To what extent does soil pH vary across Troopers Hill, and what factors influence these variations?

Group 13 – In association with Friends of Troopers Hill

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Sub-questions:

What factors are potentially influencing soil pH variations across selected sites at Troopers Hill?

How do other soil characteristics vary between those sites?

Contents

Acknowledgements

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Abstract

Soil pH has historically been a point of contention on Troopers Hill, showing a more acidic profile than generally found on the pennant (Hutchinson et.al., 2018). Areas with alkaline indicators have also been identified, suggesting an influence other than the pennant sandstone. It has been suggested that sites on the hill consist of soil tipped from other areas, but this proved difficult to measure with certainty. The variation of soil pH and appropriate characteristics were investigated using soil samples at six sites, as well as taking in situ soil moisture measurements. Laboratory tests for pH, nutrients, carbonates, loss on ignition and soil moisture were filtered into the results and represented graphically, with comparisons to relevant secondary research and further statistical analysis. The interaction of coal spoils with soil may explain the acidity in places, while the construction of two limestone paths may give reason for the alkaline indicators present.

1. Introduction

1.1. Key Issues and Debates

Soil pH is one of the most fundamental features dictating the biological, physical, and chemical properties of soil, and therefore the land in which it serves for plant growth (Aciego Pietri et al, 2008). Soil is a resource considered to be non-renewable on human timescales, therefore soil degradation processes, such as acidification, can have major impacts on biodiversity and nutrient cycling, affecting land use and management. Understanding soil pH qualities is crucial for maintaining land. It is important to determine whether soil degradation is a significant issue and which management practices may be required to mitigate this (Lal, 2015).

This report investigates the variation in soil pH and the causes of these variations, across Troopers Hill, a Local Nature Reserve – (Friends of Troopers Hill a, 2024) – located in the East of Bristol. The main task was prompted by Friends of Troopers Hill, who specified sites and sub questions in which to focus analyses and configure a wide-reaching soil characterisation.

1.2. Research Question and Objectives:

This investigation was motivated by two main research questions:

RQ1: What factors are potentially influencing soil pH variations across selected sites at Troopers Hill?

RQ2: How do other soil characteristics vary between those sites?

1.3. Study Area

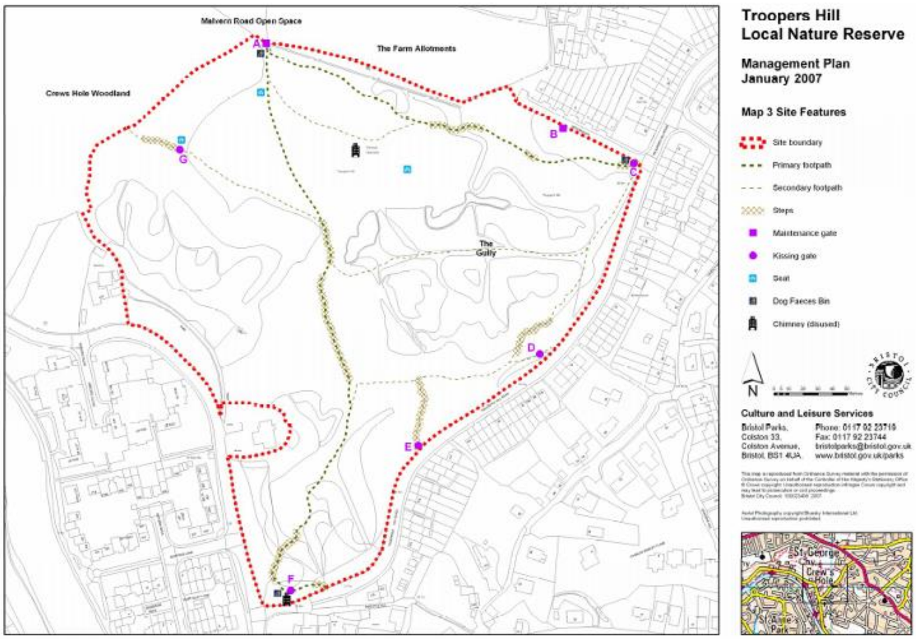
MAP 1: TROOPERS HILL IN RELATION TO BRISTOL (GOOGLE MAPS, 2024)

Troopers Hill has been identified as a site with distinctly acidic soil compared to surrounding areas, with studies recording pH values as low as 3.5 (Guisti, 2011).

