Would a soil scrape be an appropriate form of management to prevent natural succession and re-establish heathland vegetation at a site on Troopers Hill?

2409353, 2355946, 2291562, 2417234, 2380144, 2403125

Friends of Troopers Hill

Peter Watson

Word count: 7994

Table of Contents

Abstract

England has lost 85% of its lowland heathland within the last 150 years and these environments cannot survive without external management (Wildlife Trust, 2025). This paper assesses the viability of a soil scrape as a form of heathland management at Troopers Hill, Bristol and examines impacts of industrial activity and evidence for succession processes. It finds that the median topsoil in the proposed scrape site has a 1.26 greater pH than the adjacent heathland habitat, whilst total oxidised nitrogen was found to be 7.95 µg/g greater in the topsoil, showing how succession processes have made conditions more tolerable for woodland vegetation and threaten heathland survival. However, heavy metal concentrations are below the polluting threshold and should not factor into management approaches, and an assessment of soil depth revealed areas of the site deemed too shallow for a soil scrape. These limitations reveal that alternative management strategies (acidification) are more suitable.

Introduction and Literature Review

Lowland heathlands are characterised by nutrient-poor, highly acidic soils (within the pH range of 4-5.5) and provide a habitat for dwarf shrubs, gorse and rare species like the marsh gentian (English Nature, 2006; Maddock, 2008). They are a unique habitat created by anthropological processes over thousands of years, therefore, they are not only biologically important, but also key cultural heritage (Hawley et al., 2008). However, they have been in significant decline over the last century and were identified as priority habitats in the UK Biodiversity Action Plan (2011). The UK contains 20% of the world's lowland heathland and subsequently, their conservation and restoration are key focuses for UK environmental groups (English Nature, 2006).

Troopers Hill is one such area of heathland that is of great regional importance as the only heath and acid grassland habitat in Bristol (Bristol City Council, n.d.). It is additionally a hub of biodiversity, acting as a habitat for 321 invertebrate species, including 84 species of bee (Friends of Troopers Hill, 2025a). It is currently managed under a 10-year plan with Bristol City Council that is divided into 17 compartments (Bristol City Council, 2019). This project focuses on Compartment 6, where management in 2006 cleared a large area of succeeding birch (*Betula pendula*) and bramble (*Rubus fructicosus agg*). There has been concern that failure to then remove the cut down vegetation allowed a layer of organic matter rich soil to develop on top of the old heathland, accelerating natural succession processes in the compartment.

Succession processes occur where species establish on heathland soil, generating humus and forming a new organic layer on the topsoil, enriching it with nutrients like nitrogen and ammonium (Vuuren et al., 1992). This enables coloniser species like birch saplings to establish and acclimatise other woodland species to the area, developing a woodland ecosystem (England Nature, 2006). These soils are more fertile, with high nutrient content, better moisture retention, higher pH and a richer organic layer in contrast to the acidic and nutrient-poor heathland soils (Woodland Trust, 2021). The enhanced nitrogen levels increase soil pH and hinder growth of traditional specialised heathland plants like gorse (*Ulex europaeus)* and ling heather (*Calluna vulgaris*) which are not adjusted to such conditions (Diggelen et al., 2021). This paper examines the evidence for the existence of these processes at a specific site on Troopers Hill and determines the viability and ethics of restoration management (namely a soil scrape) at Compartment 6 of Troopers Hill.

A soil scrape involves removing a layer of the topsoil, aiming to reduce nutrients and expose seed banks for heathland vegetation species, ultimately stripping it back to its underlying heathland soil (Hawley et al., 2008). The efficacy of soil scrapes is supported by Tapadar et al (2002), who showed that seed banks could survive for 40 years under succeeded heathlands, which could enable regrowth if heathland conditions are restored in the subsoil. Previous implementations of soil scrapes have shown varied successes (Allison and Ausden, 2004: 2006, Britton et al., 2000). Initial studies by Gardiner and Vaughan (2008) found that topsoil removal facilitated the re-introduction of gorse and sheep's sorrel in Epping Forest, suggesting that removing the top 2cm of soil can facilitate the reintroduction of heathland species in some sites. Allison and Ausden (2006) further determined that exposing the soil to sufficient sunlight can be enough to foster its germination where there is an established seed bank. However, they also conclude that whilst this seedbank can be exposed, and soil nitrogen levels decreased, this must be considered alongside the high cost of removing and disposing of the scraped soil (*ibid*). Additionally, Natural England have concerns about the potential for "deleterious impacts to the soil and the historic environment" where sub soil is damaged and historical artefacts and traces within the soil are removed during a soil scrape (Hawley et al., 2008, p.

2). Clearly, important questions about the suitability of Compartment 6 to a soil scrape must be answered before a decision can be made about this management option.

Natural England describes the value of heathland soil as a "historical palimpsest" and this reading is a fitting way to describe Troopers Hill's rich industrial history, with the site being home to two grade 2 listed chimneys as relics from previous copper smelting, sandstone quarrying, and coal and fire clay mining at the site (Friends of Troopers Hill, 2025b; Hawley et al., 2008, p.3). These industrial activities are considered external influences in this report and have been found to release lead into soils (Wan et al., 2024). These heavy metals have been identified to decrease soil organic matter content, pH, and nutrient availability, reducing overall soil health (Oliveria et al., 2006). Previous studies at Troopers Hill support the importance of these influences, finding very high pH levels and evidence of copper, arsenic, and lead pollution in the soil (Beighton, 2013). A further consideration specific to the high slope angle at Troopers Hill is that downslope soil exhibits lower heavy metal concentrations as low pH causes increased soil solubility and metal leaching (Lindsay, 1972). There is additionally evidence of coal spoil at Compartment 6 as a legacy of coal mining. The highly acidic nature of coal spoil not only reduces phosphorus and nitrogen, but also increases zinc solubility, further amplifying these detrimental heavy metal effects in the soil (Tapadar et al., 2016). Coal spoil also reduces porosity and water availability within the soil structure, affecting the water retention of plants, and hindering nutrient cycling due to slowed microbial activity (Zhang et al., 2024, Criquet et al., 2023). Furthermore, the way these external influences are held as memories in the soil adds an ethical dimension to consideration of the suitability of a soil scrape at this site – can it be ensured that the only soil being removed is that of the added organic matter from woodland clearing, or is there a risk that artefact or biological matter could be removed and dumped? These questions will therefore be at the forefront of this report's conclusions, in line with Natural England's guidelines for heathland management (Hawley et al., 2008).

However, previous implementations of soil scrapes discussed here have largely focussed on conifer plantation sites or sites that have not previously been classed as heathland (Allison and Ausden, 2004; 2006., Gardiner and Vaughan, 2008) Whereas Compartment 6 at Trooper's Hill was previously afforested heathland, where heathland restoration processes have been determined to be more successful (Walker et al., 2004). Unfortunately, it has also been the victim of natural succession processes, largely from birch trees (Betula), which can be the most difficult invading species to control (Mitchell et al., 1999). Hence, this report examines soil characteristics (pH, nutrient concentrations, heavy metals, soil moisture and organic matter concentrations) between sites, while assessing the industrial influences on the soil that may have resulted from Troopers Hill's industrial history. This will ultimately allow the practicality and suitability of a soil scrape on a specific study site within Compartment 6 to be determined.

Research Questions

1. What evidence is there to support that natural succession is occurring on Troopers Hill and what processes are driving this? (RQ1)
2. How have industrial influences affected the soil on Troopers Hill? (RQ2)
3. Is a soil scrape a viable and ethical form of heathland management at the study site, and should alternative management options be considered? (RQ3)

Site Overview and Sampling Strategy

Site Overview

The study site (Site A) is a section of Compartment 6 experiencing early succession processes from woodland encroachment from Site C (Figure 1). To investigate the viability of a soil scrape at Site A, adjacent sites were chosen representing varying stages of succession. As such, Site A was compared to a woodland (Site C) and heathland (Site B) habitat (Figure 1). Site A was split into topsoil and subsoil samples to investigate whether removing topsoil would reveal characteristically heathland subsoil. Their proximity to Site A limited the risk of variation in historical and current land use having an impact on soil characteristics. Furthermore, a similar gradient was ensured across the three sites as a further control for run off processes. 8 samples were taken for the Site A top and subsoil as this was the focus of our investigation, with a supplementary 7 samples being taken for sites B and C.

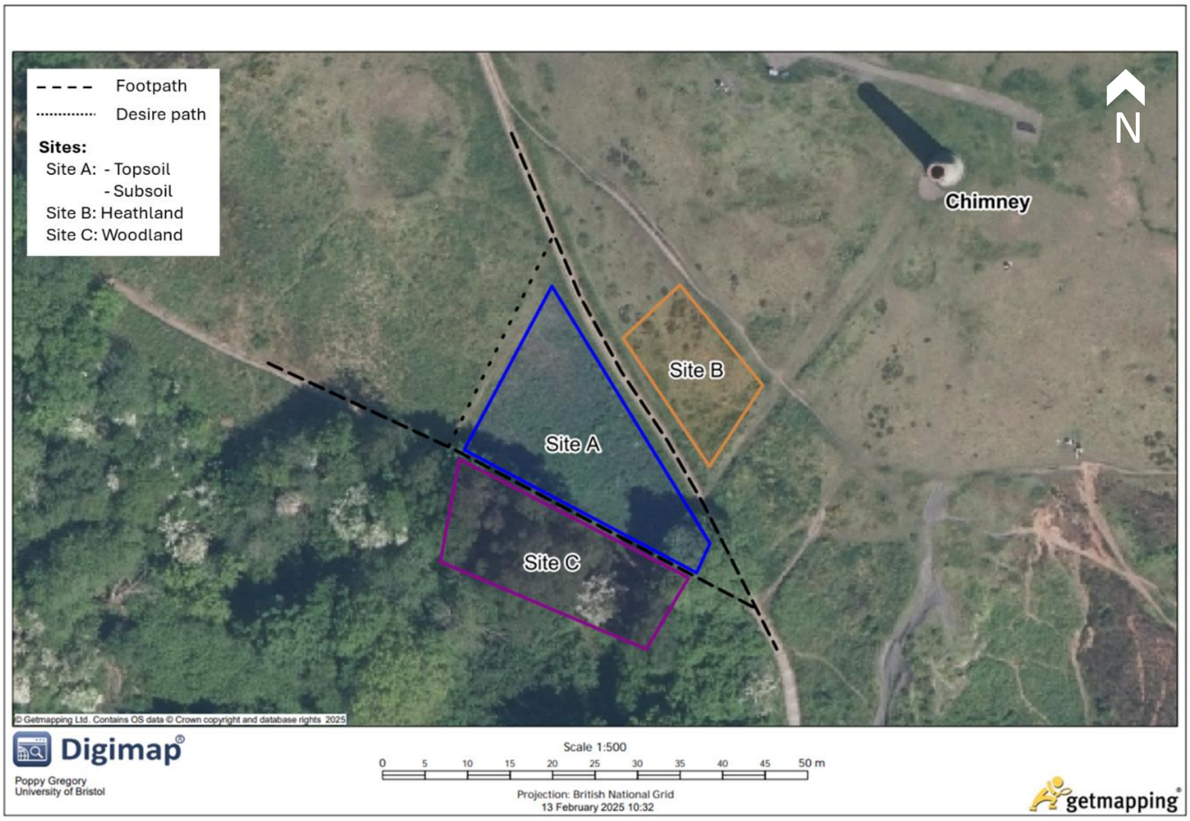

Figure 1: An aerial map of the three study sites on Troopers Hill shown via satellite (Source: Modified Ordinance Survey Map - Digimap).

Sampling Strategy

Soil samples were collected on January 28th, 2025. To mitigate contamination from foot traffic and the alkaline limestone path, samples were taken one metre from pathways. At each sample point, a what3words and GPS coordinate were recorded using the Phyphox app to map the site. To minimise bias, random sampling was used at Site A (Steenkamp, 2021). Each square metre was labelled with its what3words location, and a random number generator used to select the locations at Site A, collecting sub and topsoil samples at each location. This process was replicated in Site B, but only topsoil was collected. However, due to dense vegetation at Site C, opportunistic sampling was used, avoiding hazardous brambles and impenetrable roots (Neyens, 2018).

Field Methodology

Depth Probe

There must be a sufficiently deep soil layer for soil scrape to be possible and for heathland vegetation (such as heather) to establish (Gimmingham, 1992). Therefore, a depth probe was used during a pilot on Site A to assess soil depth. This confirmed that Site A was deep enough for coring, addressing concerns about shallow areas. Measurements were taken systematically every 2 metres, and geolocated using QGIS.

Coring

A 50cm corer was used to collect the 30 samples. To reduce site disturbance, the top layer of grass was folded back before samples were taken and returned afterwards. Samples from Site A were split based on visual differences (see Figure 2) into topsoil and subsoil and all equipment was brushed between samples to prevent cross contamination. To ensure sufficient soil mass for lab analysis was collected, samples were measured using a scale on site (50g).

Figure 2 2: Soil cored from Site A with the visual difference between subsoil and topsoil shown.

pH

pH levels were collected in the field and involved shaking 10g of each sample and 20ml of deionised water into a 50ml centrifuge tube and then leaving it to settle for 10 minutes and using a calibrated pH meter to record results (Kalra, 1995).

Soil Moisture

Soil moisture was initially tested in the field using a theta probe. As with the corer, grass was lifted before probing to avoid results being skewed by hydraulic lift (Armes et al, 2012). Due to heavy rain, soil moisture data collection was halted midway through the sample day, as theta probes lose accuracy above 70% moisture (Delta-T Devices Ltd., 2017). Subsequently, these results were omitted, and gravimetric soil moisture was measured in the lab.

Lab Methodology

Gravimetric

The gravimetric method determines soil moisture content by measuring weight loss after oven drying (Reynolds, 1970). Labelled aluminium weighing boats were weighed and then filled with ~20g of soil, above the recommended 15g minimum (*ibid*). To ensure moisture removal without affecting the organic content, samples were placed in a drying oven at 105°C for 24 hours, (FAO, 2023) and, once cooled, were reweighed to calculate soil moisture (Equation 1), (*ibid*):

$$W\ \% = \left(\frac{W_{cms} - M_{cds}}{M_{cds} - M_c}\right) \times 100$$

- W = water content (dry weight basis, expressed as %)
- M_{cms} = mass of container and moist soil (g)
- M_{cds} = mass of container and oven-dry soil (g)
- M_c = mass of container (g)

Equation 1: Calculating percentage soil moisture in soil.

