is exceeded when exchangeable Mg / CEC > 17.4.

15. pH overview

Region C: South-Central England

pH in topsoil

Representative data (large clusters removed) is shown in Table 15.1. Weighted median pH for grass and arable data was 6.7 (optimal) but with wide range: 22% of arable samples were suboptimal pH (6-6.4) and 17% acid (<pH 6.0). 22% of grassland was pH <6.0. The PAAG (2019) survey found a similar proportion of arable land of pH <6.0 (19%) and also found 19% of grassland pH <5.5. In this data a large amenity grass set averaged pH 5.5 but in other grassland only 6 points (4%) were pH <5.4 and 5% pH 5.5. Grass was sampled to 20cm and is likely to be more acid in the top 7.5 cm, especially if it has been undisturbed for a long time.

Table 15.1: Geological grouping and soil pH (median values)

	Arable				**Grassland**					
(BGS maps)	topsoil	subsoil	< 6.5 *	> 7.4	topsoil	subsoil	< 6.0	> 7.4	n	n
Charmouth Mudstone	**6.3**	6.9	25+37%	11%	**5.8**	6.2	60%	-	*56*	*5*
Whitby Mudstone	**7.0**	7.4	0+20%	20%	**5.5**	6.7	100%	-	*6*	*3*
Horsehay Sand	**5.7**	6.3	75+25%	-	**5.9**	6.3	50%	-	*4*	*2*
Limestone & Clay	**-**	-	-	-	**7.8**	7.9	-	47%		*11*
Glacial Deposits	**6.3**	6.9	24+24%	14%	**6.5**	6.7	33%	-	*29*	*6*
Oxfordian Clays	**6.8**	7.6	5+16%	26%	**6.6**	7.5	17%	33%	*43*	*18*
Ampthill & Kimmeridge	**7.2**	7.9	-	40%	**6.8**	7.6	-	-	*10*	*11*
Chilterns	**7.1**	7.3	12+13%	28%	**6.8**	7.0	25%	25%	*32*	*24*
London Clay	**-**	-	-	-	**6.6**	7.2	21%	9%		*43*
Alluvium	**7.5**	7.8	33+0%	67%	**6.5**	7.3	27%	45%	*3*	*11*
weighted median	**6.7**	7.2	17+22%	21%	**6.7**	7.3	22%	19%		

* indicates proportion of samples of pH 6.0-6.4 and <6.0%

Acid soils were most prevalent on Charmouth Mudstone, Horsehay Sand and Glacial deposits but could be found on any formation except Ampthill, (Kimmeridge Clay), Rhaetic Clay and Jurassic limestone-&-clay.

20% of topsoils were pH >7.4 (arable and grass). This compares to 5% in the Midlands soils and 16% in the NE (Carboniferous soils).

In a large arable close-cluster 10-90% pH range was 5.7-6.4 and in a large grass cluster was 6.4-7.1, ±0.3 the mean. Short range pH variation of ±0.2 is typical (see section 17).

Subsoil pH

Median subsoil pH was 7.2 and 7.3 on arable and grass there was a large range. 50-75% of the variation in subsoil pH could be explained by topsoil pH. Equations are summarised in table 15.2 and indicate a typical ratio of subsoil to topsoil pH of 0.6-0.7x plus an intercept of 2.1-3.5 units. Each 1% increase in subsoil OM (capped at 6%) was associated with a Δ0.1-0.3 decline in subsoil pH in some data sets (due to greater depth of mixing of topsoil derived material or lesser start depth of sample). An increase in one stone category (10% stones v/v) was linked to a Δ0.1 pH decline, so for the same topsoil pH subsoil was typically 0.2-0.3 units less on moderately flinty clay or gravels in the Chilterns.

Table 15.2 : Predicted subsoil pH at six levels of topsoil pH

	m	c	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**
Glacial light-medium	0.37	4.2	6.0	6.2	6.4	-	-	-
Horsehay Sand	0.78	1.84	*5.7*	6.1	6.5	6.9	7.3	-
Charmouth Clays	0.59	3.24	*6.2*	6.5	6.8	7.1	7.4	7.7
Glacial Till	0.62	2.95	*6.1*	6.4	6.7	7.0	7.3	7.6
Oxfordian Clay	0.72	2.36	*6.0*	6.3	6.7	7.0	7.4	7.8
Kimmeridge Clay	0.43	4.64	-	-	7.2	7.4	7.7	7.9
Chilterns	0.68	2.45	*5.9*	6.2	6.5	6.9	7.2	7.6
London Clay grass	0.90	1.08	*5.6*	6.0	6.5	6.9	7.4	7.8
London C. amenity	0.68	2.07	*5.5*	5.8	6.1	6.5	-	-
Alluvium grass	0.58	3.34	*6.2*	6.5	6.8	7.1	7.4	7.7
Woodland	0.93	0.63	*5.3*	5.7	6.2	6.7	7.1	7.6

Subsoil pH = Topsoil pH x m + c

For heavy loam and clay topsoil the overall fitted equations were similar
Arable : Subsoil pH = Topsoil pH x 0.67 + 2.74 r^2 =0.57
Grass : Subsoil pH = Topsoil pH x 0.72 + 2.39 r^2 =0.59

For light to medium topsoils the fitted equation was different in the grass set
Subsoil pH = Topsoil pH x 0.67 + 2.54 r^2 = 0.77
Subsoil pH = Topsoil pH x 0.82 + 1.59 r^2 = 0.68

- at topsoil pH 7 subsoil is typically p H 7.4. By pH ~7.7 subsoil and topsoil converge, usually due to the presence of carbonates. Equilibration of $CaCO_3$ with atmospheric CO_2 sets an upper limit of pH 8.4 irrespective of how much carbonate is present.
- at topsoil pH 6.5 subsoil is usually >7.0 *
- at topsoil pH 6.0 subsoil is typically 6.5 or above* .

* large differentials could occur where decalcified topsoil overlies a calcareous subsoil.

- at topsoil pH 5.5, subsoil is expected to be at least pH 6.0 in lighter or stony subsoils soils and > 6.3 in clay subsoil. Subsoil pH nearly always exceeds topsoil pH.
- at very acid pH (<5.5) subsoil pH should be at least 0.6 higher than topsoil on arable and grassland though not in all cases. In woodland subsoil pH can be almost as acid as topsoil.

In some data sets the pH difference topsoil to subsoil was more marked than others. Unexplained variation in subsoil pH could be due to recent liming, textural variation, variable subsoil sampling start depth and seasonal variation in ion concentrations in soil solution.

When pH is measured in water (ADAS method) it is at risk of being up to 0.3 units lower in summer due to accumulation of salts - nitrate, sulphate and chloride - due to fertiliser application or mineralisation as the soil warms and dries. Surplus anions (with cations) tend to be washed out in autumn leading to a rise in pH. It is likely that subsoil is less susceptible to such pH fluctuation than topsoil. It was not possible to check the effect of this on the data here.

Natural alkalinity

Once calcium carbonate content in the fine earth (<2mm) exceeds 2%, pH will normally be above 7.4, but regardless of how much $CaCO_3$ is present will not exceed 8.4 if in equilibrium with atmospheric CO_2. The limit is lower if significant solution Ca is present. See Figure 15.1.

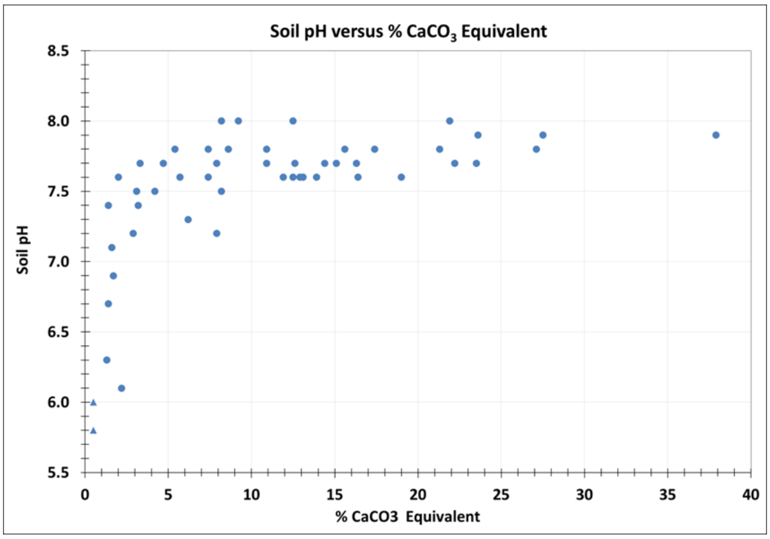


Figure 15.1 soil pH and Neutralising Value (data courtesy of NRM laboratories).

A large proportion of subsoils were >7.4 in several data sets (Table 2.6). Alkaline subsoil was common across arable (35%), grass (39%) and wood (37%) and far more than the 7% found in Midlands and 25% in the NE data sets.

Whenever $CaCO_3$ was detected by field test (HCl), pH was always 7.5+, but $CaCO_3$ was not detected in other cases of high pH suggesting very small but significant amounts of carbonate were present.

Table 2.6 : pH in relation to Geological member

Geological Grouping	**Topsoil pH**			**Subsoil pH**			*n*
(BGS maps)	median	25-75%	> 7.4	median	25-75%	*> 7.4*	*(grass)*
Rhaetic clay & limestone	**7.8**	7.2-8.0	75%	**8.0**	7.8-8.2	*100*	*4 (4)*
Charmouth Mudstone	**6.2**	5.9-6.8	10%	**6.9**	6.6-7.3	*18%*	*62 (5)*
Whitby Mudstone	**6.6**	5.8-7.1	13%	**7.1**	6.7-7.4	*25%*	*8 (3)*
Horsehay Sand *	**5.7**	5.5-6.1	0%	**6.3**	6.1-6.6	*0%*	*6 (2)*
Jurassic clay & limestone *	**7.6**	6.8-7.9	57%	**7.9**	7.2-8.2	*86%*	*7 (7)*
Glacial Till	**6.6**	6.0-6.9	16%	**6.9**	6.7-7.3	*24%*	*25 (6)*
Peterborough Member	**6.7**	6.3-6.9	9%	**7.1**	6.6-7.4	*25%*	*32 (3)*
Stewartby Mudstone	**7.3**	6.9-7.7	50%	**7.8**	7.6-7.9	*75%*	*4 (1)*
Weymouth Mudstone	**7.3**	6.8-7.7	48%	**7.9**	7.6-8.1	*86%*	*21(11)*
West Walton Formation	**7.6**	7.2-7.9	50%	**7.9**	7.6-8.0	*75%*	*4 (3)*
Ampthill Clay	**7.0**	6.7-7.5	27%	**7.7**	7.5-8.0	*80%*	*15 (7)*
Kimmeridge Clay	**6.6**	6.3-6.8	0%	**7.8**	7.5-7.9	*67%*	*6 (4)*
Chilterns – clayey	**7.1**	6.2-7.8	38%	**7.5**	6.6-7.8	*54%*	*24 (15)*
Chilterns – other subsoil *	**6.7**	6.1-7.4	22%	**7.0**	6.6-7.3	*22%*	*27 (9)*
London Clay	**6.4**	5.9-6.9	2%	**7.1**	6.3-7.4	*22%*	*63 (60)*
Alluvium	**6.5**	5.9-7.3	29%	**7.3**	6.8-7.7	*50%*	*14 (12)*

Only cases with heavy loam or clay upper subsoil are included, except *.

Table 2.6 compares pH in different types of clay. All the geological solid clays are described by BGS as containing calcareous layers.

In this data more than 80% of upper subsoils had pH >7.4 on Rhaetic clay, Oxfordian clays* (except the Peterborough Member) and Ampthill Clay^. Less than 30% were alkaline on Charmouth Mudstone^, Whitby Mudstone^ and London Clay. In places where heavy topsoils contained some hard stones this is indicative of admixture with thin (unmapped) Head deposits and such places were more likely to be acid.

^ the same SSEW map unit, Denchworth Association, is used for all these clays. Component series include Denchworth, Evesham (the calcareous variant) and some others. On the mapped Drift deposits of Alluvium (Fladbury Assocation) and Clay-with-Flints, about 50% of subsoils were pH >7.4. Clay-with-Flints becomes calcareous as it approaches the underlying Chalk.

Only 24% of Glacial Till was alkaline in the upper subsoil. Chalk stones were evident in the clay at start depths ranging from 25 to 80cm, indicating highly variable decalcification (and variable chalk content in the original Till). Since decalcification is affected by rainfall, upper soil on Till tends to be calcareous in the East of England (Hanslope Association) and prone to going acid in central England (Ragdale Association). However acid and alkaline variants can be found in both mapping units. See comment on pH testing at the end.

On limestone-&-clay soils, pH was usually alkaline where limestones were present in topsoil. Small amounts of stone (2-5%) could be found alongside pH <7.0 but such is unlikely to go acid (if occasionally cultivated).

Soils on Chiltern footslopes could be calcareous despite not being visibly chalky.

Woodland

34% of woodland topsoils had pH <6.0 of which 14% were extremely acid (pH < 5.0). All were deciduous woodland acidified by rain and leaf fall except where the topsoil contained limestone (natural) or chalk (in some disturbed topsoils). Except in the latter cases, 5-10cm organic F/H layers were present which were mixed with mineral topsoil to 20-25cm depth for analysis, and almost certainly were more acid than the overall pH analysed.

Subsoil pH strongly correlated with topsoil pH (Figure 15.2) but unlike arable/grass sites there was close to a 1:1 relationship over the whole range. The fitted equation is

Subsoil pH = Topsoil pH x 0.93 + 0.63 $r^2 = 0.80$

Accordingly, under wood at topsoil pH 5.0, subsoil is typically 5.3 and at pH 7.0 subsoil is 7.1, but a 1:1 relationship is not a significantly worse fit (Appendix G). It was unusual for subsoil pH to be lower than topsoil by more than 0.1 units.

It is hypothesised that on undisturbed sites, topsoil and subsoil reach a pH equilibrium where the input of acidity and basic ions into the topsoil and their output (leaching) from upper subsoil are more or less in balance. Levels of anions in soil solution are likely to be low in woods especially if nitrification is inhibited by low pH.

In agricultural sites topsoil pH is usually lower than subsoil except on alkaline soils. This suggests historical lime inputs (whether intended or unintended via some manures or fertilisers) are 'working their way' through awaiting a top up.

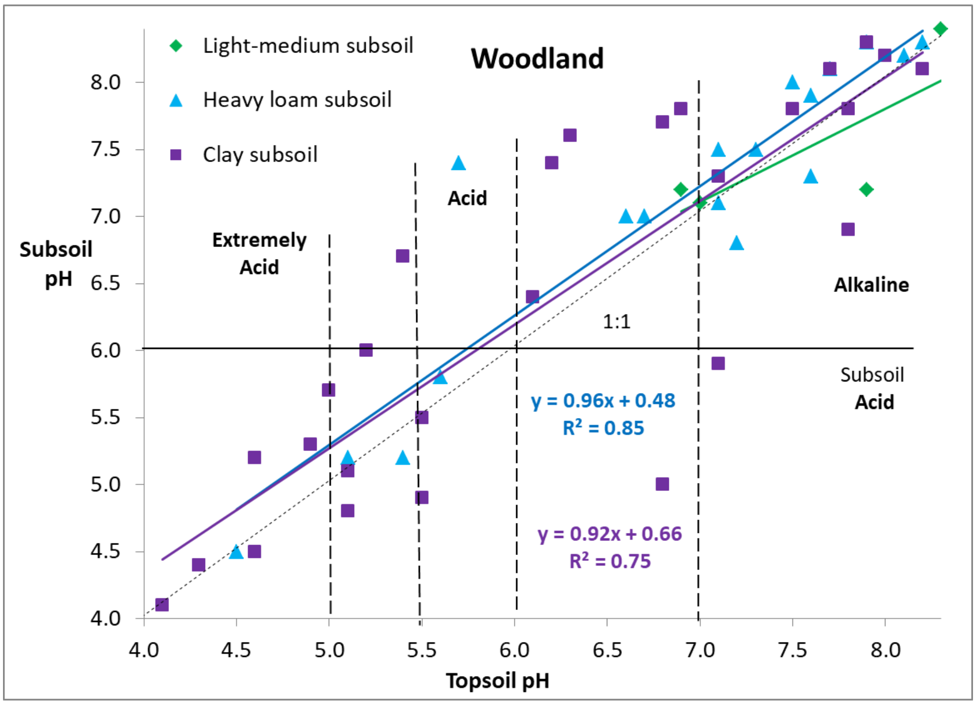


Figure 15.2 Region C Woodland; pH in topsoil and subsoil

Modification to RB209 guidance

Suggestions are as follows:

a) measurement of *subsoil* pH is prudent where topsoil pH is less than 5.5 on any soil type and if < 6.0 on stony (or sandy) subsoils or on soils that have not been limed with the past decade. Based on subsoil pH, some extra lime may need to be ploughed under, though requirements for topsoil and subsoil horizons should be reduced in accordance with stoniness.

b) on deep clays, especially Oxford Clays but also Kimmeridge, (Gault) and Lias Clays, and on Glacial Till, the same field can contain areas of calcareous (alkaline) and decalcified (potentially acid) topsoil so care is needed when pH testing (1 per ha or pH sampling within ground-truthed zones).

C) Decalcification also affects management: clay subsoils naturally of pH >7.4 tend to retain olive-greyish-brown colours and 'crack more' while naturally acid variants are very mottled and poor drained. Better structural stability is conferred when $CaCO_3$ maintains higher Ca^{2+} concentration in soil solution and stabilises OM and improves granulation. It is likely (though not proven) that heavy soils which are naturally non-calcareous could be limed to maintain pH7+ in order to induce structural benefit to both topsoil and subsoil (provided micronutrient deficiencies are controlled).

D) The soil survey field HCl test picks up alkalinity on soils containing chalk or fine limestone but care is needed on clays to detect small amounts of carbonate.

E) Variable pH is likely on the Chilterns where the Drift thins on slopes and on limestone, where stoneless patches are at risk of going acid.

f) Short range (un-mappable) pH variation may be as much as ±0.2, so when liming it is prudent to exceed target pH slightly (by 0.2) as in the current RB209 tables.

g) The Lime factors used to calculate lime requirement in RB209 are based on a 20cm 'depth of action' in arable land and 15cm in grassland. It is logical to take the soil sample to these same depths rather than the current 15 and 7.5cm. This approach might lead to slightly higher pHs (as in this data). If the acidity in the top 7.5cm is the over-riding concern then a shallower soil test (e.g. 0-10cm) would warrant a reduced lime rate. Leys might be sampled to 15cm and arable fields to 20cm.except when too hard to easily take a sample to this depth. A matrix can be supplied of different lime rates to attain pH 6.2, 6.5, 6.7 or 7.0 at depths of sampling (depth of action required) of 10, 15 or 20cm.

h) Because pH can be lower in the winter months than during the growing season, some trial sites could be monitored to follow seasonal fluctuations in topsoil (and subsoil) pH.

16. Overview of soil organic matter levels

Methodology

All data in this survey has been measured by Dumas method which involves removal of $CaCO_3$ by acid then burning at 900 °C and measuring total carbon produced (Total Organic Carbon). This has replaced the traditional Walkley Black method (see below). Organic matter is assumed TOC x 1.72.

A few samples were tested by the Loss on Ignition method. Figure 16.1 shows comparison on 8 pairs of samples in grass, arable and woodland. Textures were heavy loam or clay.

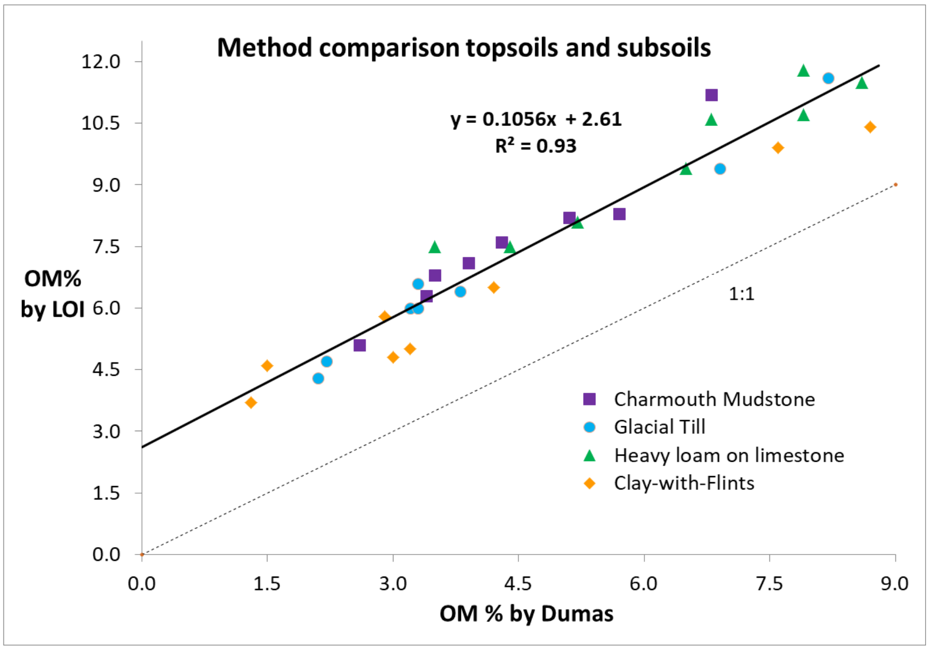


Figure 16.1 Comparison of methods for measuring organic matter

LOI gives significantly higher results especially for subsoils. Topsoil and subsoil fit the same line.

- the intercept of 2.6% corresponds to loss of structural hydroxyl from the clay minerals.
- the slope is slightly above 1:1 probably because carbon content of the OM is less than the 58% traditionally assumed (1.056 slope implies 55% C).

These discrepancies have been well researched by NRM laboratory (2018) [1] who found that LOI gave OM levels 27% higher than Dumas on clays. They also found the traditional WB method (wet oxidation with dichromate without added heat) gave results 7% higher than Dumas, probably because the 4/3 correction factor it uses was too generous. The version of WBlack that boils soil with dichromate instead of the correction (Tinsley method) was used until the past decade by ADAS and may give results closer to Dumas. Rothamstead and Lancrop laboratories now use TC analysers in conjunction with TIC analysers to give the TOC by subtraction.