With the underlying geology of Troopers Hill not differing greatly from the rest of Bristol, the hill's unusual soil acidity has created a unique grassland and heathland habitat, dominated by ling and bell heather and Scotch broom (Friends of Troopers Hill d, 2023). These habitats have been designated as 'priority habitats' within the UK Biodiversity Action Plan, meaning the nature reserve has become an area of conservation with regional and national importance (Friends of Troopers Hill b, 2024). However, an uneven spread of vegetation and unexpected plant growth on the site has raised questions about soil acidity, potential variations in this acidity, and possible factors which could be influencing these variations.

In the past, numerous forms of industrial activity were conducted on the hill, such as the mining of coal and fire clay, quarrying of pennant sandstone, and tipping of industrial waste. Additionally, copper and lead smelting operations, chemical works, and tar production previously occurred in the area.

The hill was declared a 'Local Nature Reserve' in 1995, and is now frequented by local dog walkers, runners and children visiting the playground (Friends of Troopers Hill c, 2024). Although land use has changed, current human activity involves frequent footfall, dog waste, maintenance of the site, and other factors which must all be considered alongside the hill's industrial past when exploring factors influencing soil pH. This includes the addition of two limestone paths as shown in **Map 2**, going from A to C and from A to F.



MAP 2: TROOPERS HILL MANAGEMENT PLAN (FRIENDS OF TROOPERS HILL, 2007)

Considering this information, in situ theta probe measurements of soil moisture were taken, and soil cores were collected from six sites for laboratory analysis to determine the characteristics of soil across Troopers Hill. This included tests for pH and soil moisture in the laboratory, alongside loss on ignition to determine the organic matter present. Furthermore, tests for carbonates (CO_3) and nutrients were conducted, including ammonia (NH_4-N), total oxidisable nitrogen (TON), phosphates (PO_4-P) and dissolved organic carbon (DOC).

2. Literature review

There is little past academic work examining the geology and soil of Troopers Hill. A dissertation was conducted in 2013 analysing the presence of heavy metals on the site and pH was briefly investigated. A mean pH of 4.1 was found from 6 samples taken across 3 transects (Beighton, 2013). Considering the areal extent of the hill, this small sample size may contain inaccuracies. Within the report, the influence of heavy metals on soil pH was not examined in detail. Generally, there is a lack of work investigating the geology and soil within the city of Bristol. It is briefly mentioned in the book “Geological sites of the Bristol region” (2018), stating that Troopers Hill has unusually acidic soil for the area. Available soil data (UKCEH, 2022), shows that areas surrounding the city have a pH between 6 and 7.5, higher than that of Troopers Hill. The UK soil observatory also has very little data on soil pH in Bristol, with most data originating outside the urban centre and none for Troopers Hill reflecting the limited knowledge of the site.

The reserve is a Regionally Important Geological Site (RIGS) (Wessex Ecological Consultancy, 2019) with underlying geology comprising sandstone and mudstone which is typical for the region, despite lacking limestone (British Geological Survey, 2024). Sandstones usually form acidic or neutral soils (ACES, 2018), and Gruba and Socha (2016) found that the parent material is important for soil acidity, explaining why the soil at Troopers hill is acidic. Despite this, there must be other factors involved as the soil here is much more acidic than Bristol which has a similar geology. Coal is also found here, which could explain the acidity at some sites on Troopers Hill. Coal contains sulphur (National Energy Technology Laboratory), and when sulphur is oxidised, it forms sulphuric acid (Aguilar *et al.*, 2004). Exposed coal spoils at the site could be oxidising and contributing to soil acidity, but this is hard to confirm. Most academic work around coal and its effects on the environment are centred around coal mining and waste rather than natural deposits of coal. This is not relevant to Troopers Hill because the mining that took place was underground and had ceased by 1845 (Friends of Troopers Hill c, 2024).