Loss On Ignition (LOI)

LOI measures the weight loss from a dry soil sample after high temperature ignition (Schulte and Hopkins, 1996) and is used to determine soil organic matter (OM) (Salehi et al., 2011). Samples were dried using the gravimetric method and passed through a 2mm sieve to remove clods and rocks, ensuring homogeneity in organic matter estimation, and preventing incomplete combustion during ignition (Robertson, 2011). Crucibles were weighed and 10 g of the sieved soil sample was added and the total weight recorded (Hoogsteen et al., 2015). Samples were placed in a muffle furnace and heated to 550°C for 5 hours (Salehi et al., 2011). This ensured complete oxidation and combustion of OM while minimizing the loss of structural water and carbonate decomposition (Hoogsteen et al., 2015). Samples were then left to cool and reweighed to calculate OM as the percentage of weight lost (Equation 2), (Robertson, 2011):

$$\% \, Organic \; matter = \frac{pre - ignition \; weight \; (g) - post - ignition \; weight \; (g)}{pre - ignition \; weight \; (g)} \times 100$$

Equation 2: Calculating percentage organic content in soil.

Potassium Chloride (KCl) Extraction

Bioavailable soil nutrient extraction for nitrate, ammonium, and phosphate was carried out using the KCl method (Nelson, 1983) to ensure maximum nutrient extraction (Cobb, 2024). 5g samples were well shaken to ensure homogeneity before being filtered (0.45µm filter) to prevent instrument blockage (Cobb, 2024). Moisture factor was calculated from a dried subsample of the extraction sample (Maynard et al, 2008) (Equation 3). A Gallery Plus Auto-Analyser determined nutrient extracts of samples and the concentrations were calculated using equations 3 and 4 (*ibid*):

$$Moisture \; factor = \frac{Moist \; soil \; (g)}{Dried \; soil \; (g)}$$

$$NO_3 - N \; dried \; soil \; (\mu g^{-1}) = NO_3 - N \; moist \; soil \; (\mu g^{-1}) \times mfactor$$

Equation 3: Moisture factor.

$$NO_3 - N \; in \; moist \; soil \; (\mu g^{-1}) = \frac{NO_3 - N \; in \; extract(\mu g^{-1}) \times (volume \; of \; extractant + soil \; water)(ml)}{Weight \; of \; moist \; soil \; (g)}$$

$$Soil \; water = Moist \; soil \; (g) - (\frac{Moist \; soil \; (g)}{Moisture \; factor})$$

Equation 4 and 5: Converting lab nutrient results to concentrations in soil.

Heavy Metal extraction

The bioavailable fraction of copper, zinc, lead, arsenic, aluminium, and magnesium were calculated using a weak acid extraction (Huangfu et al., 2019). 5g samples were well shaken to ensure homogeneity before being filtered (0.45µm filter), to prevent instrument blockage (Cobb, 2024). A semi-quantitative sample was used to determine a baseline for detectable elements (0.4ml of each sample). Samples were analysed using Inductively Coupled Plasma Optical Emission Spectrometry (Tawfik et al., 2024).

Data Handling and Statistical Methods

Before analysis, data was blank-corrected, cleaned to remove errors from lab or fieldwork, and checked for outliers using boxplots and analysis of standard deviations, whilst the accuracy of nutrient analysis by the Gallery Plus Auto-Analyser was validated using known nutrient concentrations to ensure reliability (Aguinis et al., 2013). Outliers were then removed if necessary and a Shapiro-Wilk test implemented to assess normality of each variable. Non-normal variables ($p < 0.05$) were transformed using log or square root transformations where appropriate. If normality was not achieved, non-parametric tests were used (Sainani, 2012). Additionally, all results were recorded to two decimal places (Bashour & Sayegh, 2007).

To compare topsoil and subsoil at Site A, a Paired T-Test (parametric) or Wilcoxon Signed-Rank Test (non-parametric) was applied (Harris, 2013). Comparisons across Sites A, B, and C were conducted using a One-Way ANOVA (normal data) or Kruskal-Wallis test (non-normal data) (McCrum-Gardner, 2008). Where significant differences were found, post-hoc tests (Tukey's HSD for normal data, Dunn's test for non-normal data) identified specific site differences. Finally, linear regression models were used to assess relationships between key soil variables based on literature.

Results

Paired statistical tests were initially conducted to assess differences in soil characteristics between the Site A topsoil and subsoil. The null hypothesis was rejected for most variables ($p<0.05$), indicating significant differences, except for aluminium and copper concentrations. Magnesium concentrations and pH levels showed highly significant differences ($p<0.001$) between soil layers.

Table 1: Comparing soil characteristics between the topsoil and subsoil at Site A using a paired statistical test (Paired T-Test or Wilcoxon Signed-Rank Test) (Asterisks (*) denote the level of significance: p-value<0.001 (***), p-value<0.01 (**), and p-value<0.05(*)) (8 samples for each site).

Soil Characteristic	Statistical Test Used	p-value	Difference Found?
pH	Paired T-test	<0.001***	YES
Soil Moisture	Paired T-test	0.0075**	YES
Soil Organic Content	Paired T-test	0.0174*	YES
Phosphate	Wilcoxon Signed-Rank Test	0.0078**	YES
Ammonium	Wilcoxon Signed-Rank Test	0.0156*	YES
Total Oxidised Nitrogen	Wilcoxon Signed-Rank Test	0.0078**	YES
Magnesium	Wilcoxon Signed-Rank Test	<0.001***	YES
Aluminium	Wilcoxon Signed-Rank Test	0.7525	NO
Copper	Paired T-test	0.9837	NO
Lead	Wilcoxon Signed-Rank Test	0.0182*	YES
Zinc	Paired T-test	0.0156*	YES

Soil Characteristic: pH

An ANOVA and post-hoc Tukey test revealed that Site A Subsoil and Site B (Heathland) are significantly different ($p<0.05$) from the Site A Topsoil and Site C (Woodland). Additionally, pH levels of the Site A Subsoil and Site B Heathland fall within the average range of those found in a heathland (Maddock, 2008) (Figure 3).

Table 2: Median and Standard Deviation (SD) pH values for each site and results from 2024 (University of Bristol, 2024).

	Site A Topsoil	**Site A Subsoil**	**Site C (Woodland)**	**Site B (Heathland)**	**2024 Results**
Median	5.95	5.00	6.51	4.69	5.07
SD	0.52	0.39	0.38	0.34	1.00

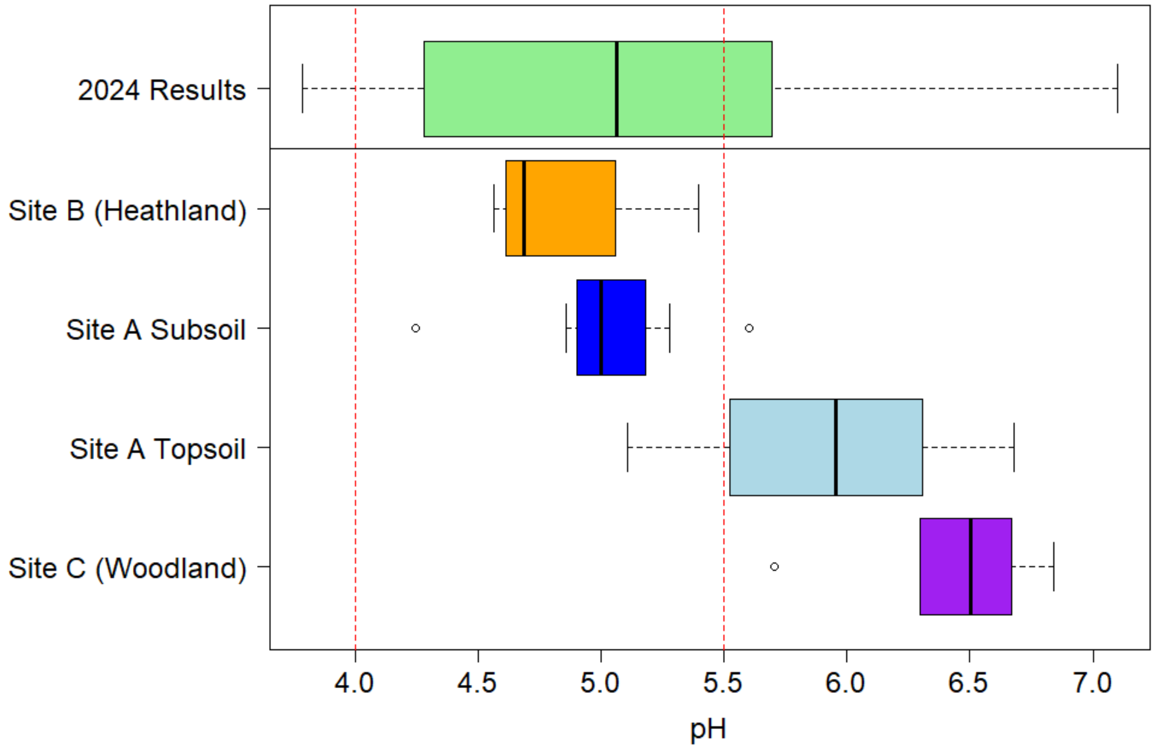

Figure 33: A comparison of soil pH from the four sites on Troopers Hill with those from the 2024 Avon Project for Troopers Hill as a whole (University of Bristol, 2024). The red dashed line indicates the average pH range for acid grassland environments (Maddock, 2008) (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B: 7 samples, Site C: 7 samples).

As Site B represented a small section of Troopers Hill's heathland, pH data from the 2024 Troopers Hill Avon Project (University of Bristol, 2024) was used for comparison to better define the target pH range for Site A subsoil. The median of Site A Subsoil is very close to that of the overall 2024 heathland median (Table 2). The use of a Tukey post-hoc test identified a significant difference between the Woodland Site B and the overall 2024 Troopers Hill heathland results ($p<0.05$).

Soil Characteristic: Nutrients

Site A Topsoil exhibits the highest median ammonium (NH_4-N) concentration (11.08µg/g) closely aligning with Site B (Heathland) (1.04µg/g) (Figure 4A), whilst the Site A Subsoil and Site C (Woodland) have lower concentrations (4.76µg/g and 5.25µg/g, respectively). However, Heathland Site A also has the largest range of results, indicating high variation in ammonium levels in the soil. A Kruskal-Wallis and Dunn's post hoc test (both $p< 0.05$) identified a significant difference between Site A Subsoil and Site A Topsoil.

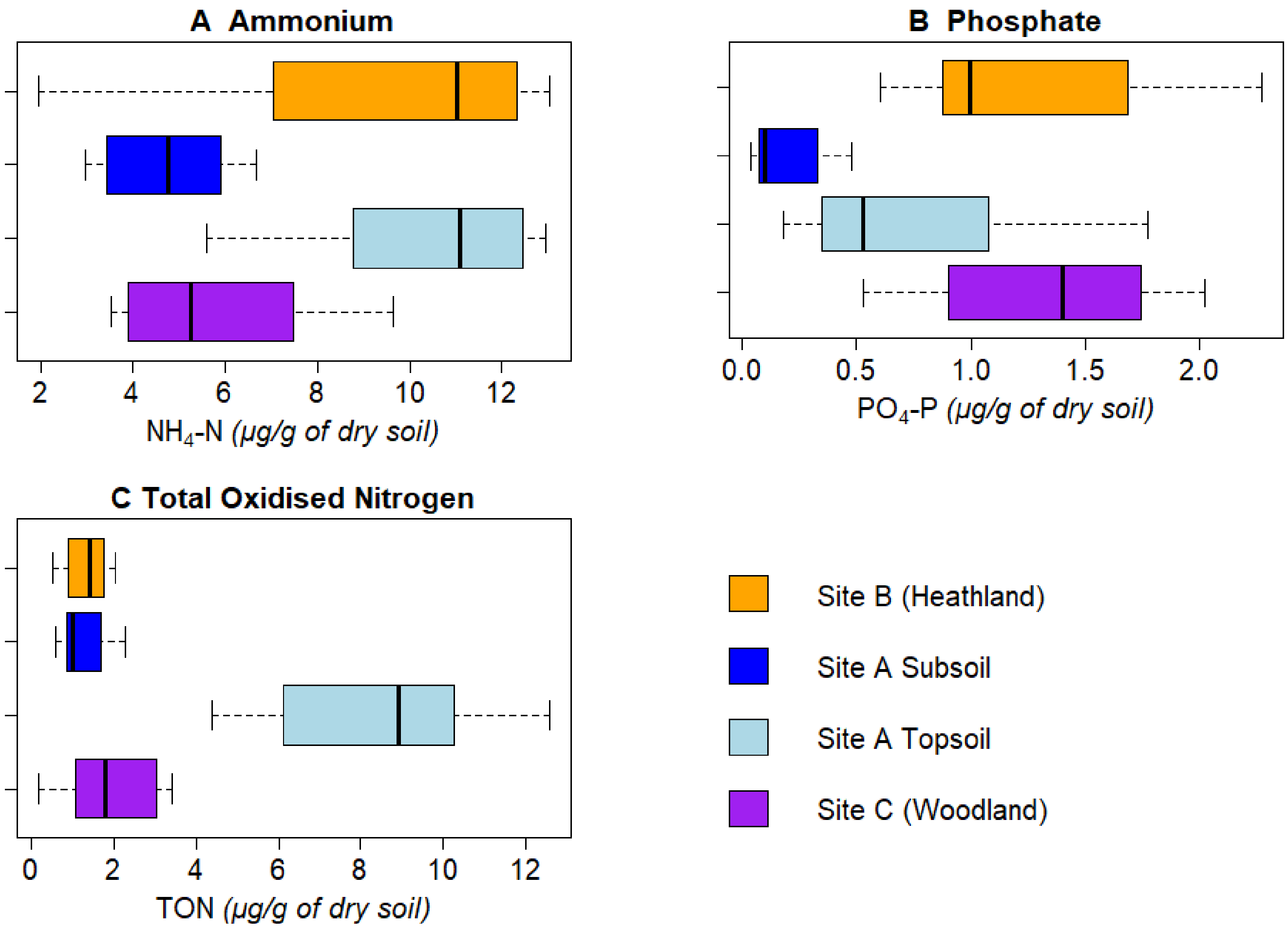

Figure 44: Comparison of nutrient levels within the soil samples the four sites on Troopers Hill (A: NH_4H – ammonium, B: PO_4-P – phosphate, C: TON – Total Oxidised Nitrogen) (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B:7 samples, Site C: 7 samples).