- PAAG could cross-check that laboratories are giving similar results for TOC (and TIC), especially if OM results are to be used to assess soil quality (see last section).

Results by LOI are excluded from the data summary below.

Organic Matter in topsoil

The weighted median OM in arable soils is 4.5% though tending to be higher on some clays and lower on the Chilterns, which has a significant range of textures. Most arable topsoils lie in the 3-6% range (Moderate to Good in the SSEW classification).

In grassland topsoils the median OM is 6.4% (high), somewhat greater on clays and lesser on Chiltern and Glacial soils. More than half grass topsoils exceeded 6% OM, 8% were <3% OM. This is measured to 20cm plus depth, with likely higher OM concentrated in the surface 10cm on *permanent* grass.

Table 16.1 Geological grouping and soil organic matter (Dumas method median values)

	Arable		topsoil		**Grassland**		topsoil			
BGS maps	topsoil	subsoil	< 3%	> 6%	topsoil	subsoil	< 3%	> 6%	n	n
Charmouth Mudstone	**4.6**	2.7	-	4%	**4.7**	3.0	-	-	*56*	*2*
Whitby Mudstone	**3.5**	1.4	20%	-	**8.2**	2.3	-	100%	*6*	*3*
Horsehay Sand	**2.2**	1.3	100%	-	**5.8**	2.2	-	50%	*4*	*2*
Limestone & Clay	**-**	-	-	-	**8.1**	3.4	-	78%		*9*
Glacial Deposits	**5.7**	2.5	12%	32%	**4.0**	1.7	14%	14%	*25*	*6*
Oxfordian Clays	**4.4**	2.0	-	4%	**6.6**	2.6	-	44%	*43*	*18*
Ampthill & Kimmeridge	**5.0**	2.7	10%	10%	**7.8**	3.1	-	91%	*10*	*11*
Chilterns	**3.5**	1.1	31%	-	**4.5**	1.7	21%	25%	*29*	*24*
London Clay	**-**	-	-	-	**6.4**	2.1	9%	65%		*43*
Alluvium	**5.0**	1.9	-	33%	**8.5**	3.6	-	73%	*3*	*11*
Weighted median	**4.5**	2.2	11%	7%	**6.4**	2.4	8%	56%		

Differences between geological clay groupings (Table 16.1) are related to the proportion of grass/arable-ley versus arable-only farming, and not geology, except in the case of Alluvium where OM is higher because of greater propensity to wetness.

To evaluate the effect of texture class all data was pooled except amenity grassland.

Table 16.2 Region C: Topsoil Texture and organic matter, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	3.3 (3.1)	3.9 (5.2)	3.9	*13*	*9*	*2*
2	SCL, mCL, mZCL	3.5 (3.5)	6.5 (6.6)	7.7 (7.8)	*24*	*36*	*9*
3	hCL, hZCL	4.7 (4.9)	7.7 (7.4)	7.7 (7.8)	*40*	*73*	*28*
4	C, ZC	4.6 (4.6)	6.2 (6.6)	5.6 (8.2)	*108*	*34*	*8*
	Overall	**4.4** (4.4)	**6.7** (6.9)	**7.6** (7.7)*	*185*	*152*	*47*

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 ZC = silty clay, C = clay.

* excluding one sample of 41% OM Amenity grassland average was 5.7%, n = 28

As shown in Table 16.2 on arable sites, compared to heavy loams or clays, OM tended to be 1% lower on medium loam and 1.5% less on light loams. On grassland light loams are 2% lower than medium to clay soils. On Woodland overall levels are 8%. Across all land uses heavy loams have the higher OM than clays despite lower clay content. This may be a genuine effect although when hand texturing soils of > 6% OM it is quite difficult to distinguish reliably heavy loams from clays.

On large clusters of samples on Charmouth Mudstone and London Clay the 10-90% range was ±13% of the mean OM, less variable than the P or K.

Organic Matter in Subsoil

Tables 16.3 and 16.4 show that the median OM in arable subsoils is similar to grassland despite the higher OM in the overlying grassland topsoils (Table 17.2).

Table 16.3 Region C: *Topsoil* texture and Subsoil organic matter, medians (means)

Class	**Topsoil Texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	1.0 (1.6)	1.5 (3.1)	2.4	*13*	*9*	*2*
2	SCL, mCL, mZCL	1.3 (1.7)	2.1 (2.5)	3.5 (4.9)	*23*	*36*	*9*
3	hCL, hZCL	2.3 (2.4)	2.6 (2.7)	3.3 (3.8)	*40*	*73*	*19*
4	C, ZC	2.6 (2.5)	2.6 (2.8)	2.9 (3.3)	*104*	*34*	*7*
	Overall	**2.3** (2.3)	**2.4** (2.7)	**3.2** (4.2)*	*180*	*152*	*37*

* peaty sample had 16.6% OM in subsoil

Clay upper subsoils have similar values to heavy loam (or medium over clay) upper subsoils.

16.4 Table Region C: *Subsoil* texture and Subsoil organic matter, medians (means)

Class	**Subsoil Texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
0	LS, S	*1.0*	*2.8*	-	*7*	*1*	*0*
1	SL, SZL	1.4 (2.0)	1.5 (2.1)	*1.9*	*8*	*6*	*1*
2	SCL, mCL, mZCL	1.3 (1.7)	2.1 (2.4)	2.6 (2.3)	*13*	*16*	*4*
3	hCL, hZCL, SC	2.3 (2.4)	2.4 (3.2)	5.1 (5.8)	*15*	*26*	*14*
4	C, ZC	2.3 (2.4)	2.6 (2.7)	2.9 (3.7)	*143*	*99*	*18*
	Overall	**2.2** (2.3)	**2.4** (2.7)	**3.2** (4.2)*	*181*	*147*	*37*

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.

Amenity grassland overall is 2.3 (2.2) %.

Where subsoil texture is assessed (Table 17.4) the likely organic matter is:
sand (1%) < light loam (1.5%) < medium (2.0%) < heavy loam, clay (2.5%)

Using topsoil texture as a proxy (Table 17.3) subsoil OM is likely to be :
sand, light loam (1.5%) < medium (2.0%) < heavy loam, clay (2.5%)

For woodland increase by 0.5%

However there are relatively few subsoils in the light to medium categories, and robust statistical evaluation of differences is prevented by some extreme values.

Less than half (30-50%) of the variation in subsoil OM could be explained by topsoil OM. On some data sets the corer method could be 0.4% higher than auger, but even in clusters when only one method was used, more than half the variation in subsoil OM was unrelated to topsoil OM. Predictability was worse in cases of higher OM topsoil on grassland where subsoil could vary from low to good. Fitted equations indicate a ratio of subsoil to topsoil OM of 0.2-0.4x plus an intercept of 0-1.0%.

Table 16.5 : Predicted subsoil OM at six levels of topsoil OM

	m	c	**1.5**	**3.0**	**4.5**	**6.0**	**7.5**	**9.0**	error
Glacial light-medium	0.24	0.72	1.1	1.4	1.8	2.2			
Horsehay Sand	0.22	0.9	1.2	1.6	1.9	2.2			
Chiltern >25% stone	0.37	0.81	1.4	1.9	2.5	3.0	3.6		
Charmouth Clays	0.63	-0.1 *	0.8	1.8	2.7	3.7	4.6	5.6	0.74
Glacial Till	no	fit							
Oxfordian Clay	0.41	0.32 *	0.9	1.6	2.2	2.8	3.4	4.0	0.74
Kimmeridge Clay	0.2	1.54	1.8	2.1	2.4	2.7	3.0	3.3	0.94
Chiltern general	0.4		0.6	1.2	1.8	2.4	3.0	3.6	0.75
London Clay med.	0.3	0.75	1.2	1.7	2.1	2.6	3.0	3.5	
London Clay	0.3			0.9	1.4	1.8	2.3	2.7	0.5
Alluvium grass	0.39			1.2	1.8	2.3	2.9	3.5	
Woodland heavy	0.29	1.4		2.0	2.3	2.6	2.9	3.2	
Heavy soils		mean	**1.1**	**1.5**	**2.1**	**2.6**	**3.1**	**3.7**	

Subsoil OM = Topsoil OM x m   +   c   * increase 0.2 if corer and decrease 0.2% if auger

As shown in Table 16.5 at topsoil OM 3% the subsoil is typically 1.5% and for every 1.5% increase in topsoil OM subsoil increases by 0.5% so that at 7.5% topsoil OM subsoil is likely to exceed 3%. However the standard error of most equations is >0.7% OM indicating large uncertainty in prediction: carry-down of crop residues into subsoil may vary according to degree of or lack of cultivation, earthworm activity and rooting depth. Start depth of subsoil sample is also important because OM% decreases with depth over the 25cm to 50cm range.

On light to medium soils at topsoil OM 3% subsoil also is ~1.5%, but liable to be somewhat higher on stony soils possibly because OM tends to be more readily carried-down by earthworms or deeper rooting. Stones concentrate the OM% in the subsoil, which is typically 0.5% higher than comparable non-stony soils.

Woodland

Data is shown in Figure 16.2. OM may be moved into heavy loam subsoils more readily than into clay subsoils

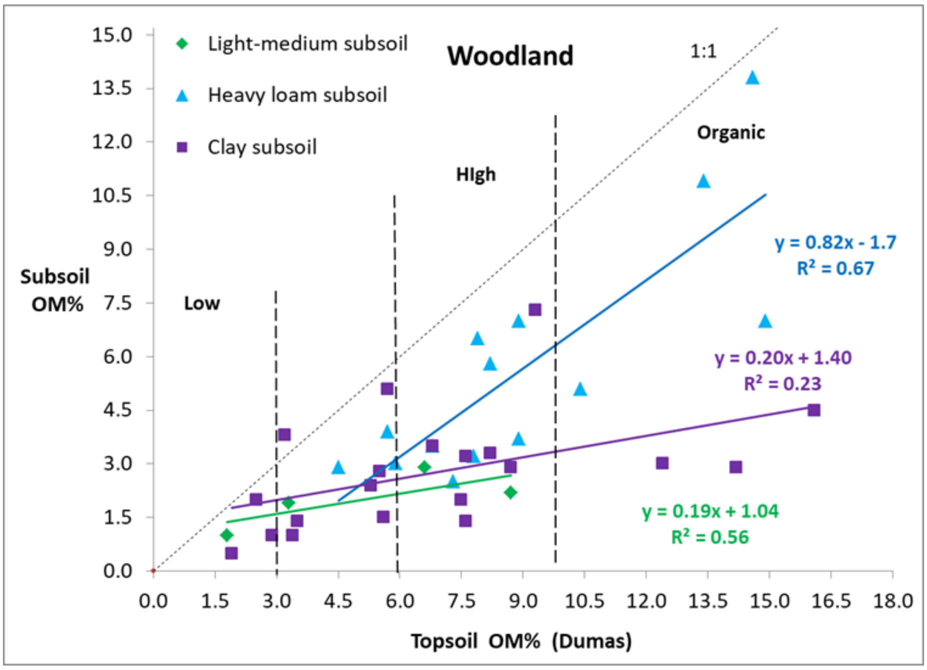


Figure 16.2 Region C Organic Matter in Woodland

Soil Organic Matter Index

This is a system for indexing UK soils recently proposed by Rothamstead (Prout et al. 2020)[2] as explained in section 2. The ratio of clay to SOC is seen as critical to soil quality with >13:1 considered as 'degraded', 10-13 as 'moderate quality', 8-10 as 'good quality' and <8 as 'very good structural condition'.

When Prout et al. used their method to index 3809 National Soil Inventory samples, 38% of arable, 15% of leys 7% of permanent grassland and 6% of woodland samples were in the "degraded class". Table 16.6 indicates that in this data (Southern region) 65% of the arable land is classed as degraded, 13% of the grassland and 19% of the woodland.

Table 16.6 Region C: Organic Matter Index and Land Use

Class	**Topsoil Texture**	**Arable**	**Leys**	**Perm. Grass**	**Wood**	***n***	***n***	***n***	***n***
A	very good	8.3%	52.7 %	72.0%	75.7%	*15*	*49*	*36*	*28*
B	good	9.4%	18.3 %	10.0%	-	*17*	*17*	*5*	-
C	moderate	16.7%	15.0 %	6.0 %	5.4%	*30*	*14*	*6*	*2*
D	degraded	65.4%	14.0 %	12.0 %	18.9%	*117*	*13*	*3*	*7*
						179	*93*	*50*	*37*

90% of the arable soils on Lias Mudstone are classed degraded and 70% on the Oxfordian / Kimmeridge Clays and Alluvium (Table 16.7). On Glacial Soils and in the Chilterns a spread of categories was present. Grassland has representation in all categories with >25% degraded in the Chilterns and on Oxfordian clays.

Table 16.7 Geological grouping and Organic Matter Index of Topsoil

BGS maps	Clay:SOC	Arable % in class D	C	B	A	Clay:SOC	Grassland % in class D	C	B	A	n	n
Charmouth Mudstone	**15**	*91*	*9*	-	-	9.9	-	*50*	-	*50*	*56*	*2*
Whitby Mudstone	**17**	*100*	-	-	-	**6.5**	-	-	-	*100*	*6*	*3*
Horsehay Sand	**11**	*50*	-	*50*	-	**5.1**	-	-	-	*100*	*4*	*2*
Limestone & Clay	**-**	-	-	-	-	**6.1**	*11*	*22*	-	*67*		*9*
Glacial Deposits	**9.4**	*27*	*12*	*35*	*26*	**7.5**	-	*17*	*33*	*50*	*26*	*6*
Oxfordian Clays	**16**	*75*	*23*	*2*	-	**11**	*33*	*34*	*22*	*11*	*43*	*18*
Ampthill & Kimmeridge	**15**	*70*	*20*	*10*	-	**7.6**	-	*18*	*9*	*73*	*10*	*11*
Chilterns	**11**	*31*	*24*	*21*	*24*	**8.4**	*25*	*13*	*21*	*41*	*29*	*24*
London Clay	**-**	-	-	-	-	**6.5**	*12*	*12*	*9*	*67*		*43*
Alluvium	**15**	*67*	-	-	*33*	**8.6**	*9*	*9*	*36*	*45*	*3*	*11*
Weighted median	**13.8**	*66*	*15*	*11*	*8*	**7.5**	*15*	*16*	*15*	*54*		

Table 16.8 indicates that topsoil texture was the major factor influencing the index. On arable land 8% of light loams were rated as degraded which jumped up to 37% on medium and heavy loams and >90% on clay-textured topsoils. The proportion in the very good class (A) fell from 54% of light loams to 0% of clays. Grassland showed a similar trend with no degraded light loam topsoil versus 11% of heavy loam and 30% of clay topsoils. Woodland is in very good class except when clay textured where 57% fell into the lower two classes.

Table 16.8 Region C Organic Matter Index according to topsoil texture

Topsoil Texture	Clay: SOC	Arable D	C	B	A	Clay: SOC	Grassland D	C	B	A	Clay: SOC	Woodland D	C	B	A
SL, SZL	7.9	*8*	*15*	*23*	*54*	5.7	-	-	*22*	*78*	5.9	-	-	-	*100*
SCL, mCL, mZCL	12.0	*38*	*33*	*24*	*5*	6.6	*7*	*2*	*5*	*86*	6.8	*13*			*87*
hCL, hZCL	12.4	*36*	*29*	*20*	*16*	8.2	*11*	*10*	*16*	*63*	8.3	*20*	-	-	*80*
ZC, C	16.2	*91*	*9*	-	-	12.1	*30*	*33*	*20*	*17*	12.7	*28*	*29*	-	*43*
Overall	**14.3**	*64*	*17*	*9*	*8*	**8.5**	*15*	*12*	*13*	*60*	**8.4**	*19*	*5*	-	*76*

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
ZC = silty clay, C = clay.

On amenity grassland Clay:SOC ratio was 6.9 with 71% in A category

Discussion of OM Index system

Typical OM levels in topsoils in this region range from 3.1% on light loams to 4.6% on heavy loams or clays, similar to the Midlands data set (3.4 to 4.4%). This is a 1.5x increase in OM whereas the heavier textures have two to four times as much clay as light loams. Therefore, use of an fixed clay:SOC ratio is bound to penalise heavier soils and especially Southern clays ('pelosols') as recognised in [3].

The general impression of the heavy soils in this survey was that the soil structural condition was not too bad and they are normally sown to high yielding cereals (except in the very wet 2019 autumn). Subsoil structure is not covered by the index system, but is very important, influenced by land management, $CaCO_3$ content and earthworm activity. Good field drainage and adequate subsoiling are critical.

For a heavy loam topsoil of 31% clay, SOM needs to exceed 4.1% to escape the threshold of the "degraded" category and a "Good" rating requires > 5.4%. This is feasible.

However a topsoil of 42% clay, SOC needs to exceed 5.5% to escape the threshold of the degraded category and a "Good" rating requires >7.2%. This certainly should give good workability and, countering the stickiness due to the high clay content, and be less prone to slumping. However >7% might be difficult to attain and sustain except in the surface.

To raise soils from 4.5 to 5.5% OM requires large inputs of carbon (15 t/ha* equivalent to at least 170 t/ha of manure^, not allowing for oxidative losses that are likely to require 3 or 4x this amount). Furthermore earthworms will move some of the OM down into the subsoil

* 1 ha to 25cm depth is at least 2,500 t   ^ manure of 25% dry solids with 35% carbon.

Even with use of ley breaks or FYM or sewage sludge or manure incorporated 3 yearly, sustaining > 7% to any meaningful depth might be difficult. However these measures certainly stimulate earthworm activity and should improve phosphorus supply.

In contrast on loamy sand and light loamy soils[3] the Index is very sensitive to small changes in OM% (and clay content). 2% OM is deemed very good on loamy sands, whereas the same structure rating is difficult to attain on clay soils, on which "degraded" might be better termed "would benefit from improvement." Ratios might need review here?

Other comments :

$CaCO_3$: the presence of natural lime in soils is known to stabilise clay and organic matter making soils granulate and cultivate more easily. In this data set there were few obvious trends of topsoil OM% increasing with pH, though the author finds OM higher on calcareous than non-calcareous topsoils on Chalkland. Sustaining pH >7 could benefit structure over-and-above its improvement of OM.

Depth of sampling: these samples were taken to depth of identifiable topsoil (at least 20cm on grassland and up to 30cm on arable land). Where farmers are shallow cultivating or minimally tilling the OM%, measured will be higher if sampled only to 15cm. A friable 0-12cm frequently belies a second topsoil horizon (12-25/30cm) denuded of organic matter and often characterised by very firm coarse blocky structure with reduced rooting. Clearly sampling depth needs to be standardised for fair Index comparison, for example 0-20cm.

Upper Subsoil : organic material in this layer is important because it improves porosity and access to nutrients. Achievement of adequate OM in the 20-40cm should be equal priority to the top 20cm. A sampling protocol is suggested below :.

- Depth of topsoil sampling for assessment to be standardised at 0-20cm.
- 20-40 cm sample may be worthwhile. The latter should have minimum of 2.5% OM.
- 40-50/55cm sampling is sometimes useful. This layer has much lower OM and P and could be used to assess risk of transmission into field drains.

Topsoil could be uprated where pH remains >7.4 and subsoil uprated if >pH 7.4 or >2% $CaCO_3$ since this is well known to improve structural stability significantly.

Analysis : measurement by LOI method increases OM by at least 2.5% on heavy soils (see above) raising the index by at least 2 grades. Clearly LOI is and unsuitable method. With Chalk soils some laboratories may crush soft chalk stones into the sample reducing the overall OM%. There are also issues of measurement on clay content, especially on calcareous soils where $CaCO_3$ may comprise a significant proportion of the clay content but not be sticky.

Carbon stocks

Carbon held in soil profile is <u>not</u> simply proportional to measured OM% because storage 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 depths but expressing at standardised 0-25cm and 25-50cm.

Mean calculated carbon 0-50cm depth was 122 t C/ha on arable land increasing to 153 t C/ha on grassland and 184 t C/ha under woodland. This compares with 95, 137 and 160 t respectively in the Midlands data and 125 t and 170 t/ha (no wood) in the north east Carboniferous soils.

In arable soils 40% of Organic Carbon was in the 25-50 cm layer, 33% in grassland.

The calculation method needs peer review and verification before more details can be given.

References

[1] NRM laboratory 2018. Advice Sheet 38: Soil Organic Matter/Carbon – which method to use?

[2] https://presentations.copernicus.org/EGU2020/EGU2020-19010_presentation.pdf

[3] https://onlinelibrary.wiley.com/doi/epdf/10.1111/ejss.13012

R values at typical topsoil OM and clay contents

Texture category	Clay content	OM 1.5%	OM 2%	OM 3.0%	OM 4.5%	OM 6.0%	OM 7.5%
LS	9 %	0.41	1.08	2.4	4.4	6.4	
SL, SZL	13 %	-0.21	0.26	1.2	2.6	4.0	5.4
SCL, mCL, mZCL	22 %		-0.50	.05	0.87	1.7	2.5
hCL, hZCL	31 %		-0.82	-0.43	0.15	0.74	1.3
ZC	38 %			-0.65	-0.17	0.31	0.78
C	42 %			-0.74	-0.31	0.12	0.55

R = ((OM% x 0.58 /clay %) – 0.0769) / 0.0481
R >1 Very good, R 0.48-1 Good, R 0-0.48 Moderate, R <0 Degraded

17. Total Nitrogen overview

Regions B and C: Southern and Midlands

Total Nitrogen 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 limits with organic matter measurement being 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 of 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 not as representative as the more widely spread PKMg pH and OM data.

Table 17.1 Region C (Southern) : Soil Total Nitrogen % (where measured)

	Topsoil			Upper Subsoil			
	mean	**median**	**10-90%**	**mean**	**median**	**10-90%**	***n***
Arable	0.30	**0.30**	0.22-0.38	0.17	**0.18**	0.11-0.23	*46*
Grassland	0.49	**0.46**	0.28-0.62	0.21	**0.19**	0.12-0.36	*38*
Amenity Grass	0.32	**0.32**	0.25-0.40	0.14	**0.13**	0.07-0.19	*22*
Wood	0.59	**0.45**	0.30-0.63	0.26	**0.23**	0.13-0.44	*31*

The average total N on arable samples was 0.3% on arable and amenity grass, 0.45% on grassland and woodland. The medians in Table 17.1 are higher than found in the Midlands data (0.19, 0.24, 0.21 and 0.28% respectively). This is linked to higher soil organic matter in the Southern data which comprises mainly heavier soils.