Troopers Hill is mostly covered by three main habitats: heathland, grassland, and woodland. These all tend to have acidic soils (JNCC, 2015; Maddock, 2008; Scottish Forestry) with lowland dry acid grassland, having a pH range between 4 and 5.5 (Maddock, 2008). According to existing data (Beighton, 2013), the hill has a mean pH within this range making it ideal for grassland. Soils must also be nutrient poor and free draining (Critchley *et al.*, 2002; JNCC, 2015; Maddock, 2008) to support these habitats, which matches with data from LandIS (2013) that show the soils on Troopers Hill to be free draining and of low fertility. The steep topography of the reserve means water runs off without building up which provides ideal conditions for these habitats.

A study by Critchley *et al.* (2002) shows that grasslands with the highest botanical value were located on soils classed as nutrient poor. They tended to have lower phosphorus concentrations but could occur at a range of nitrogen values. This shows that phosphorous is an important limiting nutrient in grasslands, whereas nitrogen has less of an influence. The three acid grasslands looked at in this study recorded soil pH values of 6.1, 4.0 and 4.9. A pH of 6.1 is unusual but could be attributed to other factors that are not mentioned in the study such as different geology, topography, and climate. In another study, phosphorous concentration impacted nitrogen (Deforest and Otuya, 2020). They found that in strongly acidic soil, the addition of phosphorous encouraged the growth of nitrogen fixing bacteria, accelerating nitrification.

Climate and topography could be responsible for the acidic soil of Troopers Hill. The climate controls temperature and precipitation which in turn impacts soil texture and minerals (Fabian, *et al.*, 2014). Minerals in soil can be weathered and leached due to precipitation (USDA Natural Resources Conservation Service, 2011). The extent to which this occurs is controlled by the topography. Surface and subsurface runoff (Zhang *et al.*, 2022) increases when there is a steep slope which causes more soil erosion (Siswanto and Sule, 2019). An area of flatter topography has less runoff and erosion because water flows slower and so it has time to percolate through the soil (McClellan a, 2007). This causes leaching of water-soluble minerals from the soil profile. Leaching is responsible for acidification when nutrients, such as nitrogen and base cations, are lost (DEFRA, 2000; Ste-Marie and Paré, 1999; USDA Natural Resources Conservation Service, 2011). In fact, Naz *et al.* (2022) mention that soils experiencing high rainfall are more acidic than those with low rainfall. The average annual rainfall in Bristol between 1991-2020 was lower than the national average (Bristol Weather Station, 2020, Met Office, 2022) which means that Troopers Hill’s pH stands out due to factors other than climate.

Soil contains many buffers that protect it against drastic pH changes. The alkalinity of base cations and nutrient retaining properties of organic matter buffer against acidification and leaching (DEFRA, 2000; USDA Natural Resources Conservation Service, 2011). When bases are lost, they are replaced by H+ ions which causes soil pH to drop. A drop in pH below 5.4 is enough for aluminium to become soluble, which leads to further acidification (McClellan b, 2007; Panda, Baluška and Matsumoto, 2009; USDA Natural Resources Conservation Service, 2011). LandIS (2013) data shows that there is low carbon at Troopers Hill, which would suggest a low organic matter content and so the soil may struggle to withstand changes in pH. This is from a simplified dataset of the National Soil Map so not specific enough to draw accurate conclusions from.

Also buffering against soil acidification, carbonates reduce the bioavailability of heavy metals, according to Wang *et al.* (2015). They found there was a minimum concentration of 1% soil carbonate content required to maintain buffering capacity. The soil forming factors, such as topography, vegetation, parent material and human activity, are responsible for the carbonate content (Alijani and Sarmadian, 2014), and therefore the buffering capacity. The parent material at Troopers Hill is mostly sandstone, no carbonate rocks, like limestone, which would suggest there is low carbonate content in the soil. Most of the vegetation is adapted to acidic soil which further reinforces this. There is an anomaly; Ploughman’s Spikenard is growing at a site on Troopers Hill. This plant prefers calcareous soil, and so a pH that is neutral or slightly alkaline (PlantIn; Taalab et al., 2019). The plant could be an indicator of high carbonate concentrations at this site. Human activities could also be responsible, for example tipping has occurred across the nature reserve (Friends of Troopers Hill c, 2024), and it is not known where material was taken from, so previous activities could have deposited material that contains a higher carbonate content.