The spread of phosphate (PO_4-P) concentrations are similar between the Heathland Site B and Woodland Site C, with Site C exhibiting the highest median concentration (1.40µg/g) (Figure 4B). A Kruskal-Wallis and Dunn's test ($p<0.05$) confirmed differences between Site A subsoil and both Woodland Site B and Heathland Site C. Additionally, ammonium and phosphate levels in Heathland Site B differ from those in Site A subsoil.

Total Oxidised Nitrogen (TON) concentration is significantly higher in Site A Topsoil than in the other three sites and has the largest range (Figure 4C). A Kruskal-Wallis test and Dunn's post-hoc test also found Site A Topsoil to be significantly different from all other sites ($p<0.05$).

Soil Characteristic: Heavy metals

There are low levels of copper and zinc across all tested sites on Troopers Hill, whilst magnesium has the highest concentrations. Arsenic concentrations were below the limits of detection for the ICP-OES (As<0.01ppm) so was excluded from analysis as the limited sample size was insufficient for statistical evaluation. The Site A Subsoil sees decreased levels of all metals compared to the other sites, most notably in magnesium and lead concentrations (Figure 5).

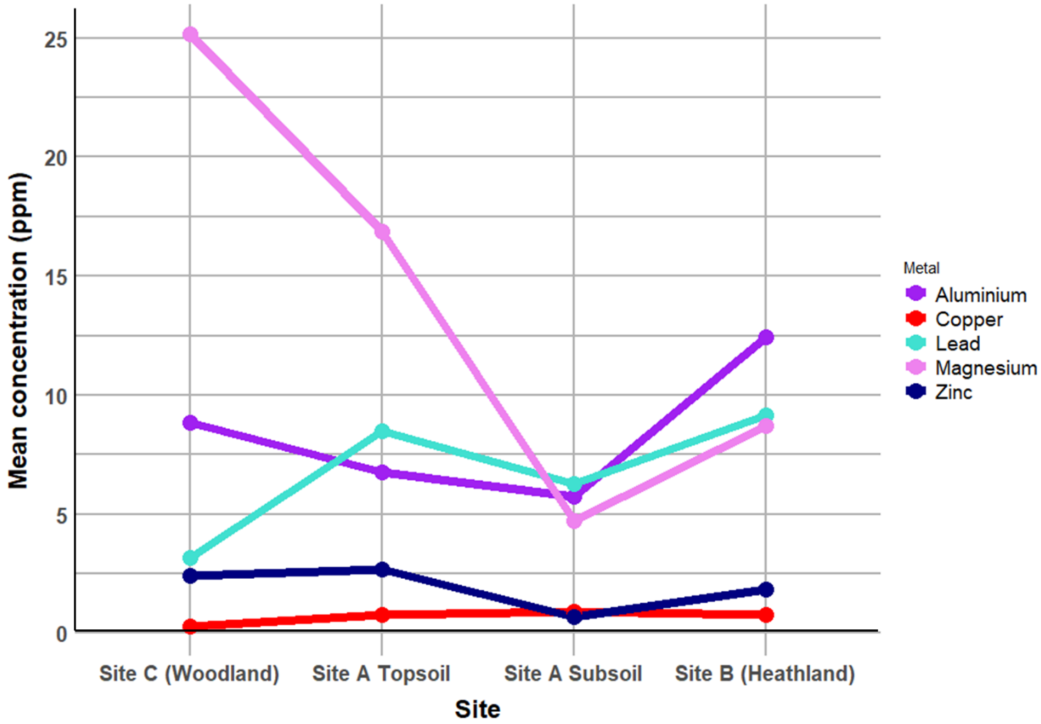

Figure 55: Mean heavy metal concentrations in parts per million (ppm) across the four sites on Troopers Hill (Metals include: Aluminium (Al), Copper (Cu), Lead (Pb), Magnesium (Mg), Zinc (Zn) (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B:7 samples, Site C: 7 samples).

The spread of results for Site A Subsoil and Site B (Heathland) are similar for both magnesium and zinc (Figure 6). Additionally, zinc concentrations in the Site A Subsoil were significantly different from the Site A Topsoil and Woodland Site C ($p<0.05$) (Kruskal-Wallis).

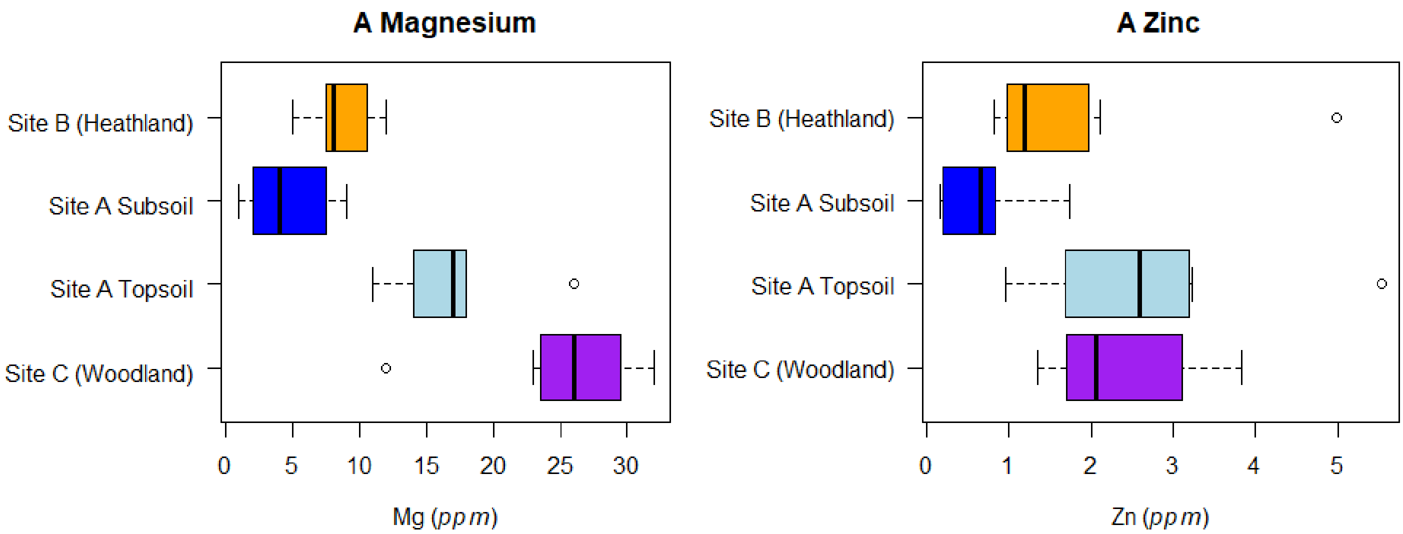

Figure 6: Comparison of bioavailable magnesium and zinc concentrations in parts per million (ppm) for each site on Troopers Hill (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B:7 samples, Site C: 7 samples).

Comparison: pH and Heavy Metals

A linear regression model returned a significant positive correlation between pH and magnesium ($p<0.001$), with an adjusted R^2 value of 0.723, suggesting that pH accounts for 72.30% of the variation in magnesium (Figure 7). Similar regression analysis found a significant positive correlation between pH and zinc ($p<0.01$) and a significant negative correlation between pH and copper ($p<0.05$). However, no significant relationship was found between pH and aluminium or lead ($p>0.05$). All models were deemed homoscedastic based on the results of Breusch-Pagan tests ($p<0.05$), increasing the validity of this statistical inference.

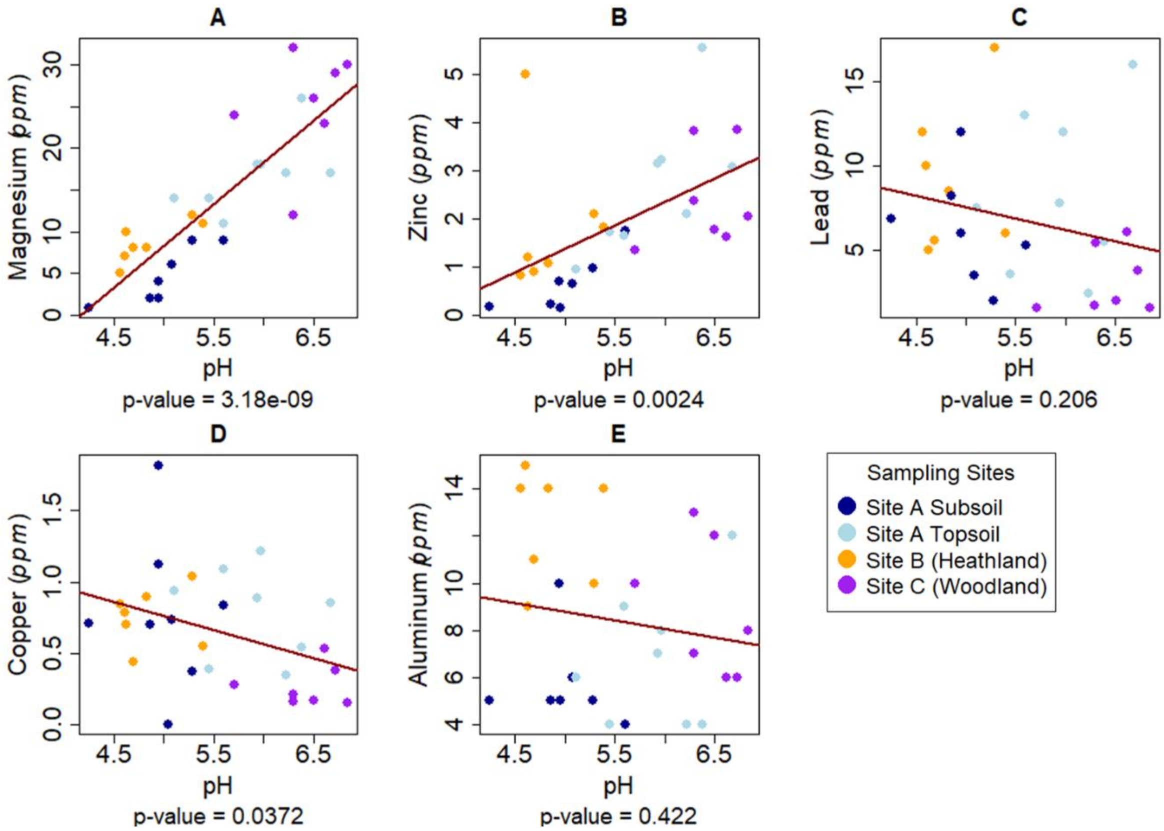

Figure 76: Relationship between pH and all tested metals in parts per million (ppm) for each sample with a linear regression model shown in red and p-value for the model indicated (A: magnesium, B: zinc, C: lead, D: copper, E: aluminium).

Soil characteristic: Soil moisture

Soil moisture was lowest in the Site A Subsoil compared to the other sites, with a mean of 9.76%, whilst the Woodland Site C has the highest moisture with a mean of 59.13%. The Heathland Site B showed the highest spread of values of soil moisture across the area as seen in Figure 8.

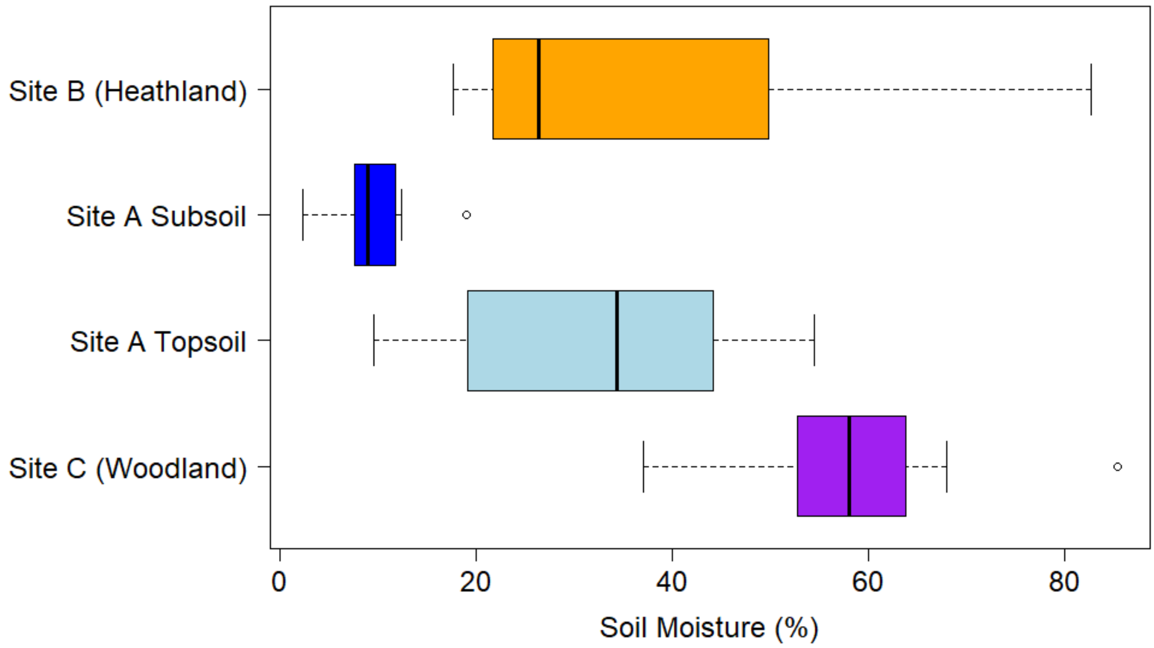

Figure 87: A comparison of the median and spread of soil moisture percentage at each sample site (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B:7 samples, Site C: 7 samples).

A Tukey test shows that Site A Subsoil is statistically different to all other sites ($p<0.05$). With only the Site A Topsoil and Heathland Site B showing no statistical difference.

Soil Characteristic: Organic Matter

The trend in soil organic matter (OM) across the sites was similar to soil moisture, with the Site A subsoil having the lowest median OM (5.85%), whilst the Woodland Site C and Heathland Site B had the highest medians (19.97% and 21.13% respectively). The Heathland Site B exhibited the greatest variability in OM as seen in Figure 9.