Of the arable samples 15% had > 0.34% N triggering a 40 kg/ha reduction in nitrogen requirement (see above and RB209 p16) and 74% were 0.23-0.34% corresponding to a reduction of 20 kg/ha, 11% warranted no adjustment. See conclusion.

TN in subsoil averages 0.18% arable, 0.23% grass, 0.13% amenity and 0.23% wood. These are much higher than in the Midlands (medians 0.10, 0.12, 0.8 and 0.14% respectively) which had a greater proportion of lighter, lower OM subsoils.

Total Nitrogen and texture

Soil texture did not have a clear relationship with TN (Tables 17.2 and 17.3) however the representation of lighter textures is low in the Southern region.

Table 17.2 Region C: Topsoil Texture and Total Nitrogen, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	-	0.35	-	*-*	*2*	*-*
2	SCL, mCL, mZCL	0.37 (0.34)	0.31 (0.30)	0.56 (0.60)	*4*	*23*	*5*
3	hCL, hZCL	0.30 (0.34)	0.53 (0.51)	0.38 (0.43)	*10*	*31*	*21*
4	C, ZC	0.29 (0.28)	0.38 (0.37)	0.35 (0.34)	*32*	*4*	*5*
	Overall	**0.30** (0.30)	**0.38** (0.41)	**0.39** (0.44)	*46*	*60*	*31*

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 ZC = silty clay, C = clay.

Table 17.3 Region C: Subsoil Texture and Total Nitrogen, medians (means)

Class	**Topsoil texture**	**Arable**	**Grass**	**Wood**	***n***	***n***	***n***
1	SL, SZL	-	-	-	*-*	*-*	*-*
2	SCL, mCL, mZCL	0.10	0.11 (0.11)	-	*2*	*8*	*-*
3	hCL, hZCL	0.18	0.15 (0.21)	0.30 (0.37)	*1*	*9*	*13*
4	C, ZC	0.18 (0.18)	0.18 (0.22)	0.16 (0.17)	*43*	*43*	*18*
	Overall	**0.18** (0.17)	**0.17** (0.20)	**0.22** (0.25)	*46*	*60*	*31*

Measurement of Carbon : Nitrogen ratio

Most soil nitrogen resides in the organic matter so TN and Total Organic Carbon tend to be well correlated (see later). Text books say it is about 10:1 in well-humified SOM.

In a few data OM was measured by LOI method and Carbon estimated dividing by 1.72.

Table 17.4 Region C: Carbon: Nitrogen ratios (mean with standard deviation)

		Carbon by Dumas		Carbon from LOI *		*n*	*n*
Arable	Topsoil	9.3	± 0.9	14.1	± 2.1	*36*	*10*
	Subsoil	8.7	± 1.0	20.5	± 5.4		
Grassland	Topsoil	10.4	± 4.4	12.7	± 1.5	*29*	*9*
	Subsoil	8.3	± 2.4	16.4	± 4.6		
Amenity Grass	Topsoil	10.6	± 1.3			*22*	*-*
	Subsoil	10.5	± 3.1				
Woodland	Topsoil	11.6	± 4.4	16.1	± 2.5	*16*	*19*
	Subsoil	10.9	± 4.9	17.7	± 3.1		

* Loss on Ignition divided by 1.72

The Dumas method agrees with the 10:1 norm (arable sites 9.5, grass 10.5 and woodland 11.5). This is very similar to the Midland data (means 10.5, 11.1 and 12.1 respectively). Subsoil tends to be slightly lower C:N than topsoil on all land uses.

However when Carbon was calculated from an LOI measurement (18 data only), C:N values averaged 13-16 in topsoil and subsoil 16-20. The higher apparent C:N in *subsoils* (which tend to lower OM) is confirmation that LOI is overestimating the carbon by a constant rather than proportional amount, distorting subsoil C:N values enormously and wrongly implying they are liable to lock up nitrogen. See OM Overview section.

What causes C:N ratio to vary?

For this the larger Midlands data set was combined with the southern data. Combined median TN is 0.22% in arable and leys increasing to 0.30% on permanent grass and 0.36% in woods. C:N averages 10.2 ,10.8 and 12:1 respectively.

Table 17.5 Regions B plus C : Total Nitrogen % and C:N ratio

	Topsoil TN%		**Subsoil TN%**		Topsoil C:N		Subsoil C:N		*n*
	mean	**median**	mean	**median**	mean	stdev	mean	stdev	
Arable	0.22	**0.22**	0.12	**0.11**	10.2	± 1.9	9.7	± 2.6	*128*
Leys	0.24	**0.22**	0.11	**0.10**	10.2	± 2.5	9.7	± 2.6	*136*
Extensive Grass	0.32	**0.31**	0.16	**0.15**	10.8	± 2.7	10.4	± 3.1	*126*
Amenity Grass	0.29	**0.28**	0.14	**0.13**	10.7	± 1.5	10.4	± 2.6	*31*
Wood	0.38	**0.36**	0.20	**0.16**	12.2	± 3.4	11.7	± 3.1	*63*

The arable data has been partitioned by topsoil texture in the Figures that follow. C:N 10:1 is equivalent to a slope of 0.058.

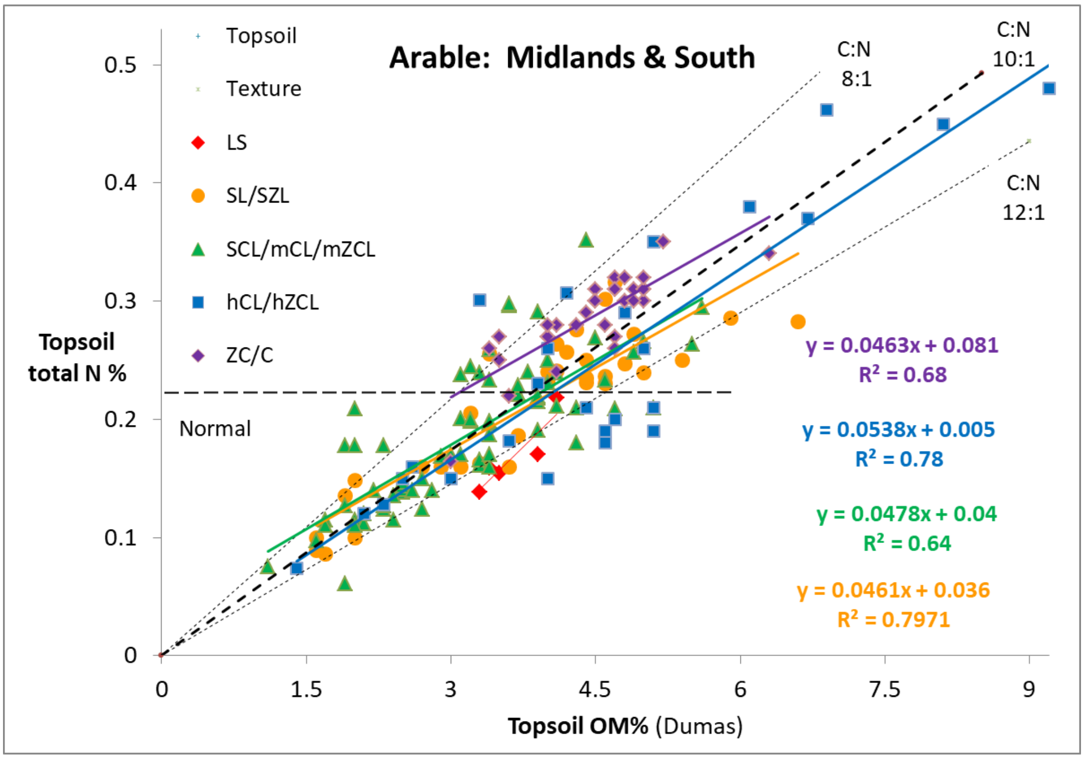


Figure 17.1 Regions B and C Arable data : Organic Matter and Total N in topsoil

In arable topsoil (Figure 17.1) light loam, medium and heavy loam textures fit to similar lines with intercept of ~0.04 and slope 0.048. C:N declines as OM (and TN) increase, and at >3% OM C:N is below 10 except in clay topsoils which have a step increase of ~0.04% TN although most of this data is confined to fields on Charmouth Mudstone. Most data lies in the C:N 8 to 12 window.

When data is plotted for subsoils in Figure 17.2 the clay subsoils again fit to a higher line, now including some clay subsoils on Glacial Till and Red Mudstone. Medium and heavy loams fit to a lower common line and light loamy and sand subsoils are lower, with C:N >12:1 for the latter compared to clay subsoils of 8-9:1. All lines fit to a similar intercept.

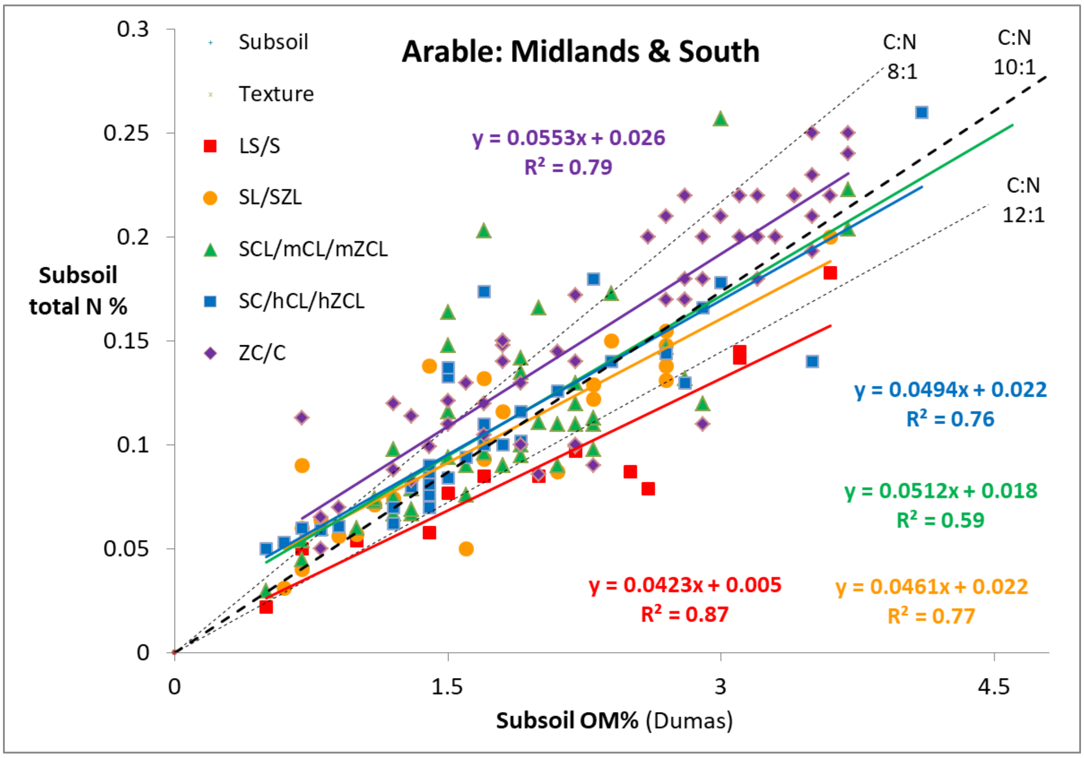


Figure 17.2 Regions B and C Arable data organic matter and total N in subsoil

Grassland topsoils are Figure 17.3. Few were hand-textured as clay. The plots show clear separation of heavy loams which adhere to C:N 10 line, with progressively lower slopes on medium loams (C:N 11), light loams (12) and sands (14). The latter again have intercepts of about 0.04%.

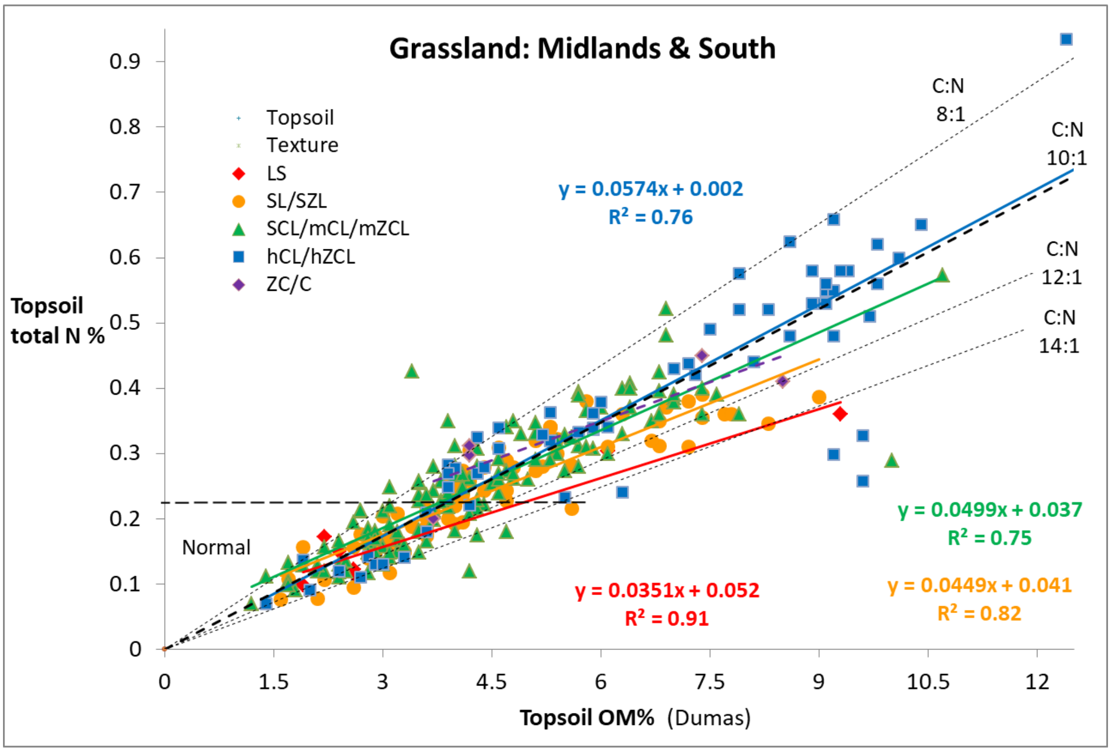


Figure 17.3 Regions B and C Grassland data Organic Matter and Total N in topsoil

Grass subsoils (Figure 17.4) again show lesser slopes on medium and light textures. Sand subsoils are C:N 14. The heavy loam plot is influenced by a few high values, and not significantly different from the clays which adhere approximately to the 10:1 line (intercept 0.02). Most data is in the 8-14:1 corridor but a few heavy subsoils have unexpectedly high TN. In some cases this might be linked to high groundwater.

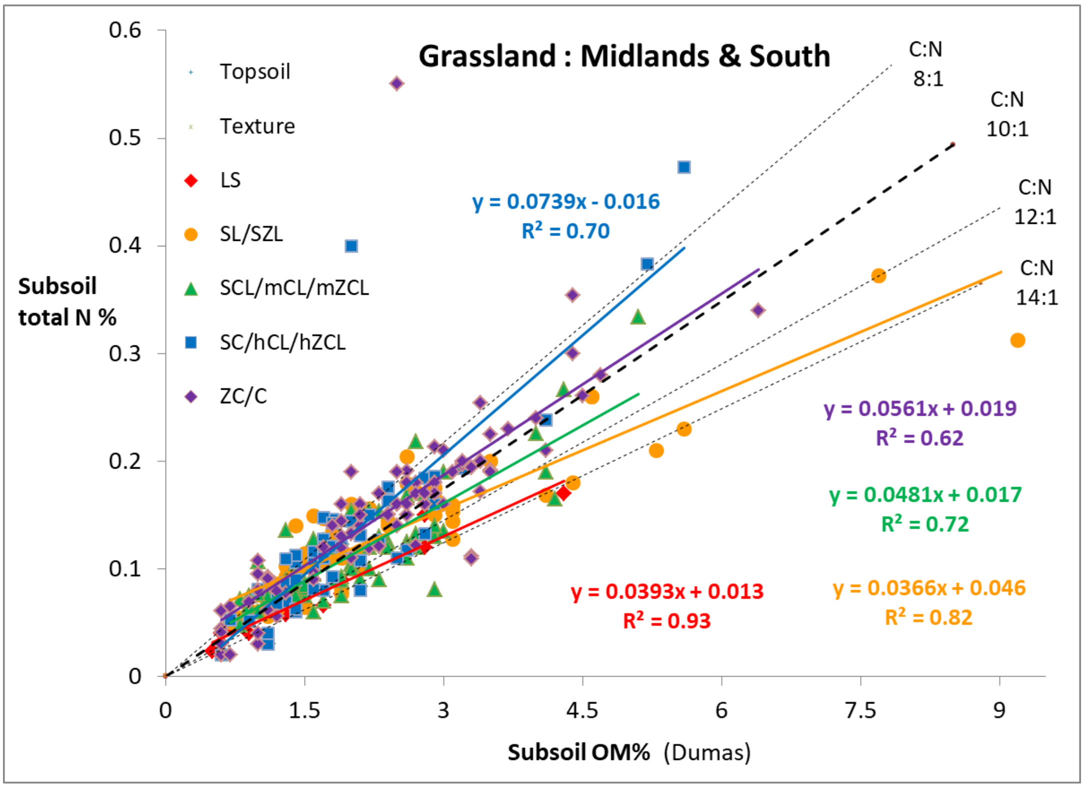


Figure 17.4 Regions B and C Grassland data Organic matter and Total N in subsoil

Woodland

This data spans OM levels up to 20% with very clear evidence of declining C:N in the 'organic' (10-20%) range. The fitted lines are not dissimilar to arable and grass (intercepts of 0.04- 0.08 and slopes ~0.44). Medium and heavier loams fit to the same line, light loams and sands to lower slopes.

The lighter topsoils tended to be acid. There is negative correlation of C:N ratio with pH (except on heavier soils). However there is also a negative correlation of pH with OM (Appendix 17), so it is likely that acidity has caused the build-up of high OM with resulting reduction of N in relation to C. The presence of some acid 'Mor' humus in the surface of topsoil sample cannot be the main reason for high C:N because high C:N is also seen in the subsoils. There was no relationship of C:N to pH for the grassland data.

The fitted line for light loam soils is identical to arable data suggesting that the relationship of C:N increasing with increasing OM level, is not peculiar to (acid) woodland soils.

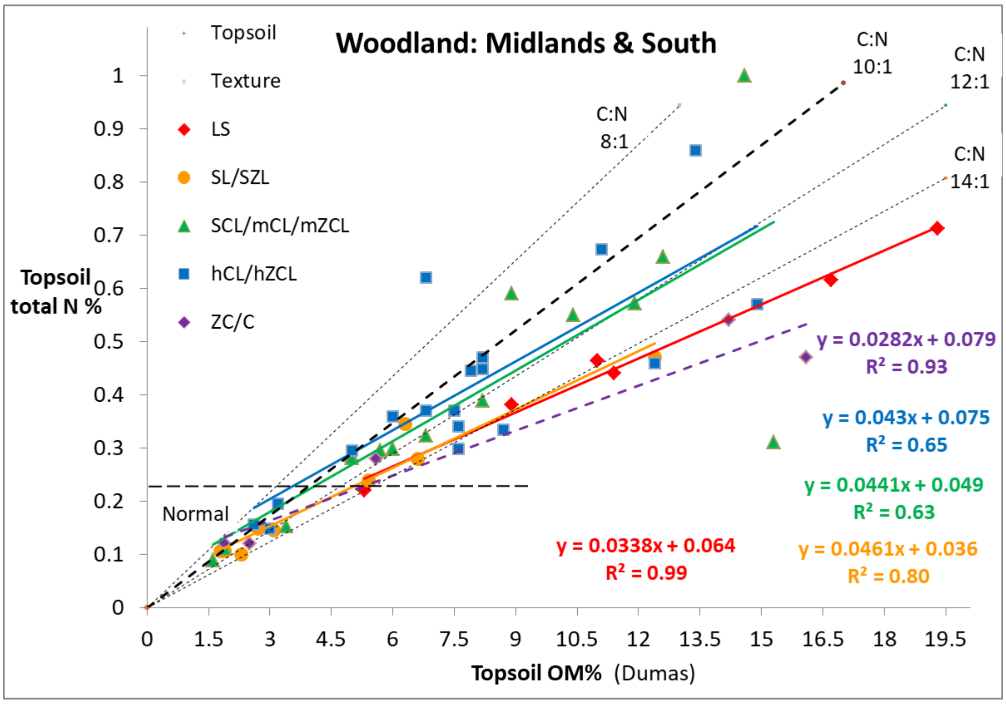


Figure 17.5 Regions B and C Woodland: Organic Matter and Total N in topsoil

Woodland subsoils have more OM than arable but fit to very similar lines with lower sloping lines in medium loams, light loams and sands. Heavy loams and clay subsoils adhere closely to the 10:1 line.