Microorganisms are incredibly important for organic matter and nutrient contents of soil (Wang *et al.,* 2022). The solubility of nitrogen, a key nutrient for plants, and its transformation processes are reliant on soil pH (Deforest and Otuya, 2020). Nitrogen-fixing bacteria were found to be acid sensitive in a study by Ste-Marie and Paré, (1999) as nitrification only occurred in samples with a pH between 4.5 and 6.5, although this pH range is not necessarily applicable to Troopers Hill as the study specifically investigated boreal forests. Human factors must also be considered, for example a study (De Frenne *et al.*, 2022) found that dog faeces and urine have a substantial impact on levels of nitrogen and phosphorus which could have a considerable impact on ecosystems. This paper specifically looked at a variety of ecosystems such as grasslands and heathlands which makes this incredibly relevant to Troopers Hill which is has these same habitats and is frequented by many dogs.

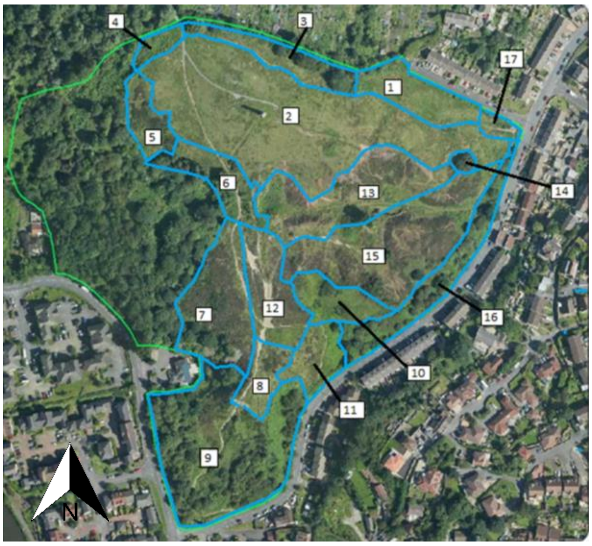
Human activity has been crucial in shaping the site and making it what it is today. From the early 18th century to 1981, when the tar works closed, there is plenty of evidence detailing the industrial activity that took place (Friends of Troopers Hill c, 2024). Starting with coal mining and copper smelting, Troopers Hill and Crew's Hole saw the growth and collapse of numerous industries such as lead, quarrying, brass and then finally tar. This history has left a mark on the soils and landscape. Heavy metals were found to be contaminating areas of the site (Beighton, 2013), quarrying created the gully which left rock formations exposed, and two chimneys remain as relics of what was once a thriving industrial area (Friends of Troopers Hill c, 2024). The presence of heavy metals on the site is not hazardous (Beighton, 2013) however soil acidification is known to increase their solubility and bioavailability which can affect plants (De Frenne *et al.*, 2022). Some of this history is forgotten which makes it hard to know exactly where certain activities took place. For example, tipping is known to have happened along with movement of material around the site. The lack of documentation makes it hard to know where material originates from. All of this is responsible to an extent for the current soil scape of Troopers Hill.

3. Methodology

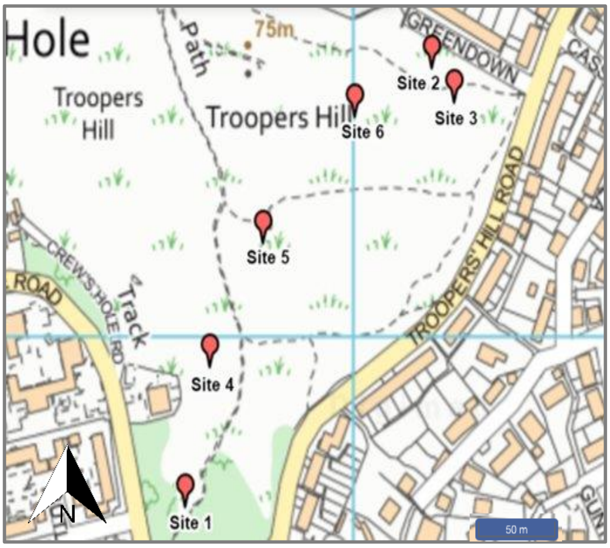
3.1. Site Locations and Justifications

Six sites were selected across Trooper's Hill, using selective sampling. They were chosen because the 'Friends of Troopers Hill' project partners indicated these six sites as areas of interest which required study.