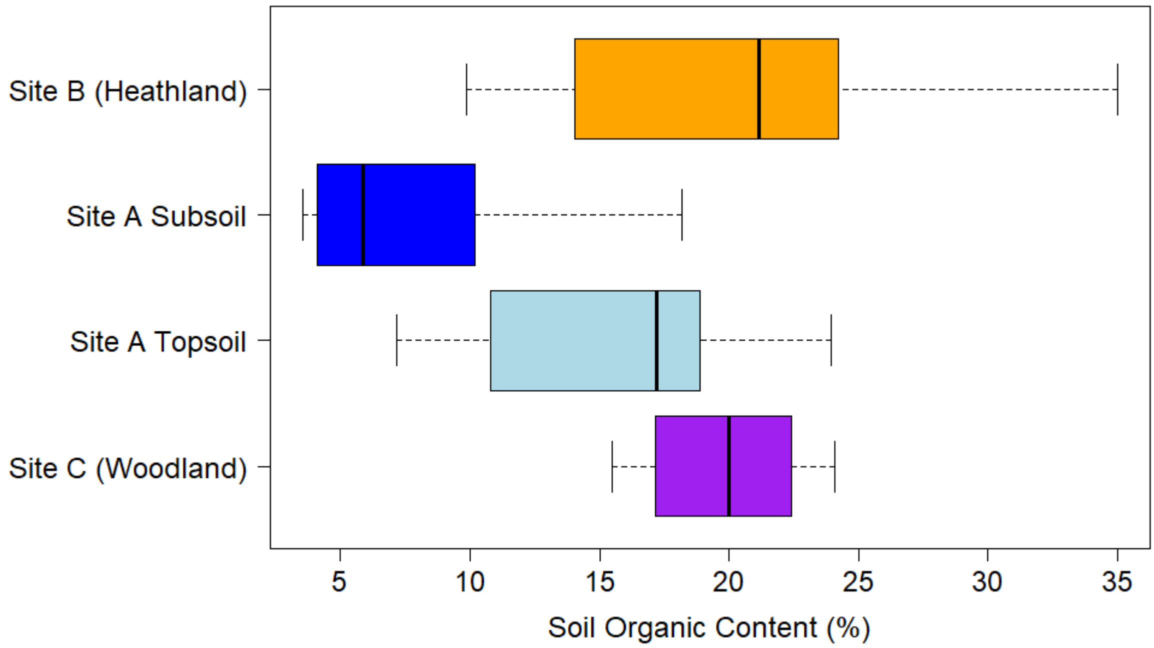

Figure 98: A comparison of the median and spread of soil organic content percentage at each site. (Site A Topsoil: 8 samples, Site A Subsoil: 8 samples, Site B:7 samples, Site C: 7 samples).

Results from a Tukey test indicated significant differences between the Site A Subsoil and both the Heathland Site B and Woodland Site C ($p<0.05$), whilst no statistically significant difference was observed between Sites B and C ($p>0.99$).

Comparison: Soil Moisture and Organic Content

Figure 10 shows a significant ($p<0.05$), positive correlation between soil moisture and organic content for the four sites. This relationship produced an R^2 value of 0.691, which shows that 69.15% of the variation in soil moisture is determined by organic content.

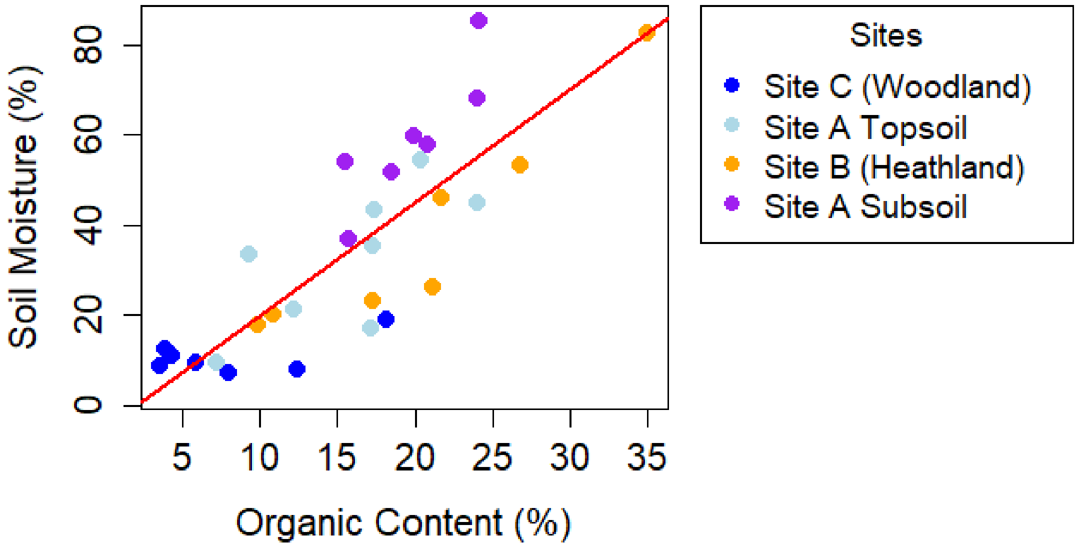

Figure 109: Relationship between soil moisture (%) and organic content (%) across the sites. Each point is color-coded by sit, with a red line representing the linear regression model between the two variables.

Figure 10 also shows that Site A Subsoil exhibits consistently lower values for both soil moisture and organic content, whereas Site C Woodland has a spread in the higher values of the two variables.

Soil Characteristic: Soil Depth

The point soil depth data was interpolated across the whole of Site A (Figure 11). This showed the soil was shallower across the southern side of the site (14.8-20cm), whilst some small patches, (particularly on the northern side of the site) exhibited comparatively deeper soil (50-59.1cm).

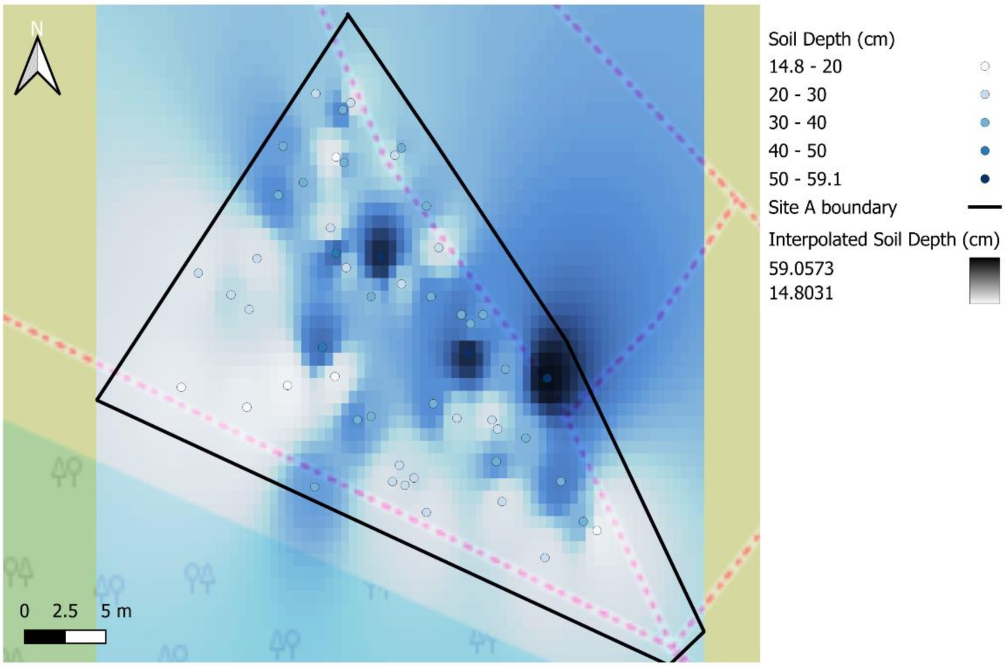

Figure 1110: Interpolated soil depth data on map of Site A using QGIS: 53 samples (dark blue being deeper soil, light blue shallower soil).

Discussion

RQ1: What evidence is there to support that natural succession is occurring on Troopers Hill and what processes are driving this?

Heathland and acid grassland environments are characterized by nutrient-poor, highly acidic soils, which support the growth of vegetation specific to these habitats (Duddigan et al., 2020). Changes in soil chemistry are often the clearest indicators of natural succession processes on a site. Therefore, analysing the similarities and differences in the topsoil and subsoil at Site A and comparing the soil to neighbouring woodland and heathland sites is crucial for understanding why heathland vegetation isn't establishing at Site A and whether natural succession is the cause.

Soil pH is a key indicator of succession, as high acidity is the defining characteristic of heathland soil (*ibid*). Table 1 shows a significant difference between the pH levels in the Site A Top and Subsoil ($p<0.001$) and significant similarity found between the topsoil and Site C. This similarity provides evidence for succession processes, as the pH increase in the topsoil is likely caused by nitrogen increases as woodland species colonise the site and increase organic matter (Diggelen et al., 2021). Furthermore, the median pH of Site A Subsoil is 5.0, which falls within the typical heathland range of 4.0 to 5.5 and is aligned with that of Site B (4.8) and the rest of Troopers Hill (Figure 3) (BRIG, 2011; University of Bristol, 2024). This suggests that the Site A soil was initially characteristically heathland before it was altered, further supporting the theory that succession has occurred here to increase pH.

Interestingly, despite a significant similarity existing between the Site A Topsoil and Site B, their medians are quite different (Topsoil = 5.95, Site C = 6.51), suggesting that the topsoil is still transitioning. Additionally, the pH of the Site A Topsoil is too alkaline to support heathland species (Land, 2020) but remains lower than that characteristic of woodland habitats (Woodland Trust, 2016). This discrepancy could be due to the regular vegetation stripping on Site A (Friends of Troopers Hill, 2024). Similar cutting practices have been shown to reduce below ground sugar flux by 80%, accelerating soil acidification and leading to pH values below 5.0 (Widyati et al., 2022). Furthermore, felled organic matter is left in situ at Site A, which may contribute to this higher topsoil pH via the decomposition of organic acids (Hawley et al., 2008; Friends of Troopers Hill, 2024.) Removing this organic matter is therefore crucial for maintaining heathland conditions. Consequently, management practices are acting here to both halt the rate of succession and increase the pH of the Site A topsoil. Ultimately, the site is not transitioning toward either woodland or heathland, but rather remains in a transitional state, with sub-optimal conditions for the characteristic vegetation of both ecosystems (Lane, 2020).

Increasing nutrient concentrations in the soil are crucial evidence and drivers for succession as establishing vegetation enriches the soil (Lawson, 2004). The highest median ammonium concentrations (11.04µg/g) are in the Site A Topsoil and are significantly different to the subsoil. Site A Topsoil additionally has significantly higher TON concentrations ($p<0.05$) than the subsoil. This supports the existence of succession processes in the topsoil, as conditions become more tolerable for woodland vegetation, allowing succession to accelerate (Soons and Hefting. 2017). Furthermore, phosphorus is the primary limiting element of birch trees (the main invasive species on Site A) (Hoyle and Bjorkbom, 1969) and Table 1 shows a significant difference in phosphate concentration between the Site A Topsoil (median 0.526µg/g) and subsoil (0.096µg/g). These higher levels in the subsoil reflect the history of birch tree encroachment and suggest potential for re-establishment, should repeated cutting cease. Interestingly, high levels of phosphate comparable to those at Site C were found at Site B (Figure 4), contradicting literature suggesting that phosphate levels are typically very low in heathland soils (Gimingham, 1972). This could be an early indicator that succession is also occurring on Site B, as succession advances upslope from Site C. The higher phosphate levels at Site B compared to Site A Topsoil might (like pH) also be an unintended consequence of vegetation stripping at Site A, as more vegetation exists on Site B to enable nutrient accumulation. Studies have equally highlighted how variable phosphorus absorption can be in different heathland sites (Chapman et al., 1989), which is supported by the very large range in phosphate values for site B. However, high ranges occur at each site, questioning the reliability of the data and limiting the ability to make accurate conclusions about phosphate. Additionally, Chapman et al (1989) found that it is the phosphate absorption capacity of the soil as opposed to the concentration that is the better indicator of succession processes, meaning that this data might not be appropriate to determine the existence of succession. Ultimately though, even excluding the phosphate data, the significant differences between ammonium and TON levels in the Site A Sub and Topsoil provide enough evidence to be confident that succession processes have enabled nutrient accumulation on Site A.

Libohova et al (2018) outlined the existence of a positive relationship between soil organic matter (OM) and soil moisture percentage due to the high moisture retention capacity of OM. Subsequently, a significant ($p<0.05$) regression model (Figure 10) was developed which showed that OM accounts for 60% of the variation in moisture across the sites (Figures 8 and 9), showing a strong correlation between them and implying that the processes work together to drive and evidence succession. On Figure 9, a significant difference ($p<0.05$) between the Site A Top and Subsoil is visible. OM content is much higher in the topsoil (median 17.21%), which would be expected under succession conditions, as increased vegetation growth and cutback increases the humus layer (Podrázský, 2012). Accordingly, moisture content increases as a greater root system has smaller soil pores, which hold water rather than promoting further infiltration, allowing a more diverse range of vegetation to establish (University of Nebraska-Lincoln, 2020).

Contrary to Mitchell et al. (1999)'s findings, Site B was found to have the highest OM percentage (median 21.13%), a positively skewed soil moisture boxplot (Figure 8), and was significantly different to the Site A Subsoil. Whilst this could be an indication that succession is also occurring on Site B, the pH and nutrients data discussed suggest that this is unlikely. Rather there may be factors outside of succession and OM (the unexplained 40%) that explain moisture variation. This could be because samples at Site B were taken from the topsoil, where higher organic matter levels are found compared to the subsoil due to accumulation (Antony et al., 2020.). Furthermore, NASA's Soil Moisture Active Passive dataset demonstrates a close alignment between moisture and slope angle (Dirt to Dinner, 2014). This may explain why soil moisture was highest in Site C, featuring a shallow slope, and lower in Site B with the steepest slope. These differences may shape succession, as drier conditions limit colonizer species that require constant moisture, and higher moisture promotes later-successional species (Wang et al., 2020). Finally, the wet conditions during sampling could have amplified the difference between Site A Subsoil and Site B, as the root structures present on Site B promoted infiltration into the sampled layer, whilst it did not have time to reach the subsoil at Site A. In conclusion, the significant difference in OM and soil moisture percentages between the Site A Top and Subsoil provides some evidence for successional processes in the topsoil, however outliers in Site B suggest that not all of this variation could be explained by succession and that it is likely that slope angle and antecedent conditions are other potential causes.

RQ2: How have industrial influences affected the soil on Troopers Hill?