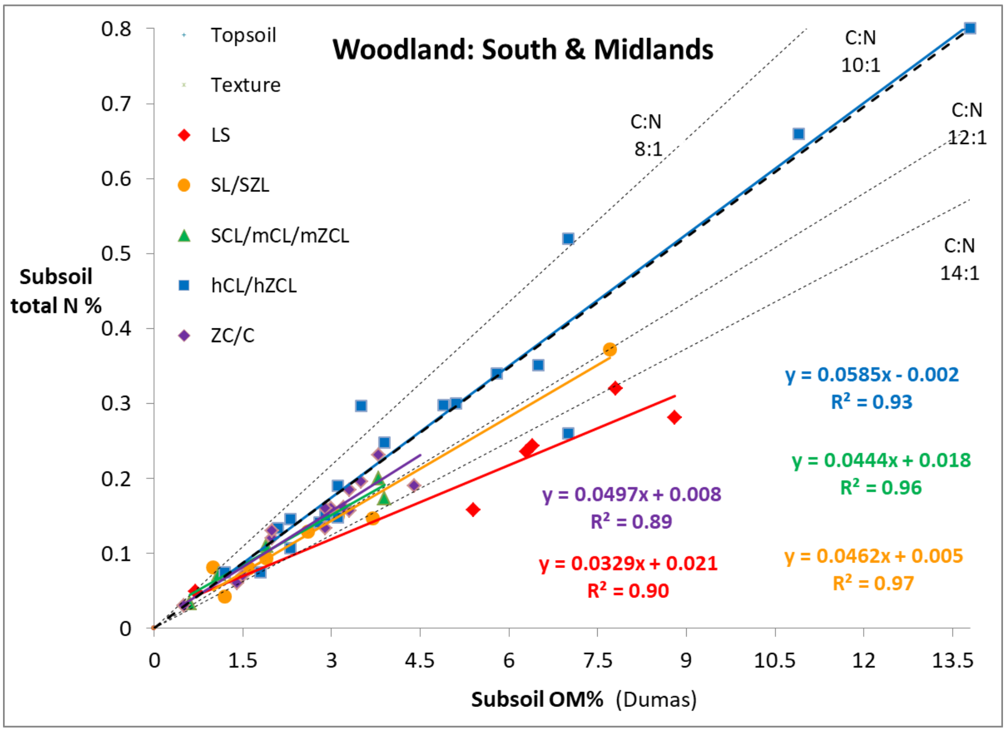


Figure 17.6 Regions B and C Woodland: Organic matter and Total N in subsoil (one clay point omitted {4.6,0.11}

Prediction of Total N from organic matter measurement

In this data, using Dumas method to measure both carbon and nitrogen, the 10:1 ratio is about right with most soils lying in the 8-12:1 range except for light subsoils at high OM. However C:N clearly shows a tendency of decreasing as OM rises and this is influenced by soil texture with C:N highest in sands and lowest in clays. The intercept is lower in subsoil than topsoil.

In order to generate equations arable, grass and wood data was combined, obvious outliers discarded and all samples excluded of OM >10% in topsoil or > 6% in subsoil. Results are shown in Table 17.6.

Table 17.6 Regions B and C : Predicting Soil Total Nitrogen from Organic Matter measured by Dumas Method Up to 10% OM in topsoil and 6% in subsoil

Texture	Class	Equation	r^2	C:N mean	std dev	TN % mean	*n*
Sandy	Topsoil	TN = OM x 0.037 + 0.041	0.93	12.2	± 1.9	0.19	*15*
	Subsoil	TN = OM x 0.042 + 0.009	0.89	9.9	± 2.4	0.08	*29*
Light loam	Topsoil	TN = OM x 0.045 + 0.037	0.83	10.8	± 1.7	0.23	*121*
	Subsoil	TN = OM x 0.041 + 0.032	0.77	10.2	± 2.4	0.12	*86*
Medium	Topsoil	TN = OM x 0.054 + 0.017	0.82	10.1	± 1.9	0.23	*120*
	Subsoil	TN = OM x 0.050 + 0.017	0.69	10.1	± 2.5	0.11	*114*
Heavy loam	Topsoil	TN = OM x 0.055 + 0.009	0.79	10.7	± 2.5	0.33	*98*
	Subsoil	TN = OM x 0.058 + 0.006	0.87	9.9	± 2.5	0.13	*96*
Clay	Topsoil	TN = OM x 0.048 + 0.069	0.77	9.3	± 1.1	0.28	*39*
	Subsoil	TN = OM x 0.054 + 0.020	0.82	9.5	± 2.4	0.15	*160*

In all cases except heavy loams the intercept is highly significant

The slopes are also significantly different according to topsoil texture
sand < light loams < medium, heavy loam, clay

Slopes are different according to subsoil texture :
sands, light loams < medium < heavy, loam clay

Using these equations to predict TN is better than simply assuming a C:N ratio of 10:1 although they have a standard error of ~0.04% in topsoil and 0.02-0.03% in subsoil (see Appendix 17). About 20% of the variation in TN is not accounted for by texture or OM level ($r^2 = 0.8$) and a few places the C:N is very different from the prediction.

Why does C:N ratio vary?

This data shows conclusively that C:N increases with increasing organic matter and decreases with clay content and the plots do not pass through the origin. Four explanations are hypothesised for this:

1) analytical: Dumas does not measure all the carbon attached to clays. This is very unlikely because of the high temperatures involved (> 900°C). Moreover TN was measured on the same fine ground sample by the same analyser.

2) mineral nitrogen: the Dumas technique used for total N includes nitrate-N and ammonium-N and these are known to vary seasonally and with management. Mineral N in topsoil varies from 20 to perhaps 150 kg/ha following a recent application of fertiliser (yet to be used by crop). Such values are small in comparison to intercepts in the fitted equations of 0.01 to 0.04 which in a 0-25cm sample* equate to 320-1,300 kg N/ha. So hypothesis 2) is <u>not</u> a sufficient explanation for the intercepts. * density 1.33 g/cm^3

3) non-exchangeable ammonium: perhaps significant amounts are trapped inside clay minerals (analogous to non-exchangeable potassium). This capacity is finite and clearly linked to clay content (textural class) and is unlikely to increase with increasing OM. However if 3) were the main explanation of the intercepts it would amount to 1000-4000 mg/kg NH_4-N which is highly unlikely given that 14g of NH_4-N is equivalent to 39 g of K.

4) organically bound- nitrogen exists in two phases – in a 'free' humic phase (of C:N about 12:1?) and in humic-clay-N complexes of inherently lower C:N. ratio. OM bound up with clay minerals may tend to a natural equilibrium of 10% clay:SOC alluded to by Prout (2020). It is possible that once the humic-clay-bound nitrogen reaches a maximum, with further increases in organic matter, more nitrogen resides in the 'free' humic form which although it has proportionally lower N content, is far more likely to mineralise for crop use.

If hypothesis 4 is true then crop-mineralisable N is not proportional to the TN as is commonly proposed but related to {Total N minus humic-clay N}.

If hypothesis 3 is significant then it needs quantifying for UK soils. Some non-exchangeable NH_4-N also may become available during the growing season which is not detected by the normal technique for extracting mineral N (ammonium exchanged by KCl extractant).

Summary

A large subset of data was analysed for Total Nitrogen although in small clusters so caution must be taken in extrapolating them to generalised values for the region(s).

TN in the Southern Region soils averaged 0.3% on arable and amenity grass and 0.45% on agricultural grassland and woodland, about 0.1% higher than found in the Midlands data set, and almost certainly due to the preponderance of heavier soils with higher organic matter in the Southern region.

Typical C:N ratio was 9.5 in arable land, 10.5 in grassland and 12 in woodland, and was slightly lower in subsoil than topsoil. In a small subset, OM was measured by Loss on Ignition with carbon estimated by dividing OM by standard 1.72 factor. This gave very high apparent C:N ratio of 13-16 in topsoil and 16-20 subsoil, which are erroneous for reasons discussed in the Carbon overview, and misleading. LOI method must never be used for gauging the C:N ratio or TN in soils.

When the Southern data was combined with the Midlands data it was evident that **C:N ratio reduces in soils of higher clay content and increases with increasing organic matter content.**

Different relationships were found for different textural classes regardless of whether arable, grass or wood, topsoil or subsoil. The higher C:N of woodlands is because many samples were in the organic range (10-20%) compared to few on grassland and almost none on arable land. The presence of 'mor' humus in some of the acid topsoils does not seem a significant influence.

In soils of normal OM content (<10%) C:N typically was 12 in sands, 10 in medium soils and 9.5% in clays. When modelled according to texture class all soil types had an intercept at theoretical zero OM (no carbon) of 0.02-0.04% in topsoil and 0.01-0.03 in subsoil. The slope, TN / OM (by Dumas) increased from 0.4 in sandy and light loams to 0.55 in medium to heavy soils (still below the 0.58 implied if C:N = 10).

Improved equations are given for predicting TN based on an OM measurement (by a TOC method), however these still leave a standard error of 02-0.04% TN in topsoil samples. Sometimes TN was unduly low or high for reasons not easy to explain. Soils sampling close to a nitrogen fertiliser application was not a likely cause, given the 0-20/25cm sampling depth, and clearly cannot explain high unduly high TN registered in some subsoils. High TN may accumulate in some waterlogged subsoils.

RB209 relevance: the 2012 HGCA wheat guide states that mineralisation giving crop-available N is related to Total N and that TN can be estimated from soil organic matter (assuming a C:N 10:1). Accordingly, RB209 suggests adjustment of N recommendations allowing for some mineralisation if OM is above 4%. The following points are relevant :

- OM calculated by LOI method is invalid and misleading if used for above purpose. Direct TOC methods like Dumas must be used.
- Based on a correct OM (carbon) measurement, N lies in range 8-12:1. TN is likely to be lower than prediction based on 10:1 in soils of above normal OM or lighter textured.

Prediction is much improved by the equations in this report, however standard errors of ±0.04 N still remain.

- In laboratories where N is measured on the same sample and machine as TOC, TN could be measured routinely with OM for minimal extra cost as a standard package.
- Soil samples should not be taken close to an application of N fertiliser or manure which might distort the total N.
- The author hypothesises that Total N exists in four different forms
    a) Soil Mineral N (as normally measured)
    b) non-exchangeable ammonium (inside clay minerals)
    c) N in clay-organic complexes
    d) N organically held in 'free' humus

a) is very small in relation to total N, however the contribution of b) is worth checking. It is very likely that nitrogen in c) is significant in quantity but the N in d) is more liable to mineralise than c). Accordingly, estimation of d) (and b) together with measurement of TN could provide a better handle for predicting the nitrogen likely to be mineralised to crops.

18. Short-range variation in soil nutrient levels

Regions B and C: Southern and Midlands

The Southern data contains some large clusters of samples taken at close spacing of about 5 per hectare, which amounts to less than 50m between sampling points.

Under Precision Farming in the UK, soil tests are taken one per hectare, or analysed in zones of 1 to 5 hectares depending on soil type variation. Closer sampling is not commercially viable for agriculture.

The close-spaced samples in this data base enable some estimation of the short-range variation of soil nutrients, that which in practical terms is "unmappable."

Method of data processing

The large cluster samples are divided into small clusters of 4 adjacent samples, each within an area of 1 hectare. For each small cluster, mean and standard deviation values are ascribed.

Other smaller cluster data sets are treated likewise, usually grouped in 3 or 4. Only samples taken by corer (0-20 or 25cm) were selected as these are depth-standardised and so less subject to variation than samples taken from auger.

Where large changes in topsoil texture occurred (more than one category) within a cluster, the small cluster groups were arranged to exclude such points.

Data is included from the Midlands-NW region; a total of 67 useable small cluster groupings were identified, 19 arable, 32 grassland, 6 amenity and 10 woods. The standard deviation is plotted against the small cluster mean nutrient in Figures 18 and summarised in Tables 18.

Topsoil textures represented range from sandy loam to heavy loam.

Phosphorus

For the arable samples the standard deviation is proportionate to the mean P of the small cluster and typically ±15%. Grassland is more variable (± 25-30%) which might be expected especially if (historically) manured or grazed, where nutrient recycling is more uneven.

Accordingly, for a soil sample measuring mid index 2 (20 mg/l) the short-range variation is 17-23 mg/l (± 3 mg/l) for arable and 15-25 (± 5 mg/l) mg/l for grassland.

Based on the assumption that soils need to be above index 1 (>15 mg/l) to diminish risk of deficiency, it is imperative that farms *maintain mid index 2* to ensure that no areas are deficient. At index 3 greater variation (± 6-10 mg/l P) is likely. This all points to the need to take thorough composite samples in well-defined areas when monitoring changes in soil P.

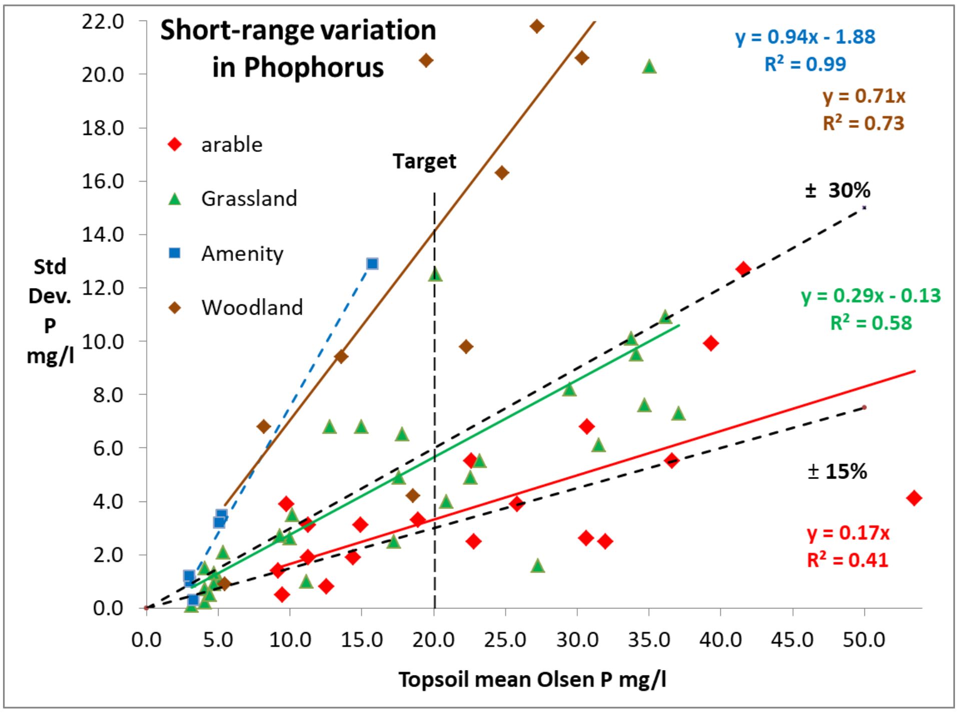


Figure 18.1 : Phosphorus variation within groups of close spaced samples.

Table 18.1 Arable: standard deviation within groups of 3-4 adjacent samples

Standard deviation ±	OM %	pH	Olsen P mg/l	K mg/l	Mg mg/l	Total N %
mean as nutrient	0.44	0.23	4.0	21	221	0.019
median as nutrient	0.31	0.22	3.1	18	140	0.014
mean % deviation *	13%		17%	13%	20%	10%
median % deviation*	11%		15%	14%	20%	7%

* standard deviation divided by mean nutrient in the group

Table 18.2 Grassland : standard deviation within groups of 3-4 adjacent samples

Standard deviation ±	OM %	pH	Olsen P mg/l	K mg/l	Mg mg/l	Total N %
mean as nutrient	0.55	0.18	5.0	28	331	0.029
median as nutrient	0.46	0.17	4.0	19	300	0.026
mean % deviation *	12%		27%	21%	16%	11%
median % deviation*	9%		26%	18%	13%	8%

* standard deviation divided by mean nutrient in the group

Potassium

For the arable samples the standard deviation is typically ±15% and for grassland ± 20%. Accordingly, for a soil sample measuring mid index 2- (150 mg/l) the short-range variation is 130-170 mg/l (± 20 mg/l) for arable and 120-180 (± 30 mg/l) for grassland.
Based on the assumption that soils need to be above index 1 (>120 mg/l) to diminish risk of deficiency, if farmers *achieve and maintain mid index 2* no parts will be deficient in the majority of cases. At K index 3 the variation can amount to less than 15% (Figure 18.2).

According to this data, short-range variation in K is less than variation due to soil texture class (a 9% increase in clay content corresponding to ~40 mg/l increase in K, Section 13). So it is *worthwhile sampling areas of different textural class separately*, provided a clear soil boundary can be realistically drawn, otherwise short-range variation might be considerably greater than the ± 20 mg/l K indicated here.

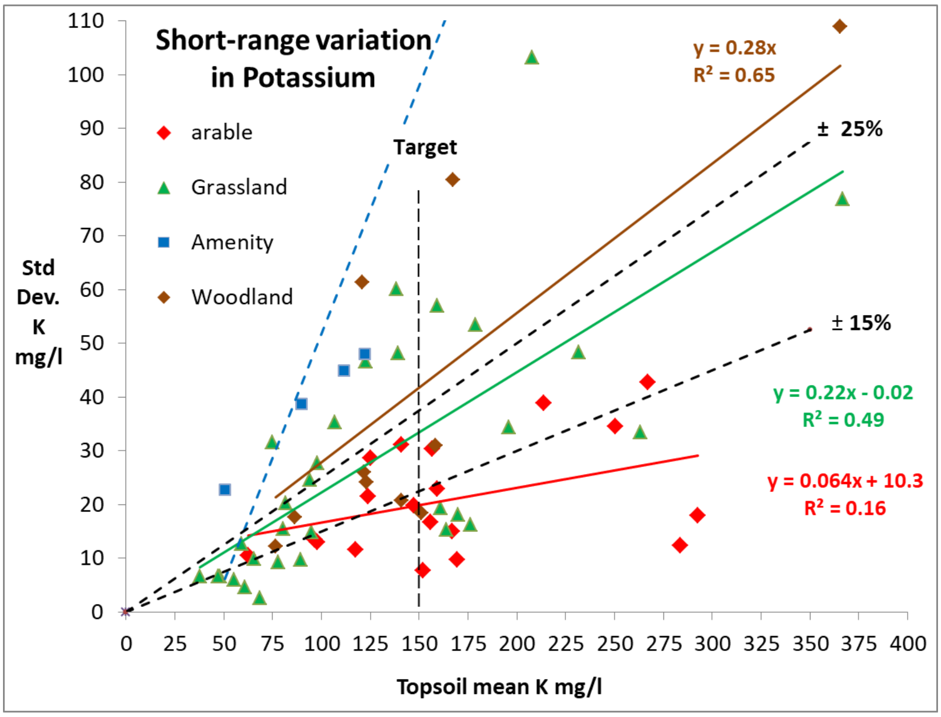


Figure 18.2 : Potassium variation within groups of close spaced samples.

Magnesium

Figure 18.3 excludes samples of Mg > 300 mg/l, nevertheless fitted lines are distorted by large variation in some small clusters of >200 mg/l Mg.

At the useful agricultural end (index 0-2) the standard deviation is typically ±15% for arable and grassland, so in a soil sample measuring mid index 2 (75 mg/l) the short-range variation is 65-85 mg/l and for soils of index 1 (<50 mg/l) variation is unlikely to exceed ± 8 mg/l though there are too few arable data to be conclusive.

When very high Mg samples are included the average deviation is up to ±20% (Tables 18.1 and 18.2). As for potassium, *areas of different textural class are best sampled separately to keep short range variation within* ± 15%.

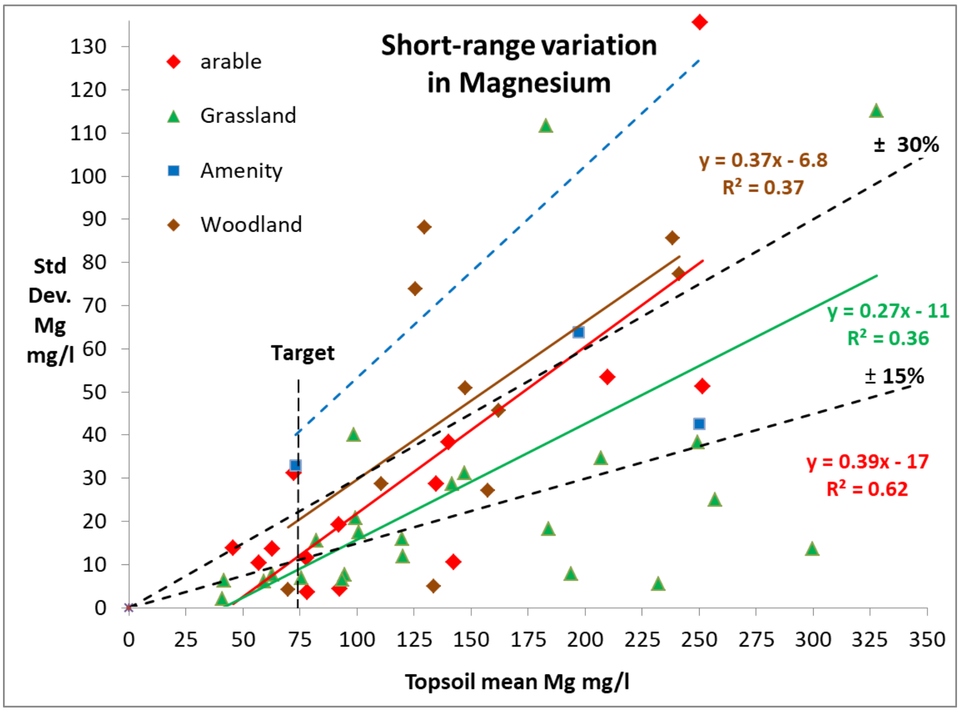


Figure 18.3: Magnesium variation within groups of close spaced samples.

pH

Figure 18.4 indicates short-range variation of ± 0.2 units in grassland and arable, though it can be much greater in some cases. This implies, within a hectare zone there could be patches of up to 0.4 less than a spot sample test [1] or 0.2 less than pH of a zone composite.

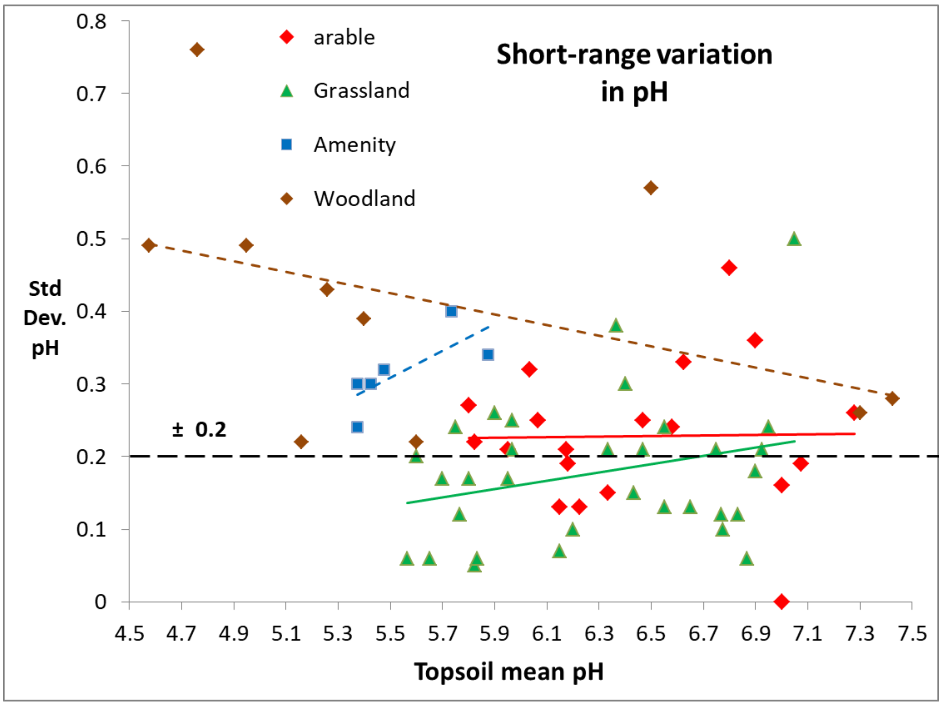


Figure 18.4 : pH variation within groups of close spaced samples.