Troopers Hill itself is divided into 17 compartments for the purpose of planning nature conservation management, implemented in 2019 by Bristol Parks and Friends of Troopers Hill (Friends of Troopers Hill b, 2024).



MAP 3: COMPARTMENT PLAN OF TROOPERS HILL (FRIENDS OF TROOPERS HILL B, 2024)



MAP 4: SELECTED SAMPLE SITES ACROSS TROOPERS HILL (GOOGLE MAPS, 2024)

Site 1 is located to the south of Troopers Hill, adjacent to the second chimney and part of Compartment 9. Ploughman's Spikenard (*Inula Conyzae*) was identified as a plant species growing in this area. This is a species which typically thrives in alkaline soil conditions, so to observe it growing in this location is unexpected due to the generally acidic soil of the Troopers Hill site. Furthermore, there is a limestone path directly adjacent to it. Soil pH readings at this site have taken place since the installation of this path, therefore investigation into the path's potential impact on surrounding soils is required.

Site 2 is in Compartment 1, which is an area managed differently to the rest of Trooper's Hill with no broom or heather. The management plan includes an annual grass cut, where the cuttings are removed to maintain poor soil quality and promote wildflower growth for pollinators. Similar to Site 1, there is a limestone path beside it, thus it experiences high footfall and lots of dog-walkers. Another area of interest is the source of the soil at this location and whether it was formed through dumping from another site.

Site 3 is found in Compartment 2 and is suspected to be a mound formed via dumping of soil. 'Friends of Troopers Hill' were unsure if the soil was local or originated from neighbouring areas of Bristol. An investigation was required to compare the soil properties of all the sites. In addition, Site 3 has allegedly been a location where bonfires have taken place in the past, therefore tests are required to provide evidence for or against this.

Site 4 is an area of thick heather and broom in the gently sloping Compartment 7, which experiences very little footfall. The site is expected to have an acidic soil due to the typical heathland plant species observed growing here. A study into the extent of this acidity is warranted.

Similarly, Site 5 is another area of heathland, located in Compartment 12, which is expected to have acidic soil. This site lies on a slope above an eroded area of exposed rock and coal spoils. This area of Troopers Hill has not changed significantly since the 1950s, other than minor seasonal changes. An investigation into the extent of acidity and the possible influence exposed coal may have had on the soil is needed.

Finally, Site 6 is a South facing mound located in Compartment 2 to the east of the upper chimney. The mound hosts a mass of ribwort plants not typical of the surrounding area thus requires a study into their growth. It also suffers frequent footfall due to being used as a viewing point, with the presence of dog-walkers, which may be a contributory factor to its soil characteristics.

3.2. Field Methods

3.2.1. Sampling Strategy

A 50x50cm quadrat was blindly thrown at each site, and selective sampling was used within the quadrat to choose where to take the measurements. All four corners were sampled, as well as the middle of each quadrat, to get as unbiased a representation of the site as possible.

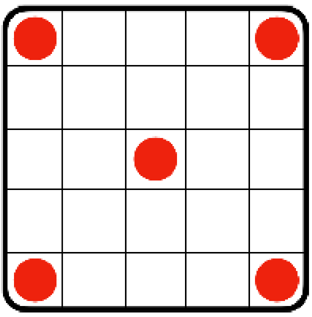


FIGURE 1: REPRESENTATION OF THE QUADRAT USED DURING THE SAMPLING (RED DOTS INDICATE SPECIFIC SQUARES WHICH WERE USED FOR SAMPLING)

3.2.2. Soil Moisture

Soil moisture was measured in situ using soil moisture theta probes to get an indication of how much soil would need to be dried for the rest of the analyses. The theta probes were calibrated in the lab beforehand.