Due to its extensive industrial history, industrial impacts are the most relevant external influences on the soil. These are investigated in this section through heavy metal analysis of each site, leading into the discussion of possible coal spoil and nitrogen deposition influences.

Heavy metal influence is likely to have a minimal impact on the soil characteristics on Troopers Hill, as suggested by low metal concentrations obtained in this study. Heavy metal bioavailable concentrations across sites were generally very low when compared to expected soil levels for each element (DEFRA, 2011; Environment Agency, 2008; ALS, 2009). Zinc exceeded no more than 2.9ppm, and whilst mean magnesium concentration has a large range from 5.3ppm in the subsoil to 24.33ppm in the woodland, both are deemed to have low contamination effect (DEFRA, 2011; Environment Agency, 2008). Despite extensive copper mining in the 18th century, copper concentrations remained under 1ppm for all sites (Friends of Troopers Hill, 2025b). Furthermore, aluminium and lead levels remained below 15 ppm, suggesting that heavy metal contamination is not a significant concern. A likely explanation for this is low pH across Site A, particularly in the subsoil, as high soil acidity increases the solubility of metals, causing leaching from the soil profile (Lindsay, 1972). Contrary to this report's findings, Beighton (2013) found high concentrations of copper and lead in Troopers Hill soils (36.29ppm and 120.7ppm respectively), suggesting that past onsite smelting and industrial practices had significantly altered soil composition. However, these differences can be attributed to methodological variations concerning measurements of bioavailable metals in this study, which have lower concentrations than that of total metal concentrations (Wang et al., 2021). Furthermore, contrasting topographies between study sites could account for some observed fluctuations, as Site A has a steeper slope than Site B and is situated further from the listed chimney, which could reduce the impact of industrial practices on the soil as metals could reduce downslope away from the main industrial location on Troopers Hill. Despite this, this study found no significant correlation between slope, adjacence to industrial sites, and heavy metal concentration, diverging from previous expectations of decreasing downslope (Zhang et al., 2020). Implying that there are further factors affecting distributions of heavy metals on Troopers Hill.

Acidification of the soil over the past decade may be one factor explaining these conflicting results. As the soil acidified, metals previously retained in the upper soil horizons may have leached further down, thereby decreasing their concentrations at the surface (Dijkstra et al., 2004). Reduced pH observed in Site B and the Site A Subsoil correlates with reduced concentrations of magnesium and zinc, though this trend was not consistent for other metals which is likely because of solubility differences where copper, aluminium, and lead are less readily soluble in acidic conditions. Interestingly, aluminium and lead concentrations were highest in the Site B nearest to the main pathways (Figure 5), suggesting that human activities, especially those associated with footpaths like littering, may also influence metal concentrations in the soil. Furthermore, Markus et al. (1996) found that human activity often increases heavy metal concentrations, most notably lead, due to rubbish and other forms of waste. This demonstrates that pH and solubility account for the majority of variation in heavy metal concentration across our sites, but human littering is a likely external factor. The limited impact of heavy metals on the soil of Troopers Hill at Site A suggests that key properties such as microbial activity and organic matter levels are likely unaffected (Oliveira et al., 2006).

Historical coal mining on Troopers Hill and mineshaft subsidence 100m north-west of our study area in 2010 meant that coal spoil was a likely factor affecting soil character on our sites (Friends of Troopers Hill, 2025b). During our field methods, noticeably darker and black soil believed to have been coal spoil (Figure 2) was present in Site A and Site B. Tendencies of coal spoil to reduce porosity and water availability are evident in Site A Subsoil, where soil moisture remains below 20%, the lowest of all sites (Criquet et al., 2023). There are similar patterns in degraded nutrient concentrations and OM, with 16% lower content in Site A Subsoil than Site B (Zhang et al., 2024). This difference between the Site A Subsoil and Site B suggests that coal spoil is hence a further industrial influence on Troopers Hill's soil, as heathland characteristics are unexpectedly intensified in the subsoil.

A final external factor influencing soil characteristics is increased atmospheric nitrogen deposition. This occurs primarily from industrial mining and combustion processes and has led to widespread ecosystem change throughout Europe (Hardtle et al., 2007). Ammonia (NH_3) and nitrogen oxides (NOx) deposition onto Troopers Hill topsoil could have caused reduced species richness, potentially exacerbating the shift from native shrub communities to grass-dominated ecosystems through increased biomass production and accelerated nutrient cycles (Vogels et al., 2019; Heil and Bobbink 1993). Atmospheric nitrogen deposition likely affects all study sites due to its large spatial coverage, which may explain why Site B and C experience similar high nutrient and organic matter levels (~11µg/g NH_4-N and approximately 20% OM in both) despite their distinct vegetation types (*ibid)*.

Ultimately, while heavy metals have a negligible impact on Troopers Hill's soil, coal spoil and atmospheric nitrogen deposition appear to play a more significant role in shaping the soil's overall characteristics and relationships found in this study.

RQ3: Is a soil scrape a viable and ethical form of heathland management for Site A, and should alternative management options be considered?

This report has already shown significant differences between the top and subsoil components of Site A and similarities between the Site A Subsoil and Heathland Site B, as well as providing evidence for the existence of natural succession and industrial processes in the soil. These factors are crucial when determining the viability of a soil scrape, as remaining soil should have conditions tolerable for heathland vegetation to kickstart regeneration (Gimmingham, 1992). This final section will develop this and discuss whether a soil scrape would be a suitable form of management for Site A.

Elevated nutrient and pH levels have been identified as key obstacles to heathland restoration (Lawson et al, 2004), thus analysis of these is essential to assess the suitability of different approaches. Nitrogen availability has a major impact on plant species composition, as heathland requires low nitrogen to prevent competitor species emerging (Berendse, 1990). The TON of the Site A Topsoil was found to be 8.94µg/g, significantly higher ($p<0.05$) than both the subsoil and the heathland. The Site A Subsoil (median 1.78µm/g) was also not significantly different ($p>0.05$) to Site B (0.99µg/g), suggesting that exposing such soil to sunlight may trigger the germination the desired heathland seed bank, as the subsoil has the optimum nutrient levels for Troopers Hill heathland (Gimingham, 1992). Furthermore, pH levels in Site A Subsoil were similar to Site B (Figure 3). As highly acidic soil is essential for the establishment of heathland vegetation, this provides further evidence that removing the topsoil (which this study has shown to be undergoing succession processes) would expose characteristically heathland subsoil and promote the re-establishment of heathland vegetation (Fowler and Brown, 1991). This demonstrates that conditions in the subsoil do have the potential to support a heathland habitat and therefore that a soil scrape has the potential to be successful at Site A.

However, due to the high cost and labour demands of soil scrapes, they are largely a last resort for heathland management (Gimingham, 1992). Hence, it is important to explore alternative management which could have similar results without such high costs. Soil acidification is a less intrusive form of management, which not only reduces soil pH but also soil nutrient availability (Lawson et al, 2004). This is ideal for Site A due to the previously identified large difference in TON and pH levels between the Site A Topsoil and Site B and the subsoil. Acidification therefore could reduce the TON and pH levels in the Site A Topsoil, bringing it in line with the subsoil and heathland and creating conditions tolerable to heathland vegetation without the need for invasive scraping. Furthermore, soil scrapes can force an ecosystem to shift towards phosphate limitation and cause poor heathland vegetation recovery (Vogels et al, 2020). The median phosphate level in the Site A Subsoil was already found to be low at 0.096µg/g, and exposing this soil would push the concentrations outside of those needed for heathland vegetation survival and make further supplementing of the soil with phosphates necessary. These factors suggest that soil acidification could be a better first step than a soil scrape, by reducing TON and pH levels to those satisfactory for a heathland environment without great cost and soil damage and need for further phosphate supplementation.

Furthermore, soil scrapes have been linked to low recolonisation rates, as below ground communities (which are essential for the establishment of above ground biodiversity) are often removed (Vergeer et al, 2006). This is especially important at Troopers Hill, as it is home to the endangered miner bee, along with 83 other bee species (Friends of Troopers Hill, 2025a). As soil scrapes should not be conducted in areas of soil which contain invertebrates (Gimmingham, 1992), a soil scrape at Site A could pose a significant threat to these species and undermine the sanctity of the site. A further ethical issue lies in the removal of potentially historically relevant soil. RQ2 highlighted the presence of heavy metals and coal spoil within the soil as legacies of Troopers Hill's industrial past. Although these did not exist in high enough concentrations to be harmful/polluting in the soil, it could be argued that their presence alone is significant and removing them would erase the memories of the site's history, as well as potentially previously unknown artefacts (Hawley et al., 2008). However, this is a more abstract argument and there is no scientific level of significance for approval – instead this is a factor that should be considered and justified were a soil scrape to be agreed on.

Finally, the depth of a soil scrape is vital for determining the type of species that can be supported afterwards (Gimmingham, 1992). When considering the interpolated soil depth of Site A (Figure 11), large variations across the site were clear. The shallowest values were less than 14.8 cm. Heather, the key heathland plant at Troopers Hill, has functional roots down to 15cm (Gimmingham, 1992), meaning that there is simply not enough depth of soil in some areas to remove in the first place. Additionally, the soil needs to be deep enough that scraping it would not remove the heathland seed bank in the subsoil, which cannot be guaranteed here (*ibid*). Indeed, a large limitation of this study is the inability to confirm the presence of this seedbank in the first place, as this was beyond the scope of the equipment used and knowledge available. This provides further evidence that a soil scrape is unlikely to be the most appropriate form of management for Site A, with depth data suggesting that any amount of soil removal would affect the ability of important heathland species to establish on the site. Ultimately however, no conclusive recommendations can be made without further research to ascertain the existence of a viable heathland seed bank in the Site A Subsoil, although the available soil characteristics data suggests that acidification would likely be a more successful option than a scrape. Additionally, supporting literature in this report focused on the successes of soil scrapes at establishing heathland in conifer plantations or land that was not previously heathland, whereas Troopers Hill is an example of heathland restoration (Allison and Ausden, 2004; 2006., Gardiner and Vaughan, 2008). This has allowed this study to provide new perspectives on soil scrapes in these environments, concluding that soil scrapes are unlikely to be the most suitable form of management for these contexts as the key characteristic altered by succession is pH, the reversion of which is beyond the scope of a soil scrape.

Conclusions, Limitations and Future Study

RQ1 shows that succession in the Site A Topsoil is evidenced by increased soil pH (1.26 greater than in Site B) and TON concentrations (7.95 µg/g greater than Site B). Equally, significant differences between the Site A Top and Subsoil were found for the three key succession indicators (pH, nutrients and OM). Whilst vegetation management slows woodland succession, conditions remain unsuitable for heathland recovery, keeping the site in a transitional state. High nutrient levels and a rich humus layer favour later-successional species however, making management an urgent priority before succession advances further.

In RQ2, heavy metal concentrations had little impact on soil characteristics, despite the industrial history of Troopers Hill. Bioavailable metal concentrations were lower than background UK values, as high soil acidity caused leaching, reducing concentrations, and preventing contamination. Coal spoil is also present, indicated by visibly darker soil (Figure 2), with Site A Subsoil having the lowest soil moisture and OM content. Significant differences between the ammonium and phosphate levels between Site A Subsoil and Site B support that the subsoil has unexpectedly extreme heathland conditions, in line with coal spoil influences. Nitrogen deposition was also plausible as similar levels in the topsoil of Site A and Site B (median NH_4 ~11µg/g for both) where the heathland was expected to be significantly different demonstrates the accelerated nutrient cycles correlated with nitrogen deposition.

RQ3 concluded that a soil scrape was not appropriate at Site A due to potential phosphate limitation and insufficient topsoil depth. Soil scrapes are additionally costly and intrusive and so should be a last resort for heathland management. Acidification was instead proposed to reduce the high nutrient content and pH of the Site A Topsoil and restore it to heathland conditions. Ultimately, the limited dataset prevented conclusive decisions on management, as a seedbank analysis is crucial and the viability of soil scrape is often dependent on the availability of the topsoil, whereas this study only measured total depth (Gimmingham, 1992). Although it was found that some areas were too shallow for a soil scrape, further topsoil analysis could confirm this. Lastly, the data suggests coal spoil exists at the site, further analysis of which would determine its soil impacts, and explore how management can account for this.

Ultimately, a soil scrape would not be an appropriate form of management at Compartment 6 on Troopers Hill and this study instead proposes topsoil acidification and further research into coal spoil influences.

Bibliography

(a)Friends of Troopers Hill. (2025). Invertebrate Surveys and Reports. Available at: https://www.troopers-hill.org.uk/moth.htm [Accessed: 11 Feb. 2025].

(b) Friends of Troopers Hill. (2025). History of Troopers Hill. Available at: https://www.troopers-hill.org.uk/history.htm [Accessed: 18 Mar. 2025].

Acton-Campbell, R. (2006). *Troopers Hill Local Nature Reserve Management and Action Plan Report and Update.* Available at: https://troopers-hill.org.uk/ArchiveApr2012/2006_Report.pdf [Accessed: 27 Feb. 2025].

Aguinis, H., Gottfredson, R.K. and Joo, H. (2013). 'Best-Practice Recommendations for Defining, Identifying, and Handling Outliers', *Organizational Research Methods*, 16(2), pp.270–301. Available at: https://doi.org/10.1177/1094428112470848.

Allison, M. and Ausden, M. (2004) 'Successful use of topsoil removal and soil amelioration to create heathland vegetation', *Biological Conservation*, 120(2), pp. 221–228. Available at: doi.org/10.1016/j.biocon.2004.02.017.

Allison, M. and Ausden, M. (2006) 'Effects of removing the litter and humic layers on heathland establishment following plantation removal', *Biological Conservation*, 127(2), pp. 177-182. Available at: doi.org/10.1016/j.biocon.2005.08.008.

ALS Environmental. (2023). *TM090 – TOC, TIC, DIC, DOC Method Summary*. Available at: https://www.alsenvironmental.co.uk/media-uk/method_statements/hawarden/waste-water-inorganics/tm090---toc-tic-dic-doc-method-summary_36.pdf [Accessed 18 Feb. 2025].

ALS. (2009). *Right Solutions • Right Partner Heavy Metal Guidelines in Soil TECHNICAL DATASHEET Assessment of Potentially Toxic Elements*. Available at: https://www.alsenvironmental.co.uk/media-uk/pdf/datasheets/contaminated-land/als_cl_heavy-metals-guidelines-in-soil_uk_feb_17_v2.pdf [Accessed 24 Mar. 2025].