The consequences of short range variation are partially mitigated by liming to 0.2 units above target pH, though this can be increased to 0.5 (see section 15). This data also indicates that spot pH tests taken 1 ha or more apart, or zonal composite tests, only warrant a difference in lime rate from the adjoining spot or zone test if the pH difference is 0.2 or more (or the texture/stoniness is significantly different).

[1] In this data survey each spot sample was a composite of five within a 10m radius. If there are more samples in the composite (15-20) the pH could be more representative than here, reducing the possible deviation. Zonal samples should comprise at least 20 cores.

However when testing for pH and liming *specifically*, spot sampling can be made more selective, avoiding atypical patches and soil with residual lime particles and aiming for the mossiest and more slaked patches in order to find the most acidic end of the short-scale pH range [2]

[2] the author's own experience in lime testing

Organic Matter

For the arable samples the deviation is typically ±11% of the mean, so at a typical level of 3.5% in topsoil the typical range is 3.1-3.9% OM. Grassland has similar variation so at typical 4.5% OM in topsoil, the range is 4.1-5.0% OM and on more organic soils the variation is proportionate (a sample of 9% OM = range 8-10% OM). However, there are examples in arable and grass clusters of much higher short range variation. This should be obvious to a soil sampler (darker soil) who might avoid sampling such patches.

On the two large cluster areas (of 18 samples on uniform soil type) when divided into smaller cluster areas the differences in mean values between clusters were smaller than the derivations within the clusters.

These findings imply that if soil organic matter is to be monitored (retested after 5 years) it needs a large composite (20) sample taken either from
a) a small (~0.2 ha) geo referenced area or
b) a larger (1-4 ha) zone of uniform soil type.

In both cases subsamples should be taken by a fairly uniform grid within GPS-delimited areas.
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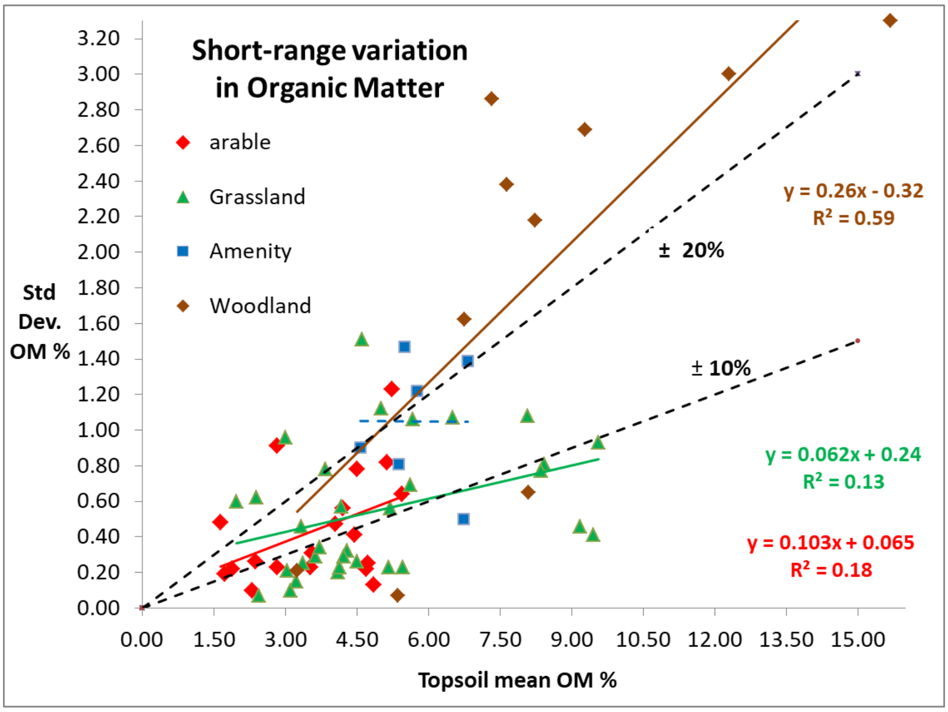

Figure 18.5 : Organic Matter variation within groups of close spaced samples.

Total Nitrogen

As shown in Figure 18.6, short range variation on arable soils alters little with TN and is typically ±0.015% N. Grassland is higher (±0.025% TN) simply because of higher organic matter levels. On both arable and grassland the TN deviation is < ±10% of the mean, and slightly less variable than organic matter. The somewhat different pattern to OM (Figure 18.5) may be because C:N ratio decreases at low organic matter levels (section 13).

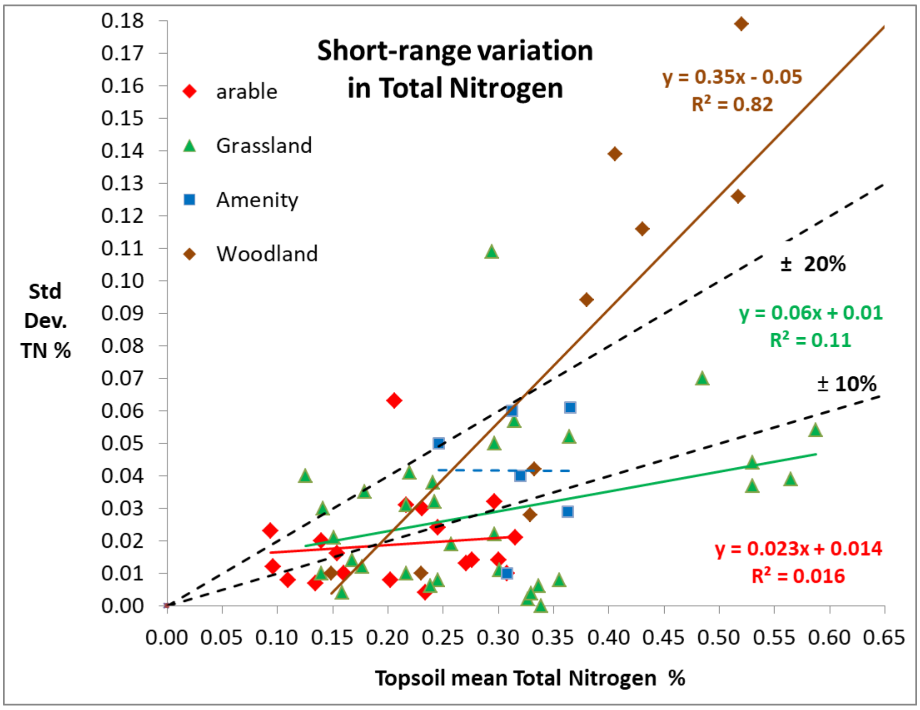

Figure 18.6 : Total Nitrogen variations within groups of close spaced samples.

Woodland and amenity grassland

Typical short-range variation is much higher in woodland
± 0.4 pH, especially in acid soils (Figure 18.4)
± 20% Organic Matter and Total Nitrogen
± 20% Potassium (similar to grassland)
± 30% Magnesium
± 65% Phosphorus (greater than the OM variability)

Table 18.3: Woodland: standard deviation within groups of 2-5 adjacent samples

Standard deviation ±	OM %	pH	Olsen P mg/l	K mg/l	Mg mg/l	Total N %
mean as nutrient	1.90	0.41	14.0	40	152	0.10
median as nutrient	2.28	0.41	13.1	25	141	0.11
mean % deviation *	21%		64%	25%	31%	20%
median % deviation*	24%		68%	20%	30%	25%

* standard deviation divided by mean nutrient in the group

Some variation is due to soil variation within the woods, but most might be linked to differences in vegetative cover, amount and type of roots etc. Samples could not be taken where undergrowth was very thick. Levels might be different nearer trees. Clearly it is necessary to take several samples (or a very thorough composite) when assessing nutrients, organic matter and pH status of woods.

On the main amenity site in this data short range variation is somewhat higher than other grass data, although very low P levels are uniformly low (Figure 18.1). Variation in nutrients and pH could be traced to differences in grass vegetation (natural or managed), proximity to trees etc. On sites with more uniform amenity grass - open parkland, playing fields etc - variation is probably less than indicated here.

Assessment of mean , standard deviation and their proportionation																			Land	Soil	Omitted
OM%			pH			P			K			Mg			TN				Use	Text	
mean	std	ratio	mean	std	ratio	mean	std	ratio	mea	std	ratio	mean	std	ratio	mea	std	ratio	n			
3.57	0.31	9%	7.0	0	0%	53.5	4.1	8%	167	15	9%	78	12	15%	0.15	0.02	10%	3	0	0	
5.23	1.23	24%	6.3	0.2	2%	41.6	12.7	31%	124	22	17%	92	19	21%	0.27	0.01	5%	3	0	1	
4.20	0.56	13%	6.1	0.3	4%	30.7	6.8	22%	98	13	13%	78	4	4%	0.22	0.03	14%	3	0	1	
4.45	0.41	9%	6.2	0.2	3%	30.7	2.6	8%	125	29	23%	92	4	5%	0.23	0.00	2%	3	0	1	
5.45	0.64	12%	6.0	0.2	4%	32.0	2.5	8%	97	13	14%	143	11	7%	0.28	0.01	5%	2	0	2	
1.73	0.19	11%	7.0	0.2	2%	14.4	1.9	13%	147	20	14%	63	14	22%	0.10	0.01	13%	4	0	2	
3.53	0.23	7%	6.5	0.3	4%	9.5	0.5	5%	117	12	10%	210	53	25%	0.23	0.03	13%	3	0	2	
2.30	0.10	4%	6.8	0.5	7%	14.9	3.1	21%	152	8	5%	72	31	43%	0.13	0.01	5%	3	0	2	
1.65	0.48	29%	6.6	0.3	5%	25.8	3.9	15%	214	39	18%	140	38	27%	0.09	0.02	24%	4	0	2	
1.88	0.22	12%	6.2	0.2	3%	36.6	5.5	15%	156	17	11%	46	14	31%	0.11	0.01	7%	5	0	2	
4.50	0.78	17%	6.6	0.2	4%	22.6	5.5	24%	170	10	6%	135	29	21%	0.20	0.01	4%	5	0	3	
2.83	0.23	8%	6.9	0.4	5%	18.9	3.3	17%	62	11	17%	250	136	54%	0.16	0.01	6%	3	0	2	
2.38	0.26	11%	7.1	0.2	3%	22.8	2.5	11%	141	31	22%	252	51	20%	0.14	0.02	14%	4	0	2	
4.85	0.13	3%	6.2	0.1	2%	12.6	0.8	6%	293	18	6%	554	81	15%	0.31	0.01	3%	4	0	4	Mg graphs
5.13	0.82	16%	6.2	0.1	2%	11.3	3.1	28%	267	43	16%	593	50	8%	0.32	0.02	7%	4	0	4	Mg graphs
4.70	0.22	5%	5.8	0.2	4%	9.2	1.4	15%	284	12	4%	505	75	15%	0.30	0.01	5%	4	0	4	Mg graphs
4.05	0.47	12%	5.8	0.3	5%	11.3	1.9	17%	157	30	19%	439	29	7%	0.25	0.02	10%	4	0	4	Mg graphs
4.73	0.25	5%	6.0	0.3	5%	9.7	3.9	40%	250	35	14%	405	81	20%	0.30	0.03	11%	3	0	4	Mg graphs
2.82	0.91	32%	7.3	0.3	4%	39.3	9.9	25%	159	23	14%	57	10	18%	0.21	0.06	31%	5	0	4	
3.63	0.29	8%	6.9	0.2	3%	37.1	7.3	20%	94	25	26%	142	29	20%	0.17	0.01	8%	4	1	2	
3.03	0.21	7%	6.8	0.1	2%	15.0	6.8	45%	98	28	28%	41	2	5%	0.16	0.00	3%	3	1	1	
3.33	0.46	14%	6.9	0.1	1%	11.1	1.0	9%	95	15	16%	59	6	10%	0.18	0.01	7%	3	1	1	
3.83	0.78	20%	6.3	0.2	3%	5.1	1.0	19%	61	5	8%	95	8	8%	0.22	0.01	5%	3	1	1	
4.30	0.32	7%	5.7	0.1	1%	20.2	12.5	62%	55	6	11%	75	7	9%	0.25	0.01	3%	4	1	1	
3.38	0.25	7%	5.8	0.1	1%	17.6	4.9	28%	48	7	14%	101	18	17%	0.18	0.04	20%	4	1	1	
3.73	0.34	9%	6.8	0.1	1%	27.3	1.6	6%	232	48	21%	184	18	10%	0.22	0.03	14%	4	1	1	
5.63	0.69	12%	6.7	0.1	2%	22.6	4.9	22%	170	18	11%	232	6	2%	0.34	0.00	0%	4	1	1	
5.00	1.12	22%	5.8	0.2	4%	5.4	2.1	39%	107	35	33%	99	21	21%	0.31	0.06	18%	4	1	2	
1.97	0.60	31%	5.7	0.2	3%	4.7	1.3	27%	38	7	18%	63	8	12%	0.14	0.03	21%	3	1	1	
2.40	0.62	26%	5.6	0.2	4%	10.0	2.6	26%	138	60	43%	42	6	15%	0.13	0.04	32%	3	1	1	
4.10	0.20	5%	5.8	0.1	1%	4.1	0.2	5%	78	9	12%	120	16	13%	0.24	0.04	16%	3	1	1	
4.17	0.57	14%	6.0	0.2	4%	3.1	0.1	3%	82	20	25%	183	112	61%	0.26	0.02	7%	3	1	1	
3.23	0.15	5%	6.5	0.2	3%	20.9	4.0	19%	164	15	9%	207	35	17%	0.24	0.01	3%	3	1	2	
3.00	0.96	32%	6.4	0.3	5%	23.2	5.5	24%	159	57	36%	301	152	50%	0.22	0.04	19%	3	1	2	
4.50	0.26	6%	5.8	0.1	2%	17.8	6.5	37%	89	10	11%	194	8	4%	0.30	0.01	4%	3	1	1	
5.67	1.06	19%	5.9	0.3	4%	36.1	10.9	30%	263	34	13%	257	25	10%	0.36	0.05	14%	3	1	2	
4.23	0.29	7%	7.1	0.5	7%	33.8	10.1	30%	276	121	44%	782	130	17%	0.30	0.02	7%	4	1	3	K Mg graphs
5.20	0.56	11%	6.8	0.1	2%	10.1	3.5	35%	59	13	21%	82	16	19%	0.30	0.05	17%	3	2	3	
5.47	0.23	4%	6.4	0.2	2%	9.3	2.7	29%	66	10	15%	93	6	7%	0.33	0.00	1%	3	2	2	
2.45	0.07	3%	6.2	0.1	1%	4.1	0.7	17%	69	3	4%	147	31	21%	0.15	0.02	14%	2	2	2	
4.13	0.23	6%	6.4	0.4	6%	4.1	1.5	37%	75	32	42%	249	38	15%	0.24	0.03	13%	3	2	1	
4.60	1.51	33%	5.6	0.1	1%	4.7	0.9	19%	80	16	19%	448	77	17%	0.29	0.11	37%	3	2	1	Mg graphs
8.43	0.81	10%	6.2	0.1	2%	12.8	6.8	53%	139	48	35%	300	14	5%	0.36	0.01	2%	3	2	1	
5.17	0.23	4%	5.8	0.2	3%	56.2	0.7	1%	367	77	21%	99	40	41%	0.34	0.01	2%	3	2	1	P graphs
6.50	1.07	16%	6.0	0.2	3%	4.4	0.5	11%	47	7	14%	328	115	35%	0.33	0.00	1%	4	2	1	
3.10	0.10	3%	6.0	0.3	4%	17.3	2.5	14%	123	47	38%	120	12	10%	0.14	0.01	7%	3	2	3	
9.55	0.93	10%	6.9	0.2	3%	35.1	20.3	58%	196	34	18%	553	73	13%	0.59	0.05	9%	4	2	3	Mg graphs
9.18	0.46	5%	6.6	0.2	4%	34.7	7.6	22%	176	16	9%	645	55	9%	0.53	0.04	8%	4	2	3	Mg graphs
9.45	0.41	4%	6.8	0.2	3%	29.5	8.2	28%	161	19	12%	529	56	11%	0.57	0.04	7%	4	2	3	Mg graphs
8.35	0.77	9%	7.0	0.2	3%	34.1	9.5	28%	179	54	30%	487	30	6%	0.53	0.04	7%	4	2	3	Mg graphs
8.08	1.08	13%	6.6	0.1	2%	31.5	6.1	19%	208	103	50%	465	151	32%	0.49	0.07	14%	4	2	3	Mg graphs
4.57	0.90	20%	5.7	0.4	7%	15.7	12.9	82%	51	23	45%	73	33	45%	0.25	0.05	20%	3	3	1	
5.38	0.81	15%	5.9	0.3	6%	3.1	1.0	33%	112	45	40%	240	163	68%	0.31	0.06	19%	4	3	2	
5.50	1.47	27%	5.4	0.2	4%	3.3	0.3	9%	145	117	81%	218	199	91%	0.31	0.01	3%	4	3	2	
5.75	1.22	21%	5.5	0.3	6%	5.3	3.5	67%	90	39	43%	197	64	32%	0.32	0.04	13%	4	3	2	
6.83	1.39	20%	5.4	0.3	6%	3.0	1.2	41%	187	137	74%	350	151	43%	0.37	0.06	17%	4	3	2	Mg graphs
6.73	0.50	7%	5.4	0.3	6%	5.1	3.2	63%	122	48	39%	250	43	17%	0.36	0.03	8%	4	3	2	
9.28	2.69	29%	5.6	0.2	4%	18.6	4.2	23%	167	80	48%	241	77	32%	0.43	0.12	27%	4	4	2	
15.68	3.30	21%	4.6	0.5	11%	30.4	20.6	68%	123	24	20%	126	74	59%	0.52	0.18	34%	4	4	1	
6.75	1.62	24%	5.4	0.4	7%	8.2	6.8	83%	141	21	15%	238	86	36%	0.33	0.04	13%	4	4	1	
5.35	0.07	1%	5.0	0.5	10%	22.3	9.8	44%	151	18	12%	70	4	6%	0.23	0.01	4%	2	4	1	
3.25	0.21	6%	6.5	0.6	9%	27.2	21.8	80%	87	18	20%	134	5	4%	0.15	0.01	7%	2	4	2	
7.64	2.38	31%	4.8	0.8	16%	13.6	9.4	69%	159	31	20%	130	88	68%	0.38	0.09	25%	5	4	3	
12.30	3.00	24%	7.3	0.3	4%	24.8	16.3	66%	121	61	51%	148	51	34%	0.82	0.21	25%	3	4	2	
7.32	2.86	39%	5.2	0.2	4%	5.5	0.9	16%	122	26	21%	157	27	17%	0.41	0.14	34%	5	4	3	
8.23	2.18	27%	7.4	0.3	4%	35.3	29.4	83%	366	109	30%	162	46	28%	0.52	0.13	24%	4	4	3	
8.10	0.65	8%	5.3	0.4	8%	19.5	20.5	105%	77	12	16%	111	29	26%	0.33	0.03	9%	5	4	3	

A. Appendices – Multiple Regression

Regions C: South-Central England

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 permitted in cases where overall r^2 is improved by their inclusion. Texture and stones are classes 0-4 and 0-3.

Different parameters are included in multiple regression analysis in order to give suitable equations for predicting subsoil parameters from the topsoil measurement.