3.2.3. Soil Cores

At each site, five 10cm soil cores were taken. Before taking the cores, a trowel was used to remove the top 1cm of grass and soil to prevent grass root contamination. The corer was then placed into the ground and twisted to remove the soil sample. A ruler was used to mark at 10cm to ensure sufficient material was collected for lab analysis. A palette knife was then used to scrape the soil sample into labelled plastic bags. The trowel was again used to cover the hole created. Gloves were worn to prevent soil contamination. The soil samples were stored in a cool box to be transported back to the lab and were subsequently transferred to the fridge until laboratory analysis was undertaken.

3.2.4. Site Limitations

On the day of sample collection, the temperature was -2°C and the soil was frosted, meaning soil core collection was difficult up to the full 10cm. This was particularly evident at Site 1 which was relatively shaded. Rocks beneath the soil exacerbated this, so additional dirt was collected from topsoil at the sites where coring to the full 10cm was not possible. This was not considered as a particularly large error because depth has little interaction with the soil characteristics measured.

At Site 4, a nest of ants was uncovered during the sample collection. As to avoid any effects this would have on the soil characteristics, and to avoid disruption of the habitat, the quadrat was rethrown and the samples retaken.

Additionally, despite randomly placing the quadrat at each site, there may have been a degree of bias involved. Generally, the quadrat was thrown from areas of interest, such as where there was presence of Ribwort. The quadrat was never thrown far to ensure safe practice, meaning areas of interest may have been sampled more frequently than would generally occur with a random sampling technique.

3.3. Laboratory Methodology

3.3.1. Moisture

To get a measure of moisture content once the samples were brought back to the lab, roughly 50g of each sample was weighed out into boats and dried at 50°C for 24 hours and reweighed. The final weight was taken once the weight was determined as constant by reweighing 2 hours apart. The moisture content was calculated as the loss in mass as a percentage.

3.3.2. pH

10 mL of a 0.01M calcium chloride solution was added to centrifuge tubes containing 10g of each dried soil sample. After mixing well and leaving the mixtures to sit for an hour, pH was taken with a calibrated pH metre making sure to use the same one for all measurements as a control (Miller & Kissel, 2010).

3.3.3. Loss on Ignition (LOI)

The dried soil samples were ground and sieved through 2mm sieves. 10g of each soil sample was weighed out into ceramic crucibles, recording sample number and precise weight. The samples were then burned in a muffle furnace for 5 hours at 550°C, and once cooled, they were reweighed. The change in weight is the loss of organic carbon by ignition, and this is expressed as a percentage (%LOI). To achieve even burning of samples, the crucibles were spread out between two muffle furnaces and with room between each one for maximum heat flow through the cavity (Ball, 1964; Hoogsteen et al., 2015).

3.3.4. Carbonates

Carbonates in the soils were measured through quantification of the gas collected when 2g of dried, ground, and sieved soil was reacted with 1.5mL of 2.0M hydrochloric acid (HCL). Ferrous chloride ($FeCl_3$) was added to the acid to prevent a reaction between the HCL and any sulphates, so that the gas collected should only be from carbonates. The soil was weighed into a serum vial, and an auto-sampler vial containing the acid placed in, ensuring to keep it upright to avoid premature mixing. A septa was placed on top of the vial and punctured to equilibrate the pressure to that of the lab. A metal crimper was then placed on top of the septa to seal the vial. Once sealed, the contents of the vial could be thoroughly mixed, and then the pressure of the vial measured with a manometer. The reading on the meter was the relative pressure between the lab and the vial. Three controls were done with just 0.1g calcium carbonate ($CaCO_3$) weighed into the vial in place of the soil.

3.3.5. Nutrients

The nutrients measured were ammonia (NH_4-N), total oxidisable nitrogen (TON), phosphates (PO_4-P) and dissolved organic carbon (DOC). The method involved dissolving 5g of each soil sample in 25mL 2.0M potassium chloride (KCL) in centrifuge tubes, and then shaken well. Once shaken the samples were centrifuged for 5 minutes at 2600 rpm, and the supernatant collected. The supernatants were then filtered through a 0.45 filter and analysed in the auto-analyser, along with three controls of just the KCL solution with no sample (Maynard et al., 2008).

4. Results

4.1. Soil pH