Antony, D., Collins, C., Clark, J. and Sizmur, T. (2022). 'Soil organic matter storage in temperate lowland arable, grassland and woodland topsoil and subsoil', *Soil Use and Management*, 38(4), pp.1532–1546. Available at: https://doi.org/10.1111/sum.12801.

Bashour, I. and Sayegh, A. (n.d.). *METHODS OF ANALYSIS FOR SOILS OF ARID AND SEMI-ARID REGIONS*. Available at: https://msibsri4313.wordpress.com/wp-content/uploads/2013/11/methods-of-soil-analysis-for-arid-semiarid-regions.pdf. [Accessed: 10 Mar. 2025].

Beighton, R. (2013). Heavy metal in soils: Investigation into an urban area of Bristol. Plymouth University Department of Geographical Sciences. Available at: https://www.troopers-hill.org.uk/Flora/SoilsInvestigation.pdf [Accessed 24 Mar. 2025].

Berendse, F. (1990) 'Organic Matter Accumulation and Nitrogen Mineralization During Secondary Succession in Heathland Ecosystems,' *Journal of Ecology*, 78(2), pp. 413–427. Available at: https://doi.org/10.2307/2261121.

Berendse, F. and Elberse, W. T. (1990) '6 - Competition and Nutrient Availability in Heathland and Grassland Ecosystems', in Grace, J.B. and Tilman, D. (eds.) *Perspectives on Plant Competition*: Academic Press, pp. 93-116. Available at: https://doi.org/10.1016/B978-0-12-294452-9.50010-2 [Accessed: 3 Mar. 2025].

BRIG. (2011). UK Biodiversity Action Plan: Priority Habitat Descriptions. JNCC, Peterborough. Available at: https://jncc.defra.gov.uk/page-5706 [Accessed 26 Mar. 2025].

Bristol City Council (2019) *Troopers Hill Local Nature Reserve Management Plan*. Available at: https://www.troopers-hill.org.uk/plan/ManPlan2019.pdf [Accessed 10 Jan. 2025].

Bristol City Council, (n.d.). *Troopers Hill*. Available at: https://www.bristol.gov.uk/residents/museums-parks-sports-and-culture/parks-and-open-spaces/nature-reserves/troopers-hill [Accessed: 11 Feb. 2025].

Britton, A. J., Marrs, R. H., Carey, P. D. and Pakeman, R. J. (2000) 'Comparison of techniques to increase Calluna vulgaris cover on heathland invaded by grasses in Breckland, southeast England', *Biological Conservation*, 95, pp. 227-232. Available at: https://doi.org/10.1016/S0006-3207(00)00047-1.

Chapman, S.B., Rose, R.J. and Basanta, M. (1989). 'Phosphorus Adsorption by Soils from Heathlands in Southern England in Relation to Successional Change', *The Journal of Applied Ecology*, 26(2), p.673. Available at: https://doi.org/10.2307/2404091.

Cobb, S., ed. Dejardin, R. (2024). Teaching laboratories manual of field and laboratory methods.
Criquet, S., Clouard, M., Borschneck, D., Ziarelli, F. and Keller, C. (2023). 'Pedobiological properties of a lignite spoil heap in the Provence coal mine basin (south-east of France)', *Geoderma Regional*, 35, p.711. Available at: https://doi.org/10.1016/j.geodrs.2023.e00711.

Delta-T Devices Ltd. (2017). *User Manual for the ML3 ThetaProbe Soil Moisture Sensor*. Available at: https://cms.esi.info/Media/documents/17031_1422543355335.pdf [Accessed: 27 Feb. 2025].

Dijkstra, J.J., Meeussen, J.C.L. and Comans, R.N.J. (2004). 'Leaching of Heavy Metals from Contaminated Soils: An Experimental and Modeling Study,' *Environmental Science & Technology*, 38(16), pp.4390–4395. Available at: https://doi.org/10.1021/es049885v.

Dirt to Dinner. (2014) 250 Soil Moisture - NASA's SMAP [PDF] Available at: https://smap.jpl.nasa.gov/system/internal_resources/details/original/250_Soil_Moisture_Dirt_to_Dinner_3.5.14.pdf [Accessed: 26 Feb. 2025].
Duddigan, S., Gil-Martínez, M., Fraser, T., Green, I., Diaz, A., Sizmur, T., Pawlett, M., Raulund-Rasmussen, K. and Tibbett, M. (2020). Evaluating heathland restoration belowground using different quality indices of soil chemical and biological properties. *Agronomy*, *10*(8), p.1140. Available at: https://doi.org/10.3390/agronomy10081140.
ELGA LabWater. (2024). *Total Organic Carbon (TOC) Analysis and Measurement*. Available at: https://www.elgalabwater.com/blog/total-organic-carbon-toc [Accessed 18 Feb. 2025].
English Nature (2006) *Lowland Heathland – a cultural and endangered landscape*. Available at: https://publications.naturalengland.org.uk/publication/81012. [Accessed: 10 Jan. 2025].

Environment Agency (2008). *Ambient background metal concentrations for soils in England and Wales*. Available at: https://www.gov.uk/government/publications/ambient-background-metal-concentrations-for-soils-in-england-and-wales [Accessed 24 Mar. 2025].

FAO. (2023). *Standard operating procedure for soil moisture content by gravimetric method*. Rome: Food and Agriculture Organization of the United Nations. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/e8811ce2-af62-470f-90fb-71b1da2d00c0/content [Accessed 6 Feb. 2025].
Fowler, A. & Brown, V., (1991). *Site management and climate*. English Nature Research Report No. 76. Peterborough: English Nature. Available at: https://publications.naturalengland.org.uk/file/75023 [accessed 10 Mar. 2025]

Gardiner, T. and Vaughan, A. (2008) 'Responses of ground flora and insect assemblages to tree felling and soil scraping as an initial step to heathland restoration at Norton Heath Common, Essex', *Conservation Evidence*, 5, pp. 95-100. Available at:

https://www.researchgate.net/publication/228646713_Responses_of_ground_flora_and_insect_assemblages_to_tree_felling_and_soil_scraping_as_an_initial_step_to_heathland_restoration_at_Norton_Heath_Common_Essex [Accessed: 27 Feb. 2025].

Gimingham, C.H. (1972). *Ecology of heathlands*. London: Chapman and Hall. Available at: https://archive.org/details/ecologyofheathla0000gimi_x3l1 [Accessed 26 Mar. 2025].

Gimingham, C.H. (1992). *The lowland heathland management handbook* (ENS08). Available at: https://publications.naturalengland.org.uk/publication/2267376 [Accessed: 27 Feb. 2025].

Härdtle, W., von Oheimb, G., Niemeyer, M., Niemeyer, T., Assmann, T. and Meyer, H. (2007). 'Nutrient leaching in dry heathland ecosystems: effects of atmospheric deposition and management', *Biogeochemistry*, 86(2), pp.201–215. Available at: https://doi.org/10.1007/s10533-007-9156-5.

Hawley, G., Anderson, P., Gash, M., Smith, P., Higham, N., Alonso, I., Ede, J. and Holloway, J. (2008) *Impact of heathland restoration and re-creation techniques on soil characteristics and the historical environment.* Available at: https://publications.naturalengland.org.uk/publication/37001. [Accessed: 12 Mar. 2025]

Heil, G.W. and Bobbink, R. (1993). ''Calluna', a simulation model for evaluation of impacts of atmospheric nitrogen deposition on dry heathlands', *Ecological Modelling*, 68(3-4), pp.161–182. Available at: https://doi.org/10.1016/0304-3800(93)90015-k

Hoogsteen, M.J., Lantinga, E.A., Bakker, E.J., Groot, J.C. and Tittonell, P.A. (2015). 'Estimating soil organic carbon through loss on ignition: effects of ignition conditions and structural water loss', *European Journal of soil science*, 66(2), pp.320-328. Available at: https://doi.org/10.1111/ejss.12224.

Hoyle, M.C. and Bjorkbom, J.C., (1969*). Birch nutrition*. In: Doolittle, WT; Bruns, PE, comps. 1969. Birch symposium proceedings; 1969 August 19-21; Durham, NH. Upper Darby, PA: US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 102-105. (pp. 102-105). Available at: https://research.fs.usda.gov/treesearch/48126 [Accessed: 26 Mar. 2025].

Huangfu, Y., Essington, M.E., Hawkins, S.A., Walker, F.R., Schwartz, J.S., Layton, A.C. and Hull, R.A. (2019). 'Evaluation of nitric acid extraction of elements from soils and sediments in two watersheds in east Tennessee', *Communications in Soil Science and Plant Analysis*, 50(11), pp.1358-1369. Available at: https://doi.org/10.1080/00103624.2019.1614611.

Jones, D.L. and Willett, V.B. (2006). 'Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil', *Soil Biology and biochemistry*, 38(5), pp.991-999. Available at: https://doi.org/10.1016/j.soilbio.2005.08.012.

Kalra, Y. P. (1995). 'Determination of pH of Soils by Different Methods: Collaborative Study', *Journal of AOAC International*, 78(2), 310-320. Available at: https://doi.org/10.1093/jaoac/78.2.310.

Lane, M. (2020). 'Heathland Restoration after Mineral Extraction'. Thesis, University of Plymouth. Available at: https://pearl.plymouth.ac.uk/gees-theses/292 [Accessed: 27 February 2025].

Lawson, C.S. et al. (2004). 'The establishment of heathland vegetation on ex-arable land: the response of Calluna vulgaris to soil acidification'. *Biological Conservation*, 116(3), pp. 409–416. Available at: https://doi.org/10.1016/S0006-3207(03)00233-7.

Libohova, Z., Seybold, C., Wysocki, D., Wills, S., Schoeneberger, P., Williams, C., Lindbo, D., Stott, D. and Owens, P.R. (2018). 'Reevaluating the effects of soil organic matter and other properties on available water-holding capacity using the National Cooperative Soil Survey Characterization Database', *Journal of soil and water conservation*, 73(4), pp.411-421. Available at: https://www.tandfonline.com/doi/abs/10.2489/jswc.73.4.411 [Accessed 26 Mar. 2025].

Lindsay, W.L. (1972). 'INFLUENCE OF THE SOIL MATRIX ON THE AVAILABILITY OF TRACE ELEMENTS TO PLANTS', *Annals of the New York Academy of Sciences*, 199(1 Geochemical E), pp.37–45. Available at: https://doi.org/10.1111/j.1749-6632.1972.tb54323.x.

M. M. I. Van Vuuren, R. Aerts, F. Berendse, W. De Visser. (1992). 'Nitrogen Mineralization in Heathland Ecosystems Dominated by Different Plant Species', *Biogeochemistry*, Vol. 16, No. 3, pp. 151-166 (16 pages) https://www.jstor.org/stable/1468877.

Maddock, A. (2008) *UK BAP priority habitat descriptions (acid grassland)*, JNCC Resource Hub Available at: https://hub.jncc.gov.uk/assets/902cafcb-578f-43de-8a99-7143f00d79a2#UKBAP-BAPHabitats-26-LowlandDryAcidGrass.pdf [Accessed: 01 Mar. 2025].

Markus, J. and Mcbratney, A. (1996). 'An urban soil study: heavy metals in Glebe, Australia', *Soil Research,* 34(3), p.453. Available at: https://doi.org/10.1071/sr9960453.

McCrum-Gardner, E. (2008). 'Which is the correct statistical test to use?' *British Journal of Oral and Maxillofacial Surgery*, [online] 46(1), pp.38–41. Available at: https://doi.org/10.1016/j.bjoms.2007.09.002.

Mitchell, R. J., Marrs, R. H., Le Duc, M. G. and Auld, M. H. D. (1999) 'A study of the restoration of heathland on successional sites: changes in vegetation and soil chemical properties', *Journal of Applied Ecology*, 36(5), pp. 770-783. Available at: https://doi.org/10.1046/j.1365-2664.1999.00443.x.

Nelson, D.W. (1983). 'Determination of ammonium in KCl extracts of soils by the salicylate method.' *Communications in Soil Science and Plant Analysis,* 14(11), pp.1051-1062. Available at: https://doi.org/10.1080/00103628309367431.

Neyens, T. (2018). 'What can we learn about 40 years of research on heathland management?', *Insects & Nature Management Symposium*, Royal Belgian Entomological Society, Brussels, Belgium. Available at: http://www.srbe-kbve.be/cm/sites/default/files/symposiums/2018/Neyens_Insects%20%26%20Nature%20Management_SRBE%202018.pdf [Accessed 26 Mar. 2025].

Nykamp, M., Becker, F. and Hoelzmann, P. (2024). 'Total organic carbon quantification in soils and sediments: Performance test of a modified sample preparation method', *MethodsX,* 13, p.102934. Available at: https://doi.org/10.1016/j.mex.2024.102934.

Oliveira, Adília, and Maria Elisa Pampulha. 'Effects of Long-Term Heavy Metal Contamination on Soil Microbial Characteristics', *Journal of Bioscience and Bioengineering*, vol. 102, no. 3, Sept. 2006, pp. 157–161. Available at: https://doi.org/10.1263/jbb.102.157.

Podrázský, V. (2012). 'Logging and forest decline effects on the surface humus horizons in the *Šumava Mts'. Journal of Forest Science*, 52(No. 10), pp.439–445. Available at: https://doi.org/10.17221/4524-jfs.

Pywell, R. F., Pakeman, R. J., Allchin, E. A., Bourn, N. A. D., Warman, E. A. and Walker, K. J. (2002). 'The potential for lowland heath regeneration following plantation removal', *Biological Conservation*, 108(2), pp. 247-258. Available at: https://doi.org/10.1016/S0006-3207(02)00115-5

Reynolds, S.G. (1970). 'The gravimetric method of soil moisture determination Part IA study of equipment, ad methodological problems', *Journal of Hydrology*, 11(3), pp.258-273. Available at: https://doi.org/10.1016/0022-1694(70)90066-1.

Robertson, S. (2011). 'Direct estimation of organic matter by loss on ignition: methods', *SFU Soil Science Lab*, pp.1-11. Available at: https://www.sfu.ca/geog/soils/lab_documents/Estimation_Of_Organic_Matter_By_LOI.pdf [Accessed 27 Mar. 2025].

Sainani, K.L. (2012). ‘Dealing With Non-normal Dat’, *PM&R*, 4(12), pp.1001–1005. Available at: https://doi.org/10.1016/j.pmrj.2012.10.013.