A3 : Charmouth Mudstone

Charmouth Mudstone

Effect of sampling method on topsoil P

Regression Statistics	
Multiple R	0.42
R Square	0.17
Adjusted R Square	0.16
Standard Error	4.49
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	234.8671	234.8671	11.66227	0.001205
Residual	55	1107.648	20.13906		
Total	56	1342.515			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	15.10	0.78	19.33	0.00	13.54	16.67	13.54	16.67
Sampling method	-4.11	1.20	-3.42	0.00	-6.52	-1.70	-6.52	-1.70

Average 4 mg/l less on corer sites (a site difference)

Charmouth Mudstone

Effect of topsoil P and sampling method on subsoil P

Regression Statistics	
Multiple R	0.70
R Square	**0.49**
Adjusted R Square	0.47
Standard Error	2.28
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	273.6652	136.8326	26.23273	1.1E-08
Residual	54	281.6695	5.216102		
Total	56	555.3347			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.96	1.11	-0.86	0.39	-3.18	1.27	-3.18	1.27
Sampling method	1.41	0.67	2.09	0.04	0.06	2.76	0.06	2.76
Topsoil P	0.49	0.07	7.17	0.00	0.35	0.63	0.35	0.63

Corer averages 1.4 mg/l higher P than auger opposite to effect on topsoil

Charmouth Mudstone

Effect of topsoil P and subsoil OM on subsoil P

Regression Statistics	
Multiple R	0.76
R Square	**0.57**
Adjusted R Square	0.55
Standard Error	2.10
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	316.6967	158.3484	35.83172	1.25E-10
Residual	54	238.638	4.419223		
Total	56	555.3347			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-2.21	1.07	-2.07	0.04	-4.35	-0.07	-4.35	-0.07
Topsoil P	0.37	0.06	6.16	0.00	0.25	0.49	0.25	0.49
Subsoil OM	1.28	0.33	3.86	0.00	0.62	1.95	0.62	1.95

Subsoil P = Subsoil OM% x 1.3 + 0.37 x Topsoil P - 2.21

Better improvement than allowing for method

Charmouth Mudstone

Effect of topsoil K and sampling method

Regression Statistics	
Multiple R	0.21
R Square	**0.04**
Adjusted R Square	0.03
Standard Error	66.34
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	10818.15	10818.15	2.458118	0.122655
Residual	55	242054.5	4400.99		
Total	56	252872.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	212.43	11.55	18.39	0.00	189.29	235.57	189.29	235.57
Sampling method	27.90	17.80	1.57	0.12	-7.76	63.57	-7.76	63.57

28 mg/l higher on corer sites though weak significance

Charmouth Mudstone

Effect of topsoil K and sampling method on subsoil K

Regression Statistics	
Multiple R	0.89
R Square	**0.79**
Adjusted R Square	0.78
Standard Error	24.91
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	127847.3	63923.64	102.9877	3.73E-19
Residual	54	33517.37	620.692		
Total	56	161364.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	28.26	11.60	2.44	0.02	5.00	51.51	5.00	51.51
Sampling method	43.49	6.83	6.37	0.00	29.80	57.19	29.80	57.19
Topsoil K	0.57	0.05	11.27	0.00	0.47	0.67	0.47	0.67

Large improvement in r2 (from 0.65). Corer values 43 mg/l higher than auger

But distorted by large correlation of topsoil K with corer (+28 mg/l)

Charmouth Mudstone

Effect of topsoil K and subsoil OM on subsoil K

Regression Statistics	
Multiple R	0.85
R Square	**0.73**
Adjusted R Square	0.72
Standard Error	28.56
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	117311.9	58655.94	71.90061	5.98E-16
Residual	54	44052.77	815.792		
Total	56	161364.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-11.22	16.70	-0.67	0.50	-44.70	22.25	-44.70	22.25
Topsoil K	0.60	0.06	10.47	0.00	0.49	0.72	0.49	0.72
Topsoil OM	18.56	4.38	4.23	0.00	9.77	27.35	9.77	27.35

Subsoil K = Subsoil OM% x 18.6 + 0.60 x Topsoil K - 11

Improvement on r2 compared to OM omission (0.63)

Charmouth Mudstone

Effect of topsoil K and subsoil pH on subsoil K

Regression Statistics	
Multiple R	0.82
R Square	**0.67**
Adjusted R Square	0.66
Standard Error	31.47
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	107872.6	53936.31	54.4485	1.13E-13
Residual	54	53492.03	990.5931		
Total	56	161364.6			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	171.86	63.02	2.73	0.01	45.52	298.20	45.52	298.20
Topsoil K	0.61	0.06	9.49	0.00	0.48	0.74	0.48	0.74
Subsoil pH	-19.03	8.32	-2.29	0.03	-35.70	-2.35	-35.70	-2.35

Subsoil K = Subsoil pH x -19 + 0.61 x Topsoil K +171

Each 1 unit pH rise decreases K by 19 mg/l but this may be an OM effect (see below)

Charmouth Mudstone

Effect of topsoil K and subsoil pH and subsoil OM on subsoil K

Regression Statistics	
Multiple R	0.86
R Square	**0.74**
Adjusted R Square	0.72
Standard Error	28.28
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	118968.9	39656.31	49.57538	2.11E-15
Residual	53	42395.72	799.9193		
Total	56	161364.6			

	Coefficier	Standard E	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0	Upper 95.0
Intercept	75.21	62.29	1.21	0.23	-49.73	200.15	-49.73	200.15
Topsoil K	0.59	0.06	10.17	0.00	0.47	0.70	0.47	0.70
Subsoil OM	16.80	4.51	3.72	0.00	7.75	25.84	7.75	25.84
Subsoil pH	-11.18	7.76	-1.44	0.16	-26.75	4.40	-26.75	4.40

Inclusion of pH makes no improvement on OM correction alone

Effect of sampling method of topsoil Mg

Multiple R	0.78
R Square	**0.61**
Adjusted R Square	0.60
Standard Error	112.69
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	1091170	1091170	85.9244	7.86E-13
Residual	55	698455	12699.18		
Total	56	1789625			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	198.72	19.62	10.13	0.00	159.41	238.04	159.41	238.04
Sampling method	280.23	30.23	9.27	0.00	219.65	340.82	219.65	340.82

Corer was mainly a field with higher Mg levels !

Charmouth Mudstone

Effect of topsoil pH on topsoil Mg

Regression Statistics	
Multiple R	0.65
R Square	**0.43**
Adjusted R Square	0.42
Standard Error	136.37
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	766773.2	766773.2	41.23035	3.33E-08
Residual	55	1022851	18597.3		
Total	56	1789625			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1561.10	194.64	8.02	0.00	1171.04	1951.15	1171.04	1951.15
Topsoil pH	-193.48	30.13	-6.42	0.00	-253.87	-133.09	-253.87	-133.09

Topsoil Mg = Topsoil pH x - 193 + 1561

Charmouth Mudstone

Effect of topsoil pH and OM on topsoil Mg

Regression Statistics	
Multiple R	0.68
R Square	**0.46**
Adjusted R Square	0.44
Standard Error	133.60
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	825750	412875	23.13086	5.55E-08
Residual	54	963874.6	17849.53		
Total	56	1789625			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1294.97	240.40	5.39	0.00	812.99	1776.96	812.99	1776.96
Topsoil OM %	48.37	26.61	1.82	0.07	-4.98	101.72	-4.98	101.72
Topsoil pH	-186.16	29.79	-6.25	0.00	-245.89	-126.43	-245.89	-126.43

Topsoil Mg = Topsoil OM% x 48 - Topsoil pH x 186 + 1295

Charmouth Mudstone

Affect of sampling method on topsoil OM

Regression Statistics	
Multiple R	0.18
R Square	**0.03**
Adjusted R Square	0.02
Standard Error	0.67
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	0.844898	0.844898	1.871488	0.176868
Residual	55	24.83019	0.451458		
Total	56	25.67509			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.42	0.12	37.83	0.00	4.19	4.66	4.19	4.66
Sampling method	0.25	0.18	1.37	0.18	-0.11	0.61	-0.11	0.61

Weak difference + 0.25% OM in topsoils cored

Charmouth Mudstone

Effect of sampling method on subsoil OM

Regression Statistics	
Multiple R	0.30
R Square	**0.09**
Adjusted R Square	0.08
Standard Error	0.85
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	3.974769	3.974769	5.545379	0.022126
Residual	55	39.42242	0.716771		
Total	56	43.39719			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.52	0.15	17.07	0.00	2.22	2.81	2.22	2.81
Sampling method	0.53	0.23	2.35	0.02	0.08	0.99	0.08	0.99

About 0.53% higher by corer

Charmouth Mudstone

Effect of topsoil pH and subsoil OM on subsoil OM

Regression Statistics	
Multiple R	0.70697
R Square	**0.50**
Adjusted R Square	0.48
Standard Error	0.37
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	7.475	3.7375	26.9791	7.53E-09
Residual	54	7.48079	0.138533		
Total	56	14.95579			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	3.70	0.59	6.29	0.00	2.52	4.88	2.52	4.88
Subsoil OM	-0.10	0.06	-1.79	0.08	-0.22	0.01	-0.22	0.01
Topsoil pH	0.56	0.08	6.68	0.00	0.39	0.73	0.39	0.73

Subsoil pH = Subsoil OM% x - 0.10 + 0.56 x Topsoil pH + 3.70

Improves r2 (from 0.47 if OM omitted)

Charmouth Mudstone

Effect of sampling method and topsoil OM on subsoil OM

Regression Statistics	
Multiple R	0.57
R Square	**0.32**
Adjusted R Square	0.30
Standard Error	0.74
Observations	57

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	13.98147	6.990736	12.83327	2.76E-05
Residual	54	29.41572	0.544736		
Total	56	43.39719			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.29	0.67	-0.44	0.66	-1.63	1.05	-1.63	1.05
Sampling method	0.38	0.20	1.88	0.07	-0.03	0.78	-0.03	0.78
Topsoil OM	0.63	0.15	4.29	0.00	0.34	0.93	0.34	0.93

Subsoil OM% = topsoil OM% x 0.63 - 0.29 + 0.38 if corer method

Improves r2 from 0.28 if method ignored

Corer averages 0.38% higher subsoil OM

A4 : Whitby Mudstone and Horsehay Sand

Whitby Mudstone and Horeshay Sand								
Influence of topsoil pH on subsoil pH								
Regression Statistics								
Multiple R	0.88							
R Square	**0.78**							
Adjusted R Sq	0.76							
Standard Errc	0.33							
Observations	14							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	4.589431	4.589431	42.67357	2.8E-05			
Residual	12	1.290569	0.107547					
Total	13	5.88						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.84	0.75	2.46	0.03	0.21	3.47	0.21	3.47
Topsoil pH	0.78	0.12	6.53	0.00	0.52	1.04	0.52	1.04
Subsoil pH = Topsoil pH x 0.78 + 1.84								
Whitby Mudstone and Horeshay Sand								
Influence of topsoil pH and subsoil OM on subsoil pH								
Regression Statistics								
Multiple R	0.89							
R Square	**0.79**							
Adjusted R Sq	0.76							
Standard Errc	0.33							
Observations	14							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	4.672564	2.336282	21.28404	0.000165			
Residual	11	1.207436	0.109767					
Total	13	5.88						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.78	0.76	2.34	0.04	0.10	3.45	0.10	3.45
Topsoil pH	0.82	0.13	6.36	0.00	0.54	1.11	0.54	1.11
Subsoil OM%	-0.09	0.10	-0.87	0.40	-0.32	0.14	-0.32	0.14
Improves r2 slightly but dubious								
Subsoil pH = Topsoil pH x 0.82 - Subsoil OM% x 0.09 + 1.78								

A5 : Limestone-and-Clay

Limestone and clay data (not wood). Two very high points excluded								
Influence of topsoil K on subsoil K								
Regression Statistics								
Multiple R	0.74							
R Square	**0.54**							
Adjusted R S	0.48							
Standard Err	53.67							
Observations	9							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	23884.38	23884.38	8.292157	0.023665			
Residual	7	20162.51	2880.358					
Total	8	44046.89						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	29.00	61.72	0.47	0.65	-116.95	174.95	-116.95	174.95
Topsoil K	0.77	0.27	2.88	0.02	0.14	1.40	0.14	1.40
Subsoil K = Topsoil K x 0.77 + 29								
Limestone and clay data (not wood). Two very high points excluded								
Influence of topsoil K and subsoil stone class on subsoil K								
Regression Statistics								
Multiple R	0.74							
R Square	**0.55**							
Adjusted R S	0.41							
Standard Err	57.21							
Observations	9							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	24408.97	12204.48	3.728852	0.088622			
Residual	6	19637.92	3272.987					
Total	8	44046.89						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	23.51	67.21	0.35	0.74	-140.94	187.97	-140.94	187.97
Topsoil K	0.72	0.30	2.37	0.06	-0.02	1.47	-0.02	1.47
Subsoil stone	9.86	24.62	0.40	0.70	-50.39	70.10	-50.39	70.10
Does not improve fit that much but associates 1 stone class with an additonal 10 mg/l K								
Subsoil K = Topsoil K x 0.72 + stone class x 10 + 24								

A6 : Glacial Deposits

Glacial Till: heavy loam and clay subsoils (2 high points excluded)								
Effect of topsoil P and subsoil OM on subsoil P								
Regression Statistics								
Multiple R	0.59							
R Square	**0.35**							
Adjusted R Squ	0.27							
Standard Error	2.30							
Observations	18							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	43.26893	21.63446	4.075369	0.038588			
Residual	15	79.62885	5.30859					
Total	17	122.8978						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.49	2.70	0.18	0.86	-5.26	6.24	-5.26	6.24
Subsoil OM%	1.78	0.85	2.08	0.06	-0.04	3.60	-0.04	3.60
Topsoil P	0.10	0.05	1.83	0.09	-0.02	0.21	-0.02	0.21
Subsoil P = Topsoil P x 0.10 + Subsoil OM x 1.8 + 0.49								

Glacial Till: all data (except two highest points)								
Effect of topsoil P and subsoil OM on subsoil P								
Regression Statistics								
Multiple R	0.63							
R Square	**0.39**							
Adjusted R Squ	0.34							
Standard Error	2.24							
Observations	27							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	77.92688	38.96344	7.769919	0.002501			
Residual	24	120.3516	5.014652					
Total	26	198.2785						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.82	1.43	1.97	0.06	-0.14	5.78	-0.14	5.78
Subsoil OM%	0.91	0.67	1.37	0.18	-0.46	2.29	-0.46	2.29
Topsoil P	0.10	0.04	2.48	0.02	0.02	0.19	0.02	0.19
Not so significant as on heavy subsoils only (though overall r2 improved)								

Glacial Till: heavy loam and clay subsoils
Effect of subsoil pH on subsoil K

Regression Statistics	
Multiple R	0.63
R Square	**0.40**
Adjusted R Squ	0.36
Standard Error	31.81
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	11344.08	11344.08	11.21312	0.003809
Residual	17	17198.54	1011.679		
Total	18	28542.62			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-185.28	89.20	-2.08	0.05	-373.47	2.91	-373.47	2.91
Subsoil pH	42.21	12.60	3.35	0.00	15.61	68.80	15.61	68.80

Each 1 unit increase of subsoil pH associated with an increase of 42 mg/l topsoil K
Subsoil K = subsoil pH x 42 - 185

Glacial Till: heavy loam and clay subsoils
Effect of topsoil K and subsoil pH on subsoil K

Regression Statistics	
Multiple R	0.87
R Square	**0.75**
Adjusted R Squ	0.72
Standard Error	21.19
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	21359.45	10679.72	23.78832	1.61E-05
Residual	16	7183.171	448.9482		
Total	18	28542.62			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-20.93	68.86	-0.30	0.77	-166.90	125.05	-166.90	125.05
Topsoil K	0.34	0.07	4.72	0.00	0.19	0.49	0.19	0.49
Subsoil pH	9.63	10.87	0.89	0.39	-13.41	32.66	-13.41	32.66

Glacial Till: heavy loam and clay subsoils
Effect of subsoil pH on topsoil K

Regression Statistics	
Multiple R	0.63
R Square	**0.40**
Adjusted R Squ	0.37
Standard Error	71.12
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	58026.46	58026.46	11.47293	0.003504
Residual	17	85980.67	5057.686		
Total	18	144007.1			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-481.57	199.44	-2.41	0.03	-902.34	-60.79	-902.34	-60.79
Subsoil pH	95.46	28.18	3.39	0.00	36.00	154.92	36.00	154.92

Each 1 unit increase of subsoil pH associated with an increase of 95 mg/l topsoil K
Topsoil K = Subsoil pH x 95 - 482

Glacial Till: heavy loam and clay subsoils

Effect of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.79
R Square	0.63
Adjusted R Squ	0.61
Standard Error	0.36
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	3.987539	3.987539	30.1267	3.26E-05
Residual	18	2.382461	0.132359		
Total	19	6.37			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.95	0.75	3.93	0.00	1.37	4.53	1.37	4.53
Topsoil pH	0.62	0.11	5.49	0.00	0.38	0.86	0.38	0.86

Glacial Till: heavy loam and clay subsoils

Effect of topsoil pH and subsoil OM on subsoil pH

Regression Statistics	
Multiple R	0.80
R Square	**0.63**
Adjusted R Squ	0.59
Standard Error	0.37
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	4.027509	2.013754	14.61428	0.000203
Residual	17	2.342491	0.137794		
Total	19	6.37			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.70	0.90	3.01	0.01	0.81	4.59	0.81	4.59
Topsoil pH	0.63	0.12	5.39	0.00	0.39	0.88	0.39	0.88
Subsoil OM%	0.06	0.11	0.54	0.60	-0.18	0.30	-0.18	0.30

Subsoil OM not signficant

A7 : Oxford Clay

Arable data on Oxford Clays

	Method	*Top Text.*	*Top Stone*	*Top OM%*	*Top pH*	*Topsoil P*	*Topsoil K*	*Top Mg*
Method	1							
Top texture	-0.11	1						
Top Stones	-0.10	-0.14	1					
Topsoil OM%	0.55	0.00	-0.39	1				
Topsoil pH	-0.26	0.30	-0.16	-0.38	1			
Topsoil P	0.11	-0.21	-0.21	0.55	-0.25	1		
Topsoil K	0.01	0.24	-0.40	0.36	0.14	0.39	1	
Topsoil Mg	0.11	0.16	-0.18	0.33	-0.22	0.24	0.38	1

Sampling method : corer had a positive effect on OM and negative effect on pH
P positvely correlated with OM, (weak) negatively with texture class, stone and pH
K is postively correlated with OM, texture class and negatively with stone.
Mg is positively correlated with K and P and OM and negatively with pH
pH is positively related to textur class and negatively with OM

All data on Oxford Clays : factors influencing subsoil P

	Method	*Topsoil P*	*Subsoil OM*	*Subsoil pH*	*Subsoil P*
Method	1				
Topsoil P	-0.10	1			
Subsoil OM	0.41	0.03	1		
Subsoil pH	-0.16	-0.01	-0.23	1	
Subsoil P	0.17	0.57	0.57	-0.20	1

Subsoil P is strongly related to topsoil P and subsoil OM
It is weakly negatively correlated with subsoil pH though this
may be because pH and OM correlate negatively.

All data on Oxford Clays: factors influencing subsoil K (1 very high data excluded)

	Method	*Topsoil K*	*Top texture*	*Subsoil OM*	*Subsoil pH*	*Subsoil K*
Samp Methoc	1					
Topsoil K	-0.36	1				
Top texture	-0.14	0.33	1			
Subsoil OM	0.38	0.07	0.18	1		
Subsoil pH	-0.12	0.36	0.22	-0.18	1	
Subsoil K	-0.15	0.76	0.43	0.35	0.40	1

Very strongly related to topsoil K and strong influence of subsoil OM
Also related to topsoil texture though may be in part because topsoil K increases with texture class
Sampling method insignificant

Arable and grass data on Oxford Clays: factors influencing subsoil pH

	Method	*Top Text*	*Top pH*	*Sub stones*	*Sub OM%*	*Sub pH*
Method	1					
Top Texture	-0.16	1				
Topsoil pH	-0.31	0.39	1			
Subsoil sones	0.12	-0.33	-0.32	1		
Subsoil OM%	0.47	0.11	-0.05	0.10	1	
Subsoil pH	-0.30	0.31	0.69	-0.34	-0.36	1.00

Subsoil pH is negatively related to method (lower by corer) and subsoil stones and OM%
Subsoil pH is postively related to topsoil texture

Oxford Clay

Influence of subsoil OM% and topsoil P on subsoil P

Regression Statistics	
Multiple R	0.80
R Square	**0.64**
Adjusted R Square	0.63
Standard Error	2.91
Observations	66

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	942.8266	314.2755	37.1949	7.09E-14
Residual	62	523.8644	8.449425		
Total	65	1466.691			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.08	3.62	-0.30	0.77	-8.31	6.15	-8.31	6.15
Subsoil OM	2.55	0.39	6.54	0.00	1.77	3.33	1.77	3.33
Subsoil pH	-0.36	0.45	-0.80	0.43	-1.25	0.54	-1.25	0.54
Topsoil P	0.25	0.03	7.51	0.00	0.18	0.31	0.18	0.31

1 unit pH associated with a very minor drop in subsoil P, and no improvement to r2

Oxford Clay

Influence of topsoil K on subsoil K

Regression Statistics	
Multiple R	0.76
R Square	**0.58**
Adjusted R Square	0.57
Standard Error	38.63
Observations	66

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	131454.5	131454.5	88.08162	1.21E-13
Residual	64	95514.68	1492.417		
Total	65	226969.2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	36.94	14.62	2.53	0.01	7.74	66.15	7.74	66.15
Topsoil K	0.58	0.06	9.39	0.00	0.46	0.70	0.46	0.70

Subsoil K = Topsoil K x 0.58 + 37

Oxford Clay

Influence of sampling method and topsoil K on subsoil K

Regression Statistics	
Multiple R	0.77
R Square	**0.60**
Adjusted R Square	0.59
Standard Error	38.00
Observations	66

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	135988.1	67994.07	47.08264	3.12E-13
Residual	63	90981.03	1444.143		
Total	65	226969.2			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	22.27	16.59	1.34	0.18	-10.88	55.43	-10.88	55.43
Sampling method	20.35	11.49	1.77	0.08	-2.60	43.31	-2.60	43.31
Topsoil K	0.62	0.07	9.53	0.00	0.49	0.75	0.49	0.75

Some effect subsoil K averaging 20 mg/l higher by corer

Oxford Clay								
Influence of subsoil OM and topsoil K on subsoil K								
Regression Statistics								
Multiple R	0.82							
R Square	**0.67**							
Adjusted R Square	0.66							
Standard Error	34.53							
Observations	66							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	151850.1	75925.05	63.67594	7.47E-16			
Residual	63	75119.08	1192.366					
Total	65	226969.2						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-3.73	16.35	-0.23	0.82	-36.41	28.95	-36.41	28.95
Topsoil K	0.57	0.06	10.19	0.00	0.45	0.68	0.45	0.68
Subsoil OM%	19.14	4.63	4.14	0.00	9.89	28.39	9.89	28.39
Subsoil OM% makes far better improvement that topsoil sampling method								
Subsoil K = Subsoil OM% x 19.1 + Topsoil K x 0.57 - 3.73								

Arable data, Oxford Clays								
Effect of sampling method on topsoil pH								
Regression Statistics								
Multiple R	0.26							
R Square	**0.07**							
Adjusted R Square	0.04							
Standard Error	0.58							
Observations	43							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.994631	0.994631	2.973853	0.092153			
Residual	41	13.71281	0.334459					
Total	42	14.70744						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	7.03	0.10	70.87	0.00	6.83	7.23	6.83	7.23
Sampling method	-0.37	0.22	-1.72	0.09	-0.81	0.06	-0.81	0.06
Corer averaged 0.37 higher but was not evenly distributed between areas.								

Arable data, Oxford Clays								
Effect of topsoil texture and OM on topsoil pH								
Regression Statistics								
Multiple R	0.49							
R Square	**0.24**							
Adjusted R Square	0.20							
Standard Error	0.53							
Observations	43							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	3.499713	1.749856	6.245177	0.004361			
Residual	40	11.20773	0.280193					
Total	42	14.70744						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	6.75	0.78	8.66	0.00	5.18	8.33	5.18	8.33
Top Texture	0.37	0.17	2.20	0.03	0.03	0.72	0.03	0.72
Topsoil OM	-0.27	0.10	-2.77	0.01	-0.47	-0.07	-0.47	-0.07
Topsoil pH about 0.4 higher on heavy topsoils and decreased 0.27 per 1% OM								

Arable and grass data, Oxford Clays

Effect of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.69
R Square	**0.48**
Adjusted R Square	0.47
Standard Error	0.49
Observations	61

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	12.74779	12.74779	53.74012	7.45E-10
Residual	59	13.99549	0.237212		
Total	60	26.74328			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.36	0.68	3.45	0.00	0.99	3.73	0.99	3.73
Topsoil pH	0.72	0.10	7.33	0.00	0.52	0.92	0.52	0.92

Arable and grass data, Oxford Clays

Effect of sampling method and topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.70
R Square	**0.48**
Adjusted R Square	0.47
Standard Error	0.49
Observations	61

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	12.95255	6.476274	27.23742	4.56E-09
Residual	58	13.79073	0.237771		
Total	60	26.74328			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.61	0.74	3.55	0.00	1.14	4.09	1.14	4.09
Sampling method	-0.13	0.14	-0.93	0.36	-0.42	0.15	-0.42	0.15
Topsoil pH	0.69	0.10	6.66	0.00	0.48	0.90	0.48	0.90

Effect of sampling method small and might not be significant

Arable and grass data, Oxford Clays

Effect of subsoil OM% and and topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.77
R Square	**0.59**
Adjusted R Square	0.57
Standard Error	0.44
Observations	61

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	15.67269	7.836344	41.05543	7.79E-12
Residual	58	11.07059	0.190872		
Total	60	26.74328			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	3.05	0.64	4.77	0.00	1.77	4.33	1.77	4.33
Topsoil pH	0.70	0.09	7.97	0.00	0.53	0.88	0.53	0.88
Subsoil OM%	-0.24	0.06	-3.91	0.00	-0.37	-0.12	-0.37	-0.12

Big improvement by inclusion of subsoil OM%

Subsoil pH = Topsoil pH x 0.70 - Subsoil OM% x 0.24 + 3.05

Arable and grass data, Oxford Clays

Effect of subsoil OM% and stones and topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.77
R Square	**0.60**
Adjusted R Square	0.57
Standard Error	0.44
Observations	61

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	15.91961	5.306535	27.94546	3.03E-11
Residual	57	10.82367	0.189889		
Total	60	26.74328			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	3.31	0.68	4.89	0.00	1.95	4.66	1.95	4.66
Topsoil pH	0.67	0.09	7.21	0.00	0.48	0.86	0.48	0.86
Subsoil stones	-0.13	0.11	-1.14	0.26	-0.36	0.10	-0.36	0.10
Subsoil OM	-0.24	0.06	-3.81	0.00	-0.36	-0.11	-0.36	-0.11

Possible small effect of stones but hardly improves equation

Oxford clays (all data except wood)

Influence of sampling method on topsoil OM

Multiple R	0.58
R Square	**0.34**
Adjusted R Square	0.33
Standard Error	1.15
Observations	61

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	40.04956	40.04956	30.39383	8.18E-07			
Residual	59	77.74355	1.317687					
Total	60	117.7931						
Intercept	4.35	0.18	24.86	0.00	4.00	4.70	4.00	4.70
Sampling method	1.78	0.32	5.51	0.00	1.13	2.42	1.13	2.42

Averaged 1.8% topsoil OM greater by corer

Oxford clays (all data except wood and samples > 9% SOM)

Influence of topsoil OM on subsoil OM

Regression Statistics	
Multiple R	0.54
R Square	**0.29**
Adjusted R Square	0.28
Standard Error	0.75
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	12.87616	12.87616	22.74725	1.36E-05
Residual	56	31.69901	0.566054		
Total	57	44.57517			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.32	0.42	0.75	0.46	-0.53	1.17	-0.53	1.17
Topsoil OM%	0.41	0.09	4.77	0.00	0.24	0.59	0.24	0.59

Subsoil OM% = Topsoil OM% x 0.41 + 0.32

Oxford clays (all data except wood and samples > 9% SOM)

Influence of sampling method on subsoil OM

Regression Statistics	
Multiple R	0.45
R Square	0.21
Adjusted R Square	0.19
Standard Error	0.79
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	9.211839	9.211839	14.58751	0.000337
Residual	56	35.36333	0.631488		
Total	57	44.57517			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.03	0.12	16.58	0.00	1.79	2.28	1.79	2.28
Sampling method	0.89	0.23	3.82	0.00	0.42	1.36	0.42	1.36

0.9% higher by corer

Oxford clays (all data except wood and samples > 9% SOM)

Influence of sampling method and topsoil OM on subsoil OM

Regression Statistics	
Multiple R	0.57
R Square	**0.33**
Adjusted R Square	0.30
Standard Error	0.74
Observations	58

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	14.64523	7.322616	13.45622	1.75E-05
Residual	55	29.92994	0.544181		
Total	57	44.57517			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.65	0.45	1.43	0.16	-0.26	1.56	-0.26	1.56
Sampling method	0.46	0.26	1.80	0.08	-0.05	0.97	-0.05	0.97
Topsoil OM	0.32	0.10	3.16	0.00	0.12	0.52	0.12	0.52

Subsoil OM% = Topsoil OM% x 0.32 + 0.65 + 0.46 for corer

Is a nonsense but indicates a sampling method difference of 0.45%

A8 : Kimmeridge Clay

Kimmeridge and Ampthill Clays (all data)

Relationship of topsoil P to subsoil P

Regression Statistics	
Multiple R	0.75
R Square	**0.57**
Adjusted R Square	0.55
Standard Error	7.63
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	1601.989	1601.989	27.52265	3.36E-05
Residual	21	1222.331	58.20622		
Total	22	2824.32			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.38	2.34	1.02	0.32	-2.49	7.25	-2.49	7.25
Topsoil P	0.30	0.06	5.25	0.00	0.18	0.42	0.18	0.42

The decent r2 hide signficant unpredictability but guide equation is

Subsoil P = Topsoil P x 0.30 + 2.4

Kimmeridge and Ampthill Clays (all data except very high point)

Relationship of topsoil K to subsoil K

Regression Statistics	
Multiple R	0.78
R Square	**0.60**
Adjusted R Square	0.58
Standard Error	59.45
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	106753.5	106753.5	30.20606	2.22E-05
Residual	20	70683.47	3534.174		
Total	21	177437			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	65.52	30.00	2.18	0.04	2.94	128.09	2.94	128.09
Topsoil K	0.57	0.10	5.50	0.00	0.35	0.79	0.35	0.79

Subsoil K = Topsoil K x 0.57 + 66

Kimmeridge and Ampthill Clays (all data except low woodland point)

Relationship of topsoil pH on topsoil Mg

Regression Statistics	
Multiple R	0.50
R Square	**0.25**
Adjusted R Square	0.21
Standard Error	83.90
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	45858.87	45858.87	6.515499	0.018972
Residual	20	140768.6	7038.429		
Total	21	186627.5			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	817.61	210.77	3.88	0.00	377.95	1257.27	377.95	1257.27
Topsoil pH	-76.63	30.02	-2.55	0.02	-139.25	-14.01	-139.25	-14.01

Topsoil Mg = 818 - topsoil pH x 77

Kimmeridge and Ampthill Clays (all data except low woodland point)

Relationship of topsoil OM and topsoil pH on topsoil Mg

Regression Statistics	
Multiple R	0.50
R Square	**0.25**
Adjusted R Square	0.17
Standard Error	85.84
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	46625.54	23312.77	3.163833	0.065164
Residual	19	140001.9	7368.522		
Total	21	186627.5			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	760.31	279.40	2.72	0.01	175.52	1345.10	175.52	1345.10
Topsoil oM	3.15	9.78	0.32	0.75	-17.31	23.62	-17.31	23.62
Topsoil pH	-71.30	34.89	-2.04	0.06	-144.31	1.72	-144.31	1.72

No improvement if allowing for OM

Kimmeridge and Ampthill Clays (all data except very high point)

Relationship of topsoil Mg to subsoil Mg

Regression Statistics	
Multiple R	0.88
R Square	**0.78**
Adjusted R Square	0.76
Standard Error	48.42
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	161797.7	161797.7	69.00206	6.49E-08
Residual	20	46896.49	2344.825		
Total	21	208694.2			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.05	33.77	0.00	1.00	-70.39	70.49	-70.39	70.49
Topsoil Mg	1.02	0.12	8.31	0.00	0.76	1.27	0.76	1.27

Kimmeridge and Ampthill Clays (all data except woodland)

Relationship of topsoil pH to subsoil pH

Regression Statistics	
Multiple R	0.75
R Square	**0.56**
Adjusted R Square	0.54
Standard Error	0.24
Observations	21

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	1.362847	1.362847	24.21062	9.5E-05
Residual	19	1.069534	0.056291		
Total	20	2.432381			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.64	0.61	7.56	0.00	3.36	5.93	3.36	5.93
Topsoil pH	0.43	0.09	4.92	0.00	0.25	0.62	0.25	0.62

Subsoil pH = topsoil pH x 0.43 + 4.64

Kimmeridge and Ampthill Clays (all data except woodland)								
Relationship of topsoil pH and subsoil OM to subsoil pH								
Regression Statistics								
Multiple R	0.78							
R Square	**0.62**							
Adjusted R Square	0.57							
Standard Error	0.23							
Observations	21							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	1.497165	0.748583	14.40789	0.000184			
Residual	18	0.935216	0.051956					
Total	20	2.432381						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	5.12	0.66	7.75	0.00	3.73	6.51	3.73	6.51
Subsoil OM	-0.08	0.05	-1.61	0.13	-0.19	0.03	-0.19	0.03
Topsoil pH	0.40	0.09	4.56	0.00	0.21	0.58	0.21	0.58
Subsoil pH = topsoil pH x 0.40 - subsoil OM x 0.08 + 5.11								
Organic matter improves r2								

Kimmeridge and Ampthill Clays (all data)								
Relationship of topsoil OM% on subsoil OM%								
Regression Statistics								
Multiple R	0.44							
R Square	**0.19**							
Adjusted R Square	0.15							
Standard Error	0.92							
Observations	23							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	4.154437	4.154437	4.90672	0.03794			
Residual	21	17.78035	0.846683					
Total	22	21.93478						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.58	0.61	2.60	0.02	0.32	2.85	0.32	2.85
Topsoil pH	0.20	0.09	2.22	0.04	0.01	0.38	0.01	0.38
Subsoil pH = topsoil pH x 0.20 + 1.54								

Kimmeridge and Ampthill Clays (all data)								
Relationship of sampling method and topsoil OM% on subsoil OM%								
Regression Statistics								
Multiple R	0.45							
R Square	**0.20**							
Adjusted R Square	0.12							
Standard Error	0.94							
Observations	23							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	4.40778	2.20389	2.514851	0.106107			
Residual	20	17.527	0.87635					
Total	22	21.93478						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.59	0.62	2.57	0.02	0.30	2.88	0.30	2.88
sampling method	0.28	0.52	0.54	0.60	-0.81	1.37	-0.81	1.37
Topsoil pH	0.19	0.09	2.05	0.05	0.00	0.38	0.00	0.38
Method effect plus 0.28% OM but very weak								

A9 : Chilterns

Chilterns data: sandy, light loam and medium subsoils									
Influence of topsoil K on subsoil K									
Regression Statistics									
Multiple R	0.62								
R Square	**0.38**								
Adjusted R Square	0.35								
Standard Error	33.27								
Observations	26								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	1	16221.04	16221.04	14.6508	0.000814				
Residual	24	26572.27	1107.178						
Total	25	42793.31							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	46.18	14.00	3.30	0.00	17.30	75.07	17.30	75.07	
Topsoil K	0.31	0.08	3.83	0.00	0.14	0.48	0.14	0.48	
Subsoil K = Topsoil K x 0.31 + 46									

Chilterns data: sandy, light loam and medium subsoils								
Influence of topsoil K and subsoil stones on subsoil K								
Regression Statistics								
Multiple R	0.62							
R Square	**0.38**							
Adjusted R Square	0.33							
Standard Error	33.92							
Observations	26							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	16327.87	8163.935	7.094932	0.003981			
Residual	23	26465.44	1150.671					
Total	25	42793.31						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	42.68	18.32	2.33	0.03	4.79	80.58	4.79	80.58
Topsoil K	0.31	0.08	3.74	0.00	0.14	0.49	0.14	0.49
Subsoil stone class	1.63	5.36	0.30	0.76	-9.45	12.72	-9.45	12.72
Subsoil stone class insignificant								

Chilterns data: sandy, light loam and medium subsoils
Influence of topsoil K and subsoil OM on subsoil K

Regression Statistics	
Multiple R	0.69
R Square	**0.47**
Adjusted R Square	0.43
Standard Error	31.30
Observations	26

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	20258.28	10129.14	10.33814	0.000627
Residual	23	22535.03	979.7839		
Total	25	42793.31			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	26.28	16.42	1.60	0.12	-7.68	60.24	-7.68	60.24
Topsoil K	0.31	0.08	4.12	0.00	0.16	0.47	0.16	0.47
Subsoil OM%	10.52	5.18	2.03	0.05	-0.20	21.23	-0.20	21.23

Each 1% subsoil OM associated with 10.5 mg/l K (probably significant)
Subsoil K = Topsoil x 0.31 + 10.5 x Subsoil OM% + 26

Chilterns data: heavy loam and clay subsoils
Influence of topsoil K on subsoil K

Regression Statistics	
Multiple R	0.89
R Square	**0.79**
Adjusted R Square	0.78
Standard Error	19.46
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	30440.49	30440.49	80.36344	1.27E-08
Residual	21	7954.492	378.7853		
Total	22	38394.98			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	32.33	8.32	3.88	0.00	15.02	49.64	15.02	49.64
Topsoil K	0.59	0.07	8.96	0.00	0.45	0.73	0.45	0.73

Chilterns data: heavy loam and clay subsoils
Influence of topsoil K and subsoil texture on subsoil K

Regression Statistics	
Multiple R	0.89
R Square	**0.80**
Adjusted R Square	0.78
Standard Error	19.62
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	30696.49	15348.25	39.8734	1.05E-07
Residual	20	7698.49	384.9245		
Total	22	38394.98			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.48	29.25	0.32	0.75	-51.54	70.50	-51.54	70.50
Topsoil K	0.59	0.07	8.84	0.00	0.45	0.72	0.45	0.72
Subsoil texture	6.74	8.26	0.82	0.42	-10.50	23.97	-10.50	23.97

Subsoil K = Topsoil K x 0.59 + 30 (or 37 if clay textured)

Chilterns data: heavy loam and clay subsoils

Influence of topsoil K and subsoil stones on subsoil K (5 cluster added)

Regression Statistics	
Multiple R	0.87
R Square	**0.75**
Adjusted R Square	0.73
Standard Error	20.69
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	32495.02	16247.51	37.95355	2.66E-08
Residual	25	10702.23	428.0893		
Total	27	43197.25			

	Coefficient:	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	26.68	10.88	2.45	0.02	4.28	49.08	4.28	49.08
Topsoil K	0.57	0.07	8.65	0.00	0.43	0.70	0.43	0.70
Sub stone class	4.86	4.53	1.07	0.29	-4.47	14.19	-4.47	14.19

Each increase in stone class has a small influence on subsoil K (5 mg/l)

Subsoil K = Topsoil K x 0.57 + stone class x 5 + 27

Chilterns data: heavy loam and clay subsoils

Influence of topsoil K and subsoil OM on subsoil K

Regression Statistics	
Multiple R	0.90
R Square	**0.81**
Adjusted R Square	0.79
Standard Error	20.36
Observations	24.00

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	36534.12	18267.06	44.05328	3.06E-08
Residual	21	8707.826	414.6584		
Total	23	45241.95			

	Coefficient:	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	31.13	10.14	3.07	0.01	10.05	52.21	10.05	52.21
Topsoil K	0.62	0.07	8.82	0.00	0.47	0.77	0.47	0.77
Subsoil OM%	-0.60	4.52	-0.13	0.90	-10.00	8.80	-10.00	8.80

OM not significant

Chilterns All data of pH < 7.5

Influence of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.85
R Square	**0.73**
Adjusted R Square	0.72
Standard Error	0.31
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	8.430224	8.430224	88.45128	7.35E-11
Residual	33	3.145205	0.095309		
Total	34	11.57543			

	Coefficient:	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.81	0.53	3.39	0.00	0.72	2.89	0.72	2.89
Topsoil pH	0.78	0.08	9.40	0.00	0.61	0.95	0.61	0.95

Subsoil pH = topsoil pH x 0.78 + 1.81

Chilterns All data of pH < 7.5

Influence of topsoil pH and subsoil OM on subsoil pH

Regression Statistics	
Multiple R	0.87
R Square	**0.75**
Adjusted R Square	0.73
Standard Error	0.30
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	8.677456	4.338728	47.90911	2.38E-10
Residual	32	2.897973	0.090562		
Total	34	11.57543			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.34	0.61	3.83	0.00	1.10	3.59	1.10	3.59
Topsoil pH	0.72	0.09	8.10	0.00	0.54	0.90	0.54	0.90
Subsoil OM%	-0.09	0.05	-1.65	0.11	-0.20	0.02	-0.20	0.02

OM gives some improvement in r2

Subsoil pH = topsoil pH x 0.72 - subsoil OM% x 0.09 + 2.34

Chilterns All data of pH < 7.5

Influence of topsoil pH and subsoil stones on subsoil pH

Regression Statistics	
Multiple R	0.86
R Square	**0.75**
Adjusted R Square	0.73
Standard Error	0.30
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	8.630655	4.315327	46.8934	3.08E-10
Residual	32	2.944774	0.092024		
Total	34	11.57543			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.17	0.58	3.75	0.00	0.99	3.35	0.99	3.35
Topsoil pH	0.74	0.09	8.59	0.00	0.56	0.91	0.56	0.91
Subsoil stone class	-0.07	0.05	-1.48	0.15	-0.17	0.03	-0.17	0.03

Gives some improvement in r2 (less than subsoil OM%)

Subsoil pH = topsoil pH x 0.72 - subsoil steone class x 0.07 + 2.17

Chilterns data (all)

Influence of topsoil OM and subsoil stone class on subsoil OM

Regression Statistics	
Multiple R	0.72
R Square	**0.52**
Adjusted R Square	0.50
Standard Error	0.75
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	29.79339	14.89669	26.46691	1.79E-08
Residual	48	27.01642	0.562842		
Total	50	56.8098			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.27	0.31	-0.87	0.39	-0.90	0.35	-0.90	0.35
Topsoil pH	0.37	0.07	5.03	0.00	0.22	0.52	0.22	0.52
Subsoil stone class	0.36	0.10	3.67	0.00	0.16	0.56	0.16	0.56

Subsoil OM = topsoil OM x 0.37 + subsoil stone class x 0.36 -0.27

A10 : London Clay

London Clay: main data with heavier subsoils plus grassland cluster (mainly clay subsoils)								
Effect of topsoil P on subsoil P								
Regression Statistics								
Multiple R	0.71							
R Square	**0.50**							
Adjusted R Square	0.50							
Standard Error	2.67							
Observations	57							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	397.826	397.826	55.9055	6.24E-10			
Residual	55	391.3824	7.116044					
Total	56	789.2084						
	Coefficier	Standard I	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0	Upper 95.0
Intercept	2.29	0.71	3.23	0.00	0.87	3.71	0.87	3.71
Topsoil P	0.20	0.03	7.48	0.00	0.15	0.26	0.15	0.26
Subsoil P = Topsoil P x 0.20 + 2.3								

London Clay: main data with heavier subsoils plus grassland cluster (mainly clay subsoils)								
Effect of topsoil P and subsoil OM (capped at 6%) on subsoil P								
Regression Statistics								
Multiple R	0.73							
R Square	**0.53**							
Adjusted R Square	0.52							
Standard Error	2.61							
Observations	57							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	421.5971	210.7985	30.9651	1.1E-09			
Residual	54	367.6114	6.807618					
Total	56	789.2084						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.21	1.31	0.16	0.88	-2.43	2.84	-2.43	2.84
Topsoil P	0.20	0.03	7.65	0.00	0.15	0.26	0.15	0.26
Subsoil OM%	0.86	0.46	1.87	0.07	-0.06	1.78	-0.06	1.78
Subsoil P = Topsoil P x 0.20 + Subsoil OM x 0.86 + 0.21								

London Clay: main data with medium subsoils plus amenity cluster								
Effect of topsoil P on subsoil P								
Regression Statistics								
Multiple R	0.93							
R Square	**0.86**							
Adjusted R Square	0.85							
Standard Error	1.71							
Observations	25							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	401.4575	401.4575	137.6163	3.47E-11			
Residual	23	67.09612	2.917223					
Total	24	468.5536						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.40	0.42	3.36	0.00	0.54	2.26	0.54	2.26
Topsoil P	0.30	0.03	11.73	0.00	0.25	0.36	0.25	0.36
Subsoil P = Topsoil P x 0.30 + 1.4								

London Clay: main data with medium subsoils plus amenity cluster								
Effect of topsoil P and subsoil OM on subsoil P								
Regression Statistics								
Multiple R	0.94							
R Square	**0.88**							
Adjusted R Square	0.86							
Standard Error	1.63							
Observations	25							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	2	410.4457	205.2229	77.69867	1.07E-10			
Residual	22	58.10786	2.641266					
Total	24	468.5536						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-0.73	1.22	-0.60	0.55	-3.26	1.80	-3.26	1.80
Topsoil P	0.30	0.02	12.35	0.00	0.25	0.35	0.25	0.35
Subsoil OM%	0.87	0.47	1.84	0.08	-0.11	1.84	-0.11	1.84
Subsoil P = Topsoil P x 0.30 + Subsoil OM x 0.87 -0.73								

London Clay: main data and amenity cluster, heavy loam and clay subsoils								
Effect of topsoil K on subsoil K								
Regression Statistics								
Multiple R	0.82							
R Square	**0.68**							
Adjusted R Square	0.67							
Standard Error	33.46							
Observations	51							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	116792.3	116792.3	104.3331	9.91E-14			
Residual	49	54851.43	1119.417					
Total	50	171643.7						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	51.42	9.68	5.31	0.00	31.97	70.87	31.97	70.87
Topsoil K	0.53	0.05	10.21	0.00	0.42	0.63	0.42	0.63
Subsoil K = Topsoil K x 0.53 + 51								