Salehi, M.H., Beni, O.H., Harchegani, H.B., Borujeni, I.E. and Motaghian, H.R. (2011). ‘Refining soil organic matter determination by loss-on-ignition’, *Pedosphere*, 21(4), pp.473-482. Available at: https://doi.org/10.1016/S1002-0160(11)60149-5.

Schulte, E.E. and Hopkins, B.G. (1996). ‘Estimation of soil organic matter by weight loss-on-ignition’, *Soil organic matter: Analysis and interpretation,* 46, pp.21-31. Available at: https://doi.org/10.2136/sssaspecpub46.c3.

Tapadar, S.A., Jha, D.K. (2016) ‘Seasonal and Temporal Dynamics of Physicochemical and Biological Properties of Chronosequence Coal Mine Spoil Soils’, *CLEAN - Soil, Air, Water*, vol. 44(10), pp. 1405–1413. Available at: https://doi.org/10.1002/clen.201500129.

Tawfik, W., El-Saeed, M., Khalil, A. and Fikry, M. (2024). ‘Detection of heavy metal elements by using advanced optical techniques’, *Journal of the Egyptian Society for Basic Sciences-Physics*, 1(1), pp.99-127. Available at: doi.org/10.21608/JESBSP.2024.255191.1002.

The Wildlife Trusts. (2025). *Heathland and moorland.* Available at: https://www.wildlifetrusts.org/habitats/heathland-and-moorland [Accessed 26 Mar. 2025].

UK Biodiversity Action Plan. (2011) *Priority Habitat Descriptions*. Available at: https://hub.jncc.gov.uk/assets/2728792c-c8c6-4b8c-9ccd-a908cb0f1432. [Accessed 10 Jan. 2025].

University of Bristol. (2024). *To what extent does soil pH vary across Troopers Hill, and what factors influence these variations?*, Available at: https://www.troopers-hill.org.uk/research/AvonProject2024.pdf [Accessed: 02 Mar. 2025].

University of Nebraska-Lincoln. (2020). *The connection between soil organic matter and soil water.* Available at: https://water.unl.edu/article/animal-manure-management/connection-between-soil-organic-matter-and-soil-water/ [Accessed 17 Mar. 2025].

Van Diggelen, R., Bobbink, R., Frouz, J., Harris, J. and Verbruggen, E. (2021) 'Chapter 13 - Converting agricultural lands into heathlands: the relevance of soil processes', in Stanturf, J.A. and Callaham, M.A. (eds.) *Soils and Landscape Restoration*: Academic Press, pp. 357-372. Available at: https://doi.org/10.1016/B978-0-12-813193-0.00013-8.

Vergeer, P. et al. (2006) ‘The effect of turf cutting on plant and arbuscular mycorrhizal spore recolonisation: Implications for heathland restoration’, *Biological Conservation*, 129(2), pp. 226–235. Available at: https://doi.org/10.1016/j.biocon.2005.10.038.

Vogels, J.J., Weijters, M.J., Bobbink, R., Rienk-Jan Bijlsma, Leon, Wilco C. E. P. Verberk and Henk Siepel. (2019). ‘Barriers to restoration: Soil acidity and phosphorus limitation constrain recovery of heathland plant communities after sod cutting’, *Applied Vegetation Science*, 23(1), pp.94–106. Available at: https://doi.org/10.1111/avsc.12471.

Walker, K. J., Pywell, R. F., Warman, E. A., Fowbert, J. A., Bhogal, A. and Chambers, B. J. (2004). 'The importance of former land use in determining successful re-creation of lowland heath in southern England', *Biological Conservation*, 116(2), pp. 289-303. Available at: https://doi.org/10.1016/S0006-3207(03)00199-X.

Wan, Y., Liu, T., Zhuang, Z., Wang, Q. and Li, H. (2024). ‘Heavy Metals in Agricultural Soils: Sources, Influencing Factors, and Remediation Strategies’, *Toxics*, 12(1), pp.63–63. Available at: https://doi.org/10.3390/toxics12010063.

Wang, J., Zhao, W., Wang, G. and Pereira, P. (2022). ‘Afforestation changes the trade-off between soil moisture and plant species diversity in different vegetation zones on the Loess Plateau’, *CATENA*, 2(19), p.106583. Available at: https://doi.org/10.1016/j.catena.2022.106583.

Wang, J.-X., Xu, D.-M., Fu, R.-B. and Chen, J.-P. (2021). 'Bioavailability Assessment of Heavy Metals Using Various Multi-Element Extractants in an Indigenous Zinc Smelting Contaminated Site, Southwestern China', *International Journal of Environmental Research and Public Health*, 18(16), p.8560. Available at: https://doi.org/10.3390/ijerph18168560.

Widyati E, Irianto RS, Susilo A. (2022). 'Rhizosphere upheaval after tree cutting: Soil sugar flux and microbial behavior', *Communicative & Integrative Biology*, 15(1), pp.105–114. Available at: https://doi.org/10.1080/19420889.2022.2068110.

Yang, H., Ma, H., Shi, B., Li, L. and Yan, W. (2024). 'Experimental Study on the Effects of Heavy Metal Pollution on Soil Physical Properties and Microstructure Evolution', *Applied Sciences*, 41(25), pp.10631–10638. Available at: https://doi.org/10.3390/app14052022.

Zhang, Y., Zhang, X., Bi, Z., Yu, Y., Shi, P., Ren, L. and Shan, Z. (2020). 'The impact of land use changes and erosion process on heavy metal distribution in the hilly area of the Loess Plateau, China', *Science of The Total Environment,* [online] 718, p.137305. Available at: https://doi.org/10.1016/j.scitotenv.2020.137305.

Appendix

Total Organic Carbon (TOC) Methodology

TOC quantifies total organic carbon present in organic compounds and involves using a non-dispersive infrared (NDIR) detector (ELGA LabWater, 2024; ALS Environmental, 2023)

2 mL of the filtered KCl sample was transferred into a 50 mL centrifuge tube, then passed through a 0.45 µm membrane filter to prevent clogging the Shimadzu TOC-L machine (Cobb, 2024). After filtration, the sample was diluted with 18 mL of deionised water. Three method blanks (1M KCL) were included for contamination control. A similar methodology was used for the KCl samples; however, they were diluted in a 1:10 ratio with deionised water to ensure a salinity within acceptable levels for the Shimadzu TOC-L instrument (Cobb, 2024).

Samples were analysed using the Shimadzu TOC-L, following Jones and Willet's (2006) procedure. This involves catalytic oxidation of the sample suspension at high temperature, converting organic carbon to CO_2. This CO_2 is measured with a Non-dispersive Infrared (NDIR) sensor (Nykamp et al., 2024) and a calibration curve based on known standards used to calculate the concentration of organic carbon in the sample.

pH and Heavy Metals for Each Site

Site	**Sample**	**pH**	**Magnesium (*ppm*)**	**Aluminium (*ppm*)**	**Copper (ppm)**	**Lead (*ppm*)**	**Zinc (*ppm*)**	**Arsenic (*ppm*)**
AS	**AS1**	5.281	9	5	0.3716	2	0.97	<0.1
AS	**AS2**	5.078	6	6	0.7374	3.5	0.66	0.1216
AS	**AS3**	5.603	9	4	0.8332	5.3	1.74	<0.1
AS	**AS4**	5.045	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
AS	**AS5**	4.945	4	10	1.1199	6	0.71	0.2012
AS	**AS6**	4.951	2	5	1.8182	12	0.16	0.3155
AS	**AS7**	4.86	2	5	0.7044	8.2	0.22	0.1797
AS	**AS8**	4.248	0.9	5	0.7108	6.9	0.17	0.2574
AT	**AT1**	6.225	17	4	0.3437	2.4	2.09	<0.1
AT	**AT2**	5.45	14	4	0.3865	3.6	1.73	<0.1
AT	**AT3**	6.384	26	4	0.5437	5.5	5.54	<0.1
AT	**AT4**	5.972	18	8	1.2132	12	3.23	0.1787
AT	**AT5**	5.935	18	7	0.8855	7.8	3.15	0.1949
AT	**AT6**	6.678	17	12	0.8542	16	3.08	0.3541
AT	**AT7**	5.594	11	9	1.0930	13	1.65	0.1935
AT	**AT8**	5.108	14	6	0.9372	7.5	0.96	0.3001
B	**B1**	4.623	10	9	0.6989	5	1.19	0.1236
B	**B2**	4.83	8	14	0.8936	8.5	1.07	0.1671
B	**B3**	4.606	7	15	0.7881	10	4.99	<0.1
B	**B4**	4.688	8	11	0.4350	5.6	0.9	<0.1
B	**B5**	5.395	11	14	0.5490	6	1.82	0.1781
B	**B6**	5.29	12	10	1.0415	17	2.11	0.3134
B	**B7**	4.562	5	14	0.8484	12	0.82	0.4082
C	**C1**	5.706	24	10	0.2787	1.6	1.35	<0.1
C	**C2**	6.296	32	7	0.1556	1.7	2.38	<0.1

C	**C3**	6.505	26	12	0.1672	2	1.78	<0.1
C	**C4**	6.841	30	8	0.1470	1.6	2.06	<0.1
C	**C5**	6.726	29	6	0.3784	3.8	3.84	<0.1
C	**C6**	6.617	23	6	0.5293	6.1	1.62	<0.1
C	**C7**	6.298	12	13	0.2115	5.4	3.82	<0.1

2024's Avon Project results for pH across all of Troopers Hill (University of Bristol, 2024)

Site	**Sample**	**pH**
S1	S1R1	6.044
S1	S1R2	6.808
S1	S1R3	7.1
S1	S1R4	6.758
S1	S1R5	6.785
S2	S2R1	5.245
S2	S2R2	5.14
S2	S2R3	5.28
S2	S2R4	5.494
S2	S2R5	4.346
S3	S3R1	4.992
S3	S3R2	3.875
S3	S3R3	6.531
S3	S3R4	5.623
S3	S3R5	4.571
S4	S4R1	4.463
S4	S4R2	4.315
S4	S4R3	4.279
S4	S4R4	4.445
S4	S4R5	4.281
S5	S5R1	3.828
S5	S5R2	3.94
S5	S5R3	3.786
S5	S5R4	3.936
S5	S5R5	4.097
S6	S6R1	4.747
S6	S6R2	5.505
S6	S6R3	5.185
S6	S6R4	5.75
S6	S6R5	5.696

Soil Moisture Results for Each Site

Site	**Sample**	**Boat weight**	**Moist weight and Boat**	**Moist weight no boat**	**Dry weight and Boat**	**Dry weight no boat**	**Soil Moisture (%)**	**In field soil moisture (%)**

AS	**AS1**	1.7512	25.0628	23.3116	22.4912	20.74	12.3992	NA
AS	**AS2**	1.7587	25.0025	23.2438	22.6609	20.9022	11.2026	NA
AS	**AS3**	1.7703	25.0273	23.257	23.0395	21.2692	9.3459	NA
AS	**AS4**	1.7707	25.0813	23.3106	21.3516	19.5809	19.0476	NA
AS	**AS5**	1.7783	25.0101	23.2318	23.4693	21.691	7.1034	NA
AS	**AS6**	1.7606	24.9242	23.1636	23.1985	21.4379	8.0500	NA
AS	**AS7 (rock)**	1.7532	25.0328	23.2796	24.4983	22.7451	2.3500	NA
AS	**AS8**	1.7585	25.0794	23.3209	23.2427	21.4842	8.5491	NA
AT	**AT1**	1.7775	25.0246	23.2471	19.1728	17.3953	33.6401	NA
AT	**AT2**	1.7534	25.0078	23.2544	22.9793	21.2259	9.5567	NA
AT	**AT3**	1.76	25.0142	23.2542	20.9453	19.1853	21.2084	NA
AT	**AT4**	1.7603	24.991	23.2307	18.9422	17.1819	35.2045	NA
AT	**AT5**	1.7533	25.024	23.2707	16.815	15.0617	54.5025	NA
AT	**AT6**	1.7686	25.684	23.9154	22.1725	20.4039	17.2100	*NA*
AT	**AT7**	1.7878	24.9914	23.2036	17.7892	16.0014	45.0098	*NA*
AT	**AT8**	1.7884	25.0195	23.2311	17.9981	16.2097	43.3160	*NA*
B	**B1**	1.8034	25.0235	23.2201	21.1378	19.3344	20.0973	*17.7*
B	**B2**	1.8046	25.0445	23.2399	16.9511	15.1465	53.4341	*47.8*
B	**B3**	1.8169	25.0539	23.237	17.7133	15.8964	46.1778	*41.0*
B	**B4**	1.8152	24.9518	23.1366	21.4718	19.6566	17.7040	*26.3*
B	**B5**	1.7865	25.0035	23.217	14.4942	12.7077	82.7002	*86.6*
B	**B6**	1.7685	25.0155	23.247	20.6177	18.8492	23.3315	*40.0*
B	**B7**	1.8035	24.9869	23.1834	20.1506	18.3471	26.3600	*51.2*
C	**C1**	1.8178	25.0134	23.1956	18.7375	16.9197	37.0923	*31.8*
C	**C2**	1.8026	25.0995	23.2969	14.3675	12.5649	85.4125	*NA*

C	**C3**	1.825 4	25.0901	23.2647	15.6699	13.8445	68.0429	*NA*
C	**C4**	1.811 5	25.0438	23.2323	17.1366	15.3251	51.5964	*NA*
C	**C5**	1.811 3	24.9539	23.1426	16.456	14.6447	58.0271	*NA*
C	**C6**	1.790 3	25.0445	23.2542	16.8867	15.0964	54.0380	*NA*
C	**C7**	1.795	25.0289	23.2339	16.3442	14.5492	59.6919	*NA*