London Clay: main data and amenity cluster, heavy loam and clay subsoils

Effect of topsoil K and subsoil OM (capped at 6%) on subsoil K

Regression Statistics	
Multiple R	0.83
R Square	**0.68**
Adjusted R Square	0.67
Standard Error	33.56
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	117569.3	58784.66	52.18117	9.14E-13
Residual	48	54074.36	1126.549		
Total	50	171643.7			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	63.54	17.53	3.62	0.00	28.29	98.79	28.29	98.79
Topsoil K	0.53	0.05	10.22	0.00	0.43	0.64	0.43	0.64
Subsoil OM%	-5.39	6.49	-0.83	0.41	-18.45	7.66	-18.45	7.66

Dubious significance and no improvement on r2

London Clay: main data and amenity cluster, heavy loam and clay subsoils

Effect of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.83
R Square	**0.68**
Adjusted R Square	0.68
Standard Error	0.50
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	27.00538	27.00538	106.3875	7.13E-14
Residual	49	12.43815	0.25384		
Total	50	39.44353			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	1.08	0.55	1.95	0.06	-0.03	2.19	-0.03	2.19
Topsoil pH	0.90	0.09	10.31	0.00	0.73	1.08	0.73	1.08

Subsoil pH = Topsoil pH x 0.90 + 1.08

London Clay: main data and amenity cluster, heavy loam and clay subsoils

Effect of topsoil pH and subsoil OM% (capped at 6%) on subsoil pH

Regression Statistics	
Multiple R	0.87
R Square	**0.75**
Adjusted R Square	0.74
Standard Error	0.45
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	2	29.59027	14.79513	72.07422	3.49E-15
Residual	48	9.853264	0.205276		
Total	50	39.44353			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.38	0.62	3.85	0.00	1.14	3.62	1.14	3.62
Topsoil pH	0.82	0.08	9.94	0.00	0.65	0.98	0.65	0.98
Subsoil OM%	-0.32	0.09	-3.55	0.00	-0.51	-0.14	-0.51	-0.14

Subsoil pH = Topsoil pH x 0.82 - Subsoil OM x 0.32 + 2.38

AG : General correlations

t-Test: Two-Sample Assuming Unequal Variances

Topsoil P on arable		
	Text 1	*Text 2*
Mean	39.26	34.50
Variance	569.54	629.06
Observations	13	24
Hypothesized Mean	0	
df	26	
t Stat	0.569	
P(T<=t) one-tail	0.287	
t Critical one-tail	1.706	
P(T<=t) two-tail	0.575	
t Critical two-tail	2.056	

P not different in light loams and medium topsoils

Subsoil P in arable		
	Sub Text 2	*Sub text 3*
Mean	26.02	29.43
Variance	630.22	1115.01
Observations	13	13
Hypothesized Mean	0	
df	22	
t Stat	-0.295	
P(T<=t) one-tail	0.385	
t Critical one-tail	1.717	
P(T<=t) two-tail	0.771	
t Critical two-tail	2.074	

P not significantly higher in heavy loams than medium loams

Topsoil P on arable		
	Text 3	*Text 4*
Mean	31.57	17.74
Variance	694.82	82.10
Observations	40	104
Hypothesized Mean	0	
df	43	
t Stat	3.246	
P(T<=t) one-tail	0.001	
t Critical one-tail	1.681	
P(T<=t) two-tail	0.002	
t Critical two-tail	2.017	

P significantly lower in clays than heavy loam topsoils

Topsoil P on grassland		
	Text 3	*Text 4*
Mean	25.54	14.64
Variance	673.13	233.14
Observations	75	32
Hypothesized Mean	0	
df	94	
t Stat	2.704	
P(T<=t) one-tail	0.004	
t Critical one-tail	1.661	
P(T<=t) two-tail	0.008	
t Critical two-tail	1.986	

P significantly lower in clays than heavy loam topsoils

Topsoil P in woodland		
	Text 3	*Text 4*
Mean	22.17	10.93
Variance	408.78	72.63
Observations	33	8
Hypothesized Mean	0	
df	28	
t Stat	2.427	
P(T<=t) one-tail	0.011	
t Critical one-tail	1.701	
P(T<=t) two-tail	0.022	
t Critical two-tail	2.048	

P significantly lower in clays than heavy loam topsoils

Arable heavy loam and clay topsoils (P up to 45 mg/l)

Influence of topsoil OM on topsoil P

Regression Statistics	
Multiple R	0.24
R Square	**0.06**
Adjusted R Square	0.05
Standard Error	9.08
Observations	135

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	690.5145	690.5145	8.370939	0.004457
Residual	133	10971.1	82.48949		
Total	134	11661.62			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	9.56	3.21	2.98	0.00	3.21	15.90	3.21	15.90
Topsoil OM%	1.94	0.67	2.89	0.00	0.61	3.27	0.61	3.27

OM is significant, 1.9 mg/l increase per 1% topsoil OM

Arable heavy loam and clay topsoils (P up to 45mg/l)

Influence of topsoil pH on topsoil P

Regression Statistics	
Multiple R	0.11
R Square	0.01
Adjusted R Square	0.00
Standard Error	15.41
Observations	142

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	379.2335	379.2335	1.597782	0.208318
Residual	140	33229	237.35		
Total	141	33608.23			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	4.42	13.01	0.34	0.73	-21.31	30.15	-21.31	30.15
Topsoil pH	2.43	1.92	1.26	0.21	-1.37	6.23	-1.37	6.23

Dubious significance of OM on topsoil P

Arable heavy loam and clay topsoils

Relationship of subsoil K to topsoil K (1 very high point excluded)

Regression Statistics	
Multiple R	0.75
R Square	**0.56**
Adjusted R Square	0.55
Standard Error	**39.79**
Observations	147

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	287909.3	287909.3	181.8268	2.27E-27
Residual	145	229596.7	1583.426		
Total	146	517506			

	Coefficier	Standard E	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0	Upper 95.0
Intercept	39.86	9.46	4.22	0.00	21.17	58.55	21.17	58.55
Topsoil K	0.56	0.04	13.48	0.00	0.48	0.64	0.48	0.64

Subsoil K = Topsoil K x 0.56 + 40

Arable light to medium loam subsoils (1 point excluded)

Relationship of subsoil K to topsoil K

Regression Statistics	
Multiple R	0.90
R Square	0.82
Adjusted R Square	0.81
Standard Error	17.03
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	28529.05	28529.05	98.36845	1.4E-09
Residual	22	6380.491	290.0223		
Total	23	34909.54			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	19.44	6.06	3.21	0.00	6.88	31.99	6.88	31.99
Topsoil K	0.42	0.04	9.92	0.00	0.34	0.51	0.34	0.51

Subsoil K = Topsoil K x 0.42 + 19

Arable heavy loam and clay topsoils

Influence of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.76
R Square	**0.57**
Adjusted R Square	0.57
Standard Error	0.39
Observations	148

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	30.37137	30.37137	196.1278	8.7E-29
Residual	146	22.60883	0.154855		
Total	147	52.9802			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.74	0.32	8.52	0.00	2.10	3.37	2.10	3.37
Topsoil pH	0.67	0.05	14.00	0.00	0.57	0.76	0.57	0.76

Subsoil pH = Topsoil pH x 0.67 + 2.74

Grassland heavy loam and clay topsoils

Influence of topsoil pH on subsoil pH

Regression Statistics	
Multiple R	0.77
R Square	**0.59**
Adjusted R Square	0.59
Standard Error	0.45
Observations	103

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	29.05895	29.05895	146.6632	2.18E-21
Residual	101	20.01153	0.198134		
Total	102	49.07049			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.39	0.40	5.91	0.00	1.59	3.19	1.59	3.19
Topsoil pH	0.72	0.06	12.11	0.00	0.60	0.84	0.60	0.84

Subsoil pH = Topsoil pH x 0.72 + 2.39

Arable light to medium topsoils									
Influence of topsoil pH on subsoil pH									
Regression Statistics									
Multiple R	0.88								
R Square	**0.77**								
Adjusted R Square	0.76								
Standard Error	0.29								
Observations	37								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	1	9.534547	9.534547	116.284	1.14E-12				
Residual	35	2.869778	0.081994						
Total	36	12.40432							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	2.54	0.41	6.14	0.00	1.70	3.38	1.70	3.38	
Topsoil pH	0.67	0.06	10.78	0.00	0.54	0.79	0.54	0.79	
Subsoil pH = Topsoil pH x 0.67 + 2.54									

Grassland light to medium topsoils									
Influence of topsoil pH on subsoil pH									
Regression Statistics									
Multiple R	0.82								
R Square	**0.68**								
Adjusted R Square	0.67								
Standard Error	0.43								
Observations	50								
ANOVA									
	df	*SS*	*MS*	*F*	*gnificance F*				
Regression	1	18.88945	18.88945	100.2675	2.42E-13				
Residual	48	9.042749	0.188391						
Total	49	27.9322							
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*	
Intercept	1.59	0.54	2.96	0.00	0.51	2.67	0.51	2.67	
Topsoil pH	0.82	0.08	10.01	0.00	0.66	0.99	0.66	0.99	
Subsoil pH = Topsoil pH x 0.82 + 1.59									

Woodland heavy loam and clay subsoils
Relationship of subsoil P to topsoil P

Regression Statistics	
Multiple R	0.80
R Square	**0.63**
Adjusted R Square	0.62
Standard Error	4.91
Observations	46

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	1830.105	1830.105	75.92622	3.9E-11
Residual	44	1060.564	24.10373		
Total	45	2890.669			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	2.08	1.09	1.92	0.06	-0.11	4.27	-0.11	4.27
Topsoil P	0.42	0.05	8.71	0.00	0.32	0.52	0.32	0.52

Subsoil P = topsoil P x 0.42 + 2.1

Woodland heavy loam and clay subsoils
Relationship of subsoil K to topsoil K

Regression Statistics	
Multiple R	0.91
R Square	**0.82**
Adjusted R Square	0.82
Standard Error	39.07
Observations	46

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	313373.5	313373.5	205.3268	3.51E-18
Residual	44	67153.6	1526.218		
Total	45	380527.1			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	44.13	9.76	4.52	0.00	24.46	63.79	24.46	63.79
Topsoil K	0.52	0.04	14.33	0.00	0.45	0.60	0.45	0.60

Subsoil K = topsoil K x 0.52 + 44

Woodland : relationship of subsoil pH to topsoil pH

Regression Statistics	
Multiple R	0.89
R Square	**0.80**
Adjusted R Square	0.79
Standard Error	0.61
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	1	68.44729	68.44729	186.9027	3.59E-18
Residual	48	17.57851	0.366219		
Total	49	86.0258			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.63	0.45	1.40	0.17	-0.28	1.54	-0.28	1.54
Topsoil pH	0.93	0.07	13.67	0.00	0.79	1.07	0.79	1.07

Subsoil pH = Topsoil pH x 0.93 + 0.63
Interept of dubious significance

A17 : Total Nitrogen

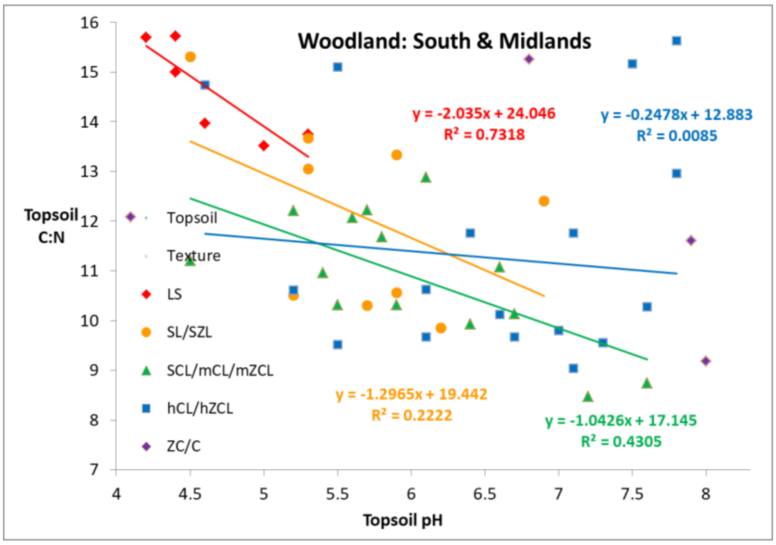

Figure A17.1 : Woodland topsoil pH and C:N ratio

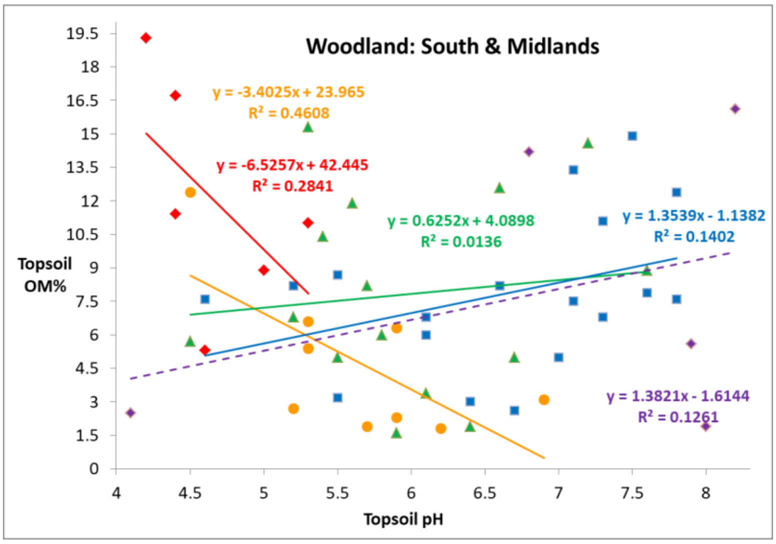

Figure A17.2 : Woodland topsoil pH and OM

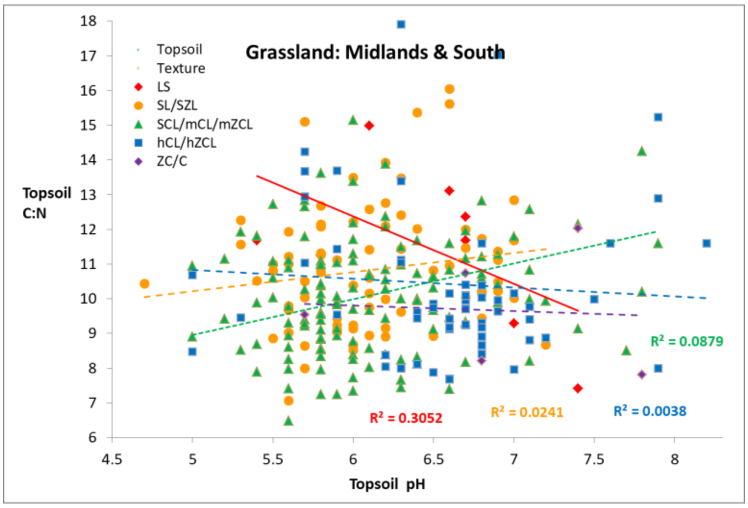

Figure A17.3 : Grassland topsoil pH and C:N

Sand topsoils - all data								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.99							
R Square	0.98							
Adjusted R Squ	0.98							
Standard Error	0.02							
Observations	19							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.566399	0.566399	1009.867	1.39E-16			
Residual	17	0.009535	0.000561					
Total	18	0.575934						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.049	0.009	5.559	0.000	0.031	0.068	0.031	0.068
Topsoil OM	0.035	0.001	31.778	0.000	0.033	0.037	0.033	0.037

Sand topsoils - all data < 10% OM								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.96							
R Square	0.93							
Adjusted R Squ	0.92							
Standard Error	0.02							
Observations	15							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.099269	0.099269	162.1064	1.02E-08			
Residual	13	0.007961	0.000612					
Total	14	0.107229						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.041	0.014	3.033	0.010	0.012	0.071	0.012	0.071
Topsoil N	0.037	0.003	12.732	0.000	0.030	0.043	0.030	0.043
If organic soils omitted similar slope and lower intercept								
Topsoil TN = Topsoil OM x 0.045 + 0.037								

Light loam topsoils								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.91							
R Square	0.82							
Adjusted R Squ	0.82							
Standard Error	0.03							
Observations	121							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.67056	0.67056	555.0226	1.24E-46			
Residual	119	0.143772	0.001208					
Total	120	0.814332						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.048	0.008	5.789	0.000	0.032	0.064	0.032	0.064
Topsoil OM%	0.043	0.002	23.559	0.000	0.039	0.046	0.039	0.046

Light loam topsoils (<10%)								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.91							
R Square	0.83							
Adjusted R Squ	0.83							
Standard Error	0.03							
Observations	120							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.625367	0.625367	566.9822	6.94E-47			
Residual	118	0.130151	0.001103					
Total	119	0.755518						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.037	0.009	4.341	0.000	0.020	0.054	0.020	0.054
Topsoil OM%	0.045	0.002	23.811	0.000	0.042	0.049	0.042	0.049
Omission of one high point changes slope and intercept								
Slope is significantly higher than light loam data (95% ranges hardly overlap)								
Topsoil TN = Topsoil OM x 0.045 + 0.037								

Medium topsoils of OM < 10%								
Relationship of OM to TN								
Multiple R	0.90							
R Square	0.82							
Adjusted R Squ	0.81							
Standard Error	0.04							
Observations	214							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	1.453135	1.453135	938.7662	8.11E-80			
Residual	212	0.328159	0.001548					
Total	213	1.781295						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.017	0.007	2.370	0.019	0.003	0.032	0.003	0.032
Topsoil OM%	0.054	0.002	30.639	0.000	0.050	0.057	0.050	0.057
Slope is significantly higher than sand data (95% ranges hardly overlap)								
Topsoil TN = Topsoil OM x 0.054 + 0.017								

Heavy loam topsoils of OM < 10%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.89							
R Square	0.79							
Adjusted R Squ	0.79							
Standard Error	0.07							
Observations	98							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	1.734697	1.734697	362.3043	2.36E-34			
Residual	96	0.459644	0.004788					
Total	97	2.194341						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.009	0.018	0.513	0.609	-0.027	0.045	-0.027	0.045
Topsoil OM%	0.055	0.003	19.034	0.000	0.049	0.060	0.049	0.060
Intercept not significant. Slope is the same as medium soils								
Topsoil TN = Topsoil OM x 0.055 + 0.009								

Clay topsoils of OM < 10%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.88							
R Square	0.78							
Adjusted R Squ	0.77							
Standard Error	0.03							
Observations	39							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.113128	0.113128	128.9517	1.28E-13			
Residual	37	0.03246	0.000877					
Total	38	0.145588						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.069	0.020	3.536	0.001	0.029	0.109	0.029	0.109
Topsoil OM%	0.048	0.004	11.356	0.000	0.039	0.056	0.039	0.056
Intercept is significant								
Topsoil TN = Topsoil OM x 0.048 + 0.069								

Sandy subsoil of OM up to 20%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.97							
R Square	0.94							
Adjusted R Squ	0.94							
Standard Error	0.02							
Observations	35							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.173898	0.173898	523.062	8.18E-22			
Residual	33	0.010971	0.000332					
Total	34	0.184869						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.021	0.005	4.281	0.000	0.011	0.030	0.011	0.030
Subsoil OM%	0.034	0.001	22.871	0.000	0.031	0.037	0.031	0.037

Sandy subsoil of OM < 10%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.95							
R Square	0.90							
Adjusted R Squ	0.90							
Standard Error	0.01							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.046504	0.046504	257.2605	1.21E-15			
Residual	28	0.005061	0.000181					
Total	29	0.051565						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.011	0.005	2.215	0.035	0.001	0.021	0.001	0.021
Subsoil OM	0.040	0.002	16.039	0.000	0.035	0.045	0.035	0.045
Intercept is significant								
Subsoil TN = Subsoil OM x 0.040 + 0.011								

Sandy subsoil of OM < 6%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.943							
R Square	0.889							
Adjusted R Squ	0.885							
Standard Error	0.013							
Observations	29							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.038569	0.038569	215.7187	2.14E-14			
Residual	27	0.004827	0.000179					
Total	28	0.043396						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.009	0.005	1.684	0.104	-0.002	0.020	-0.002	0.020
Subsoil OM	0.042	0.003	14.687	0.000	0.036	0.047	0.036	0.047
Subsoil TN = Subsoil OM x 0.042 + 0.009								
Intercept borderline significant								

Light loam subsoil of OM < 6%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.87							
R Square	**0.77**							
Adjusted R Squ	0.76							
Standard Error	0.02							
Observations	86							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.165762	0.165762	274.205	3.48E-28			
Residual	84	0.05078	0.000605					
Total	85	0.216542						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.032	0.006	5.545	0.000	0.021	0.044	0.021	0.044
Subsoil OM%	0.041	0.003	16.559	0.000	0.036	0.046	0.036	0.046
Intercept is signifcant Slope no different to sands								
Subsoil TN = Subsoil OM x 0.041 + 0.032								

Medium loam subsoil of OM =< 6%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.83							
R Square	0.69							
Adjusted R Squ	0.68							
Standard Error	0.03							
Observations	114							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.183668	0.183668	245.7964	5.11E-30			
Residual	112	0.083691	0.000747					
Total	113	0.267359						
	Coefficient	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.017	0.006	2.563	0.012	0.004	0.030	0.004	0.030
subsoil OM%	0.050	0.003	15.678	0.000	0.044	0.056	0.044	0.056
Intercept significant. Slope greater than lighter soils								
Subsoil TN = Subsoil OM x 0.050 + 0.017								

Heavy loam subsoil of OM < 6%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.93							
R Square	0.87							
Adjusted R Squ	0.87							
Standard Error	0.03							
Observations	96							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.402391	0.402391	610.4162	6.82E-43			
Residual	94	0.061966	0.000659					
Total	95	0.464357						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.006	0.006	1.172	0.244	-0.004	0.017	-0.004	0.017
Subsoil OM%	0.058	0.002	24.707	0.000	0.053	0.062	0.053	0.062
Intercept almost gnificant. Slope greater than medium soils								
Subsoil TN = Subsoil OM x 0.058 + 0.008								
Clay subsoil of OM < 6%								
Relationship of OM to TN								
Regression Statistics								
Multiple R	0.90							
R Square	0.82							
Adjusted R Squ	0.81							
Standard Error	0.03							
Observations	160							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	0.496933	0.496933	699.8667	6.3E-60			
Residual	158	0.112186	0.00071					
Total	159	0.609119						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0.020	0.005	3.684	0.000	0.009	0.031	0.009	0.031
Subsoil OM%	0.054	0.002	26.455	0.000	0.050	0.059	0.050	0.059
Intercept gnificant. Slope same as heavy loams								