Soil Organic Matter Results for Each Site

Site	**Sample**	**Crucible weight**	**Wet Weight (plus crucible)**	**Wet Weight (no crucible)**	**Dry weight (plus crucible)**	**Dry Weight (no crucible)**	**Organic Matter *(g)***	**Organic matter *(%)***
AS	**AS1**	29.0757	39.0471	9.9714	38.658	9.5823	0.389	3.90216
AS	**AS2**	29.3665	39.3952	10.0287	38.9613	9.5948	0.434	4.32658 3
AS	**AS3**	27.876	37.8689	9.9929	37.2845	9.4085	0.584	5.84815 2
AS	**AS4**	27.0574	37.062	10.0046	35.2436	8.1862	1.818	18.1756 4
AS	**AS5**	26.0165	36.1455	10.129	35.3408	9.3243	0.805	7.94451 6
AS	**AS6**	23.9612	33.929	9.9678	32.6924	8.7312	1.237	12.406
AS	**AS7**	26.1337	34.1218	7.9881	38.8313	12.6976	-4.710	-58.956
AS	**AS8**	27.8119	37.842	10.0301	37.4871	9.6752	0.355	3.538
AT	**AT1**	24.9435	34.9057	9.9622	33.9747	9.0312	0.931	9.345
AT	**AT2**	26.6686	36.1698	9.5012	35.4889	8.8203	0.681	7.167
AT	**AT3**	26.4528	36.4402	9.9874	35.221	8.7682	1.219	12.207
AT	**AT4**	27.4945	37.4178	9.9233	35.7086	8.2141	1.709	17.224
AT	**AT5**	25.5444	35.4599	9.9155	33.4385	7.8941	2.021	20.386
AT	**AT6**	26.6295	36.6539	10.0244	34.9305	8.301	1.723	17.192
AT	**AT7**	27.6281	37.6462	10.0181	35.2454	7.6173	2.401	23.965
AT	**AT8**	27.1439	37.2861	10.1422	35.5216	8.3777	1.765	17.398
B	**B1**	27.4292	37.4415	10.0123	36.3569	8.9277	1.085	10.833
B	**B2**	26.2492	36.3944	10.1452	33.6726	7.4234	2.722	26.828
B	**B3**	29.2353	39.2195	9.9842	37.057	7.8217	2.163	21.659
B	**B4**	28.875	38.8043	9.9293	37.8271	8.9521	0.977	9.842
B	**B5**	27.0377	37.0609	10.0232	33.5523	6.5146	3.509	35.005
B	**B6**	27.2456	37.351	10.1054	35.6075	8.3619	1.744	17.253
B	**B7**	24.3024	34.3103	10.0079	32.1954	7.893	2.115	21.132
C	**C1**	28.7365	38.7143	9.9778	37.141	8.4045	1.573	15.768
C	**C2**	26.3197	36.1112	9.7915	33.7518	7.4321	2.359	24.096
C	**C3**	29.2781	39.275	9.9969	36.8758	7.5977	2.399	23.999

C	**C4**	32.4666	42.0645	9.5979	40.2872	7.8206	1.777	18.518
C	**C5**	26.2517	36.2655	10.0138	34.1784	7.9267	2.087	20.842
C	**C6**	27.4588	37.7118	10.253	36.1259	8.6671	1.586	15.468
C	**C7**	27.2636	37.3309	10.0673	35.3203	8.0567	2.011	19.972

Raw and Final Nutrients Results for Each Site

Site	**Sample**	**Moisture Factor**	**Soil Water**	**Weight of Moist Soil (g)**	**Lab TON Results (*µg/l*)**	**TON Results (dilution and blank corrected) (*mg/l*)**	**Final TON Results (*µg/g of dry soil*)**
AS	**AS1**	1.1240	2.5716	23.3116	255.7452	2.4991	3.3222
AS	**AS2**	1.1120	2.3416	23.2438	75.58645	0.6975	0.9124
AS	**AS3**	1.0935	1.9878	23.257	171.197	1.6536	2.0982
AS	**AS4**	1.1905	3.7297	23.3106	193.0535	1.8722	2.7469
AS	**AS5**	1.0710	1.5408	23.2318	125.5373	1.1970	1.4646
AS	**AS6**	1.0805	1.7257	23.1636	105.6011	0.9976	1.2437
AS	**AS7**	1.0235	0.5345	23.2796	19.40877	0.1357	0.1524
AS	**AS8**	1.0855	1.8367	23.3209	280.7447	2.7491	3.4340
AT	**AT1**	1.3364	5.8518	23.2471	253.9621	2.4812	4.4007
AT	**AT2**	1.0956	2.0285	23.2544	724.4351	7.1860	9.1504
AT	**AT3**	1.2121	4.0689	23.2542	836.9677	8.3113	12.5930
AT	**AT4**	1.3520	6.0488	23.2307	387.4613	3.8162	6.8962
AT	**AT5**	1.5450	8.2090	23.2707	401.4342	3.9570	8.7224
AT	**AT6**	1.1721	3.5115	23.9154	798.0293	7.9219	11.0697
AT	**AT7**	1.4501	7.2022	23.2036	270.9703	2.6513	5.3357
AT	**AT8**	1.4332	7.0214	23.2311	486.1898	4.8035	9.4891
B	**B1**	1.2010	3.8857	23.2201	46.06194	0.4022	0.6010
B	**B2**	1.5343	8.0934	23.2399	46.3169	0.4048	0.8844
B	**B3**	1.4618	7.3406	23.237	60.10686	0.5427	1.1041
B	**B4**	1.1770	3.4800	23.1366	65.68249	0.5984	0.8671
B	**B5**	1.8270	10.5093	23.2170	163.0982	1.5726	4.3944
B	**B6**	1.2333	4.3978	23.2470	151.7539	1.4592	2.2758
B	**B7**	1.2636	4.8363	23.1834	66.89302	0.6106	0.9929
C	**C1**	1.3709	6.2759	23.1956	50.83909	0.4500	0.8318
C	**C2**	1.8541	10.732	23.2969	247.3263	2.4149	6.8674
C	**C3**	1.6804	9.4202	23.2647	62.21168	0.5637	1.4016
C	**C4**	1.5160	7.9072	23.2323	100.0126	0.9418	2.0222
C	**C5**	1.5803	8.4979	23.1426	69.96083	0.6412	1.4667
C	**C6**	1.5404	8.1578	23.2542	29.98558	0.2415	0.5304
C	**C7**	1.5970	8.6847	23.2339	47.9632	0.4213	0.9753
BLANK	**BLANK1**				6.2240		
BLANK	**BLANK2**						
BLANK	**BLANK3**				5.4511		

Site	Sample	Lab TOC Results (*mg/L*)	Final TOC (*µg/g of dry soil*)	Lab NH_4-N Results (*µg/l*)	NH_4-N Results (accounting for blanks and dilution) (*mg/L*)	Final NH_4-N Results (*µg/g of dry soil*)
AS	**AS1**	1.061	14.1049	473.1919	4.6244	6.1477
AS	**AS2**	1.641	21.4655	300.9340	2.9018	3.7958
AS	**AS3**	0.9443	11.9819	456.3909	4.4564	5.6546
AS	**AS4**	1.141	16.7411	362.3376	3.5159	5.1586
AS	**AS5**	1.276	15.6130	366.6601	3.5591	4.3549
AS	**AS6**	1.222	15.2341	545.5245	5.3477	6.6668
AS	**AS7**	1.075	12.0683	276.1407	2.6539	2.9794
AS	**AS8**	0.7132	8.9088	255.1287	2.4438	3.0526
AT	**AT1**	1.729	30.6650	740.9487	7.3020	12.951
AT	**AT2**	1.094	13.9307	527.2242	5.1647	6.5766
AT	**AT3**	1.345	20.3790	742.9518	7.3220	11.0941
AT	**AT4**	1.165	21.0523	673.6382	6.6289	11.9788
AT	**AT5**	0.9375	20.6706	508.8563	4.9811	10.9826
AT	**AT6**	1.178	16.4608	411.6717	4.0092	5.6023
AT	**AT7**	1.412	28.4160	1324.2374	13.1349	26.4334
AT	**AT8**	1.991	39.3311	570.6122	5.5986	11.0598
B	**B1**	2.34	34.9597	749.5026	7.3875	11.0370
B	**B2**	2.281	49.8373	607.7242	5.9697	13.0432
B	**B3**	3.147	64.0245	582.0222	5.7127	11.6223
B	**B4**	2.324	33.6719	144.3432	1.3359	1.9356
B	**B5**	2.194	61.3072	1121.6094	11.1086	31.0409
B	**B6**	2.302	35.9027	641.9579	6.3121	9.8445
B	**B7**	1.775	28.8653	270.7213	2.5997	4.2277
C	**C1**	1.239	22.9028	213.1899	2.0244	3.7421
C	**C2**	2.344	66.6586	1231.7850	12.210	34.7237
C	**C3**	1.018	25.3095	398.8581	3.8811	9.6491
C	**C4**	0.5169	11.0993	175.2927	1.6454	3.5332
C	**C5**	1.948	44.5580	243.9952	2.3324	5.3352
C	**C6**	1.621	35.6037	195.0863	1.8434	4.0488
C	**C7**	1.409	32.6215	237.5174	2.2677	5.2502
BLANK	**BLANK1**	1.504		7.32362		
BLANK	**BLANK2**	1.392		NA		
BLANK	**BLANK3**	0.6877		14.17681		

Site	Sample	Lab PO_4-P Results (*µg/l*)	PO_4-P Results (accounting for blanks and dilution) (*mg/g*)	Final PO_4-P (*µg/g of dry soil*)
AS	**AS1**	13.82192	0.07984365	0.106143548
AS	**AS2**	11.21517	0.05377615	0.070343121

AS	**AS3**	12.58671	0.06749155	0.085637845
AS	**AS4**	21.75652	0.15918965	0.233567961
AS	**AS5**	40.94049	0.35102935	0.429514535
AS	**AS6**	8.42459	0.02587035	0.032251443
AS	**AS7**	12.42123	0.06583675	0.073910798
AS	**AS8**	44.25391	0.38416355	0.479872741
AT	**AT1**	30.83639	0.24998835	0.443372093
AT	**AT2**	37.51708	0.31679525	0.403398698
AT	**AT3**	46.06206	0.40224505	0.609467724
AT	**AT4**	22.13572	0.16298165	0.294518339
AT	**AT5**	44.40115	0.38563595	0.85027482
AT	**AT6**	18.77046	0.12932905	0.180718647
AT	**AT7**	94.15692	0.88319365	1.777393138
AT	**AT8**	71.66423	0.65826675	1.300370945
B	**B1**	46.06194	0.40224385	0.600954526
B	**B2**	46.3169	0.40479345	0.884428189
B	**B3**	60.10686	0.54269305	1.104087646
B	**B4**	65.68249	0.59844935	0.867079632
B	**B5**	163.0982	1.57260645	4.394355723
B	**B6**	151.7539	1.45916345	2.27575681
B	**B7**	66.89302	0.61055465	0.992892158
C	**C1**	50.83909	0.45001535	0.831848974
C	**C2**	247.3263	2.41488745	6.867444895
C	**C3**	62.21168	0.56374125	1.401573663
C	**C4**	100.0126	0.94175045	2.022196945
C	**C5**	69.96083	0.64123275	1.466738857
C	**C6**	29.98558	0.24148025	0.530388293
C	**C7**	47.9632	0.42125645	0.975304288
BLANK	**BLANK1**	6.22397		
BLANK	**BLANK2**	NA		
BLANK	**BLANK3**	5.45114		

Location and Elevation of Samples for Each Site

Site	**Sample**	**Latitude**	**Longitude**	**Elevation (ft)**
AS	**AS1**	51.455915	-2.535744	200
AS	**AS2**	51.455869	-2.535625	200
AS	**AS3**	51.455850	-2.535560	201
AS	**AS4**	51.455767	-2.535480	198
AS	**AS5**	51.455844	-2.535439	206
AS	**AS6**	51.455908	-2.535494	208
AS	**AS7**	51.455948	-2.535606	207
AS	**AS8**	51.455892	-2.535672	200
AT	**AT1**	51.455915	-2.535744	200
AT	**AT2**	51.455869	-2.535625	200

AT	**AT3**	51.455850	-2.535560	201
AT	**AT4**	51.455767	-2.535480	198
AT	**AT5**	51.455844	-2.535439	206
AT	**AT6**	51.455908	-2.535494	208
AT	**AT7**	51.455948	-2.535606	207
AT	**AT8**	51.455892	-2.535672	200
B	**B1**	51.455994	-2.535524	213
B	**B2**	51.456030	-2.535464	218
B	**B3**	51.456001	-2.535396	220
B	**B4**	51.455985	-2.535331	221
B	**B5**	51.455875	-2.535373	212
B	**B6**	51.455913	-2.535417	212
B	**B7**	51.455947	-2.535388	216
C	**C1**	51.455834	-2.535677	196
C	**C2**	51.455836	-2.535730	194
C	**C3**	51.455840	-2.535783	193
C	**C4**	51.455852	-2.535877	191
C	**C5**	51.455680	-2.535883	173
C	**C6**	51.455915	-2.535789	198
C	**C7**	51.455793	-2.535620	188

<u>Soil Depth for 53 points across Site A</u>

Latitude	**Longitude**	**Soil Depth(cm)**
51.455995	-2.535591	36.3
51.455999	-2.535584	24.1
51.455974	-2.535539	31.1
51.455942	-2.535517	32.1
51.455919	-2.535506	24.5
51.455877	-2.535478	35
51.455882	-2.535486	38.9
51.455847	-2.535410	59.1
51.455819	-2.535454	29
51.455790	-2.535398	38.1
51.455768	-2.535378	31.7
51.455763	-2.535366	15.8
51.455748	-2.535412	22
51.455814	-2.535429	31.2
51.455824	-2.535459	22.4
51.455852	-2.535447	32.6
51.455882	-2.535467	34.2
51.455892	-2.535513	35.6
51.455899	-2.535539	29
51.455916	-2.535597	42
51.455970	-2.535545	25.8
51.455966	-2.535590	32.4

51.455969	-2.535597	18.4
51.456004	-2.535615	29.8
51.455975	-2.535644	33.4
51.455948	-2.535648	35.5
51.455955	-2.535626	31.1
51.455930	-2.535602	24.1
51.455892	-2.535566	30.8
51.455914	-2.535557	54.6
51.455861	-2.535480	54.8
51.455825	-2.535490	26.6
51.455833	-2.535511	35.4
51.455801	-2.535455	34.2
51.455773	-2.535517	22
51.455790	-2.535547	22.8
51.455799	-2.535541	25.8
51.455826	-2.535566	32
51.455787	-2.535616	33.4
51.455864	-2.535609	41
51.455908	-2.535588	28.6
51.455913	-2.535667	22.2
51.455893	-2.535690	26.6
51.455905	-2.535719	20.4
51.455885	-2.535674	25.4
51.455848	-2.535598	18.4
51.455824	-2.535578	35
51.455792	-2.535528	26.2
51.455788	-2.535536	24.2
51.455779	-2.535450	22.2
51.455842	-2.535734	18.2
51.455831	-2.535676	16.9
51.455843	-2.535640	14.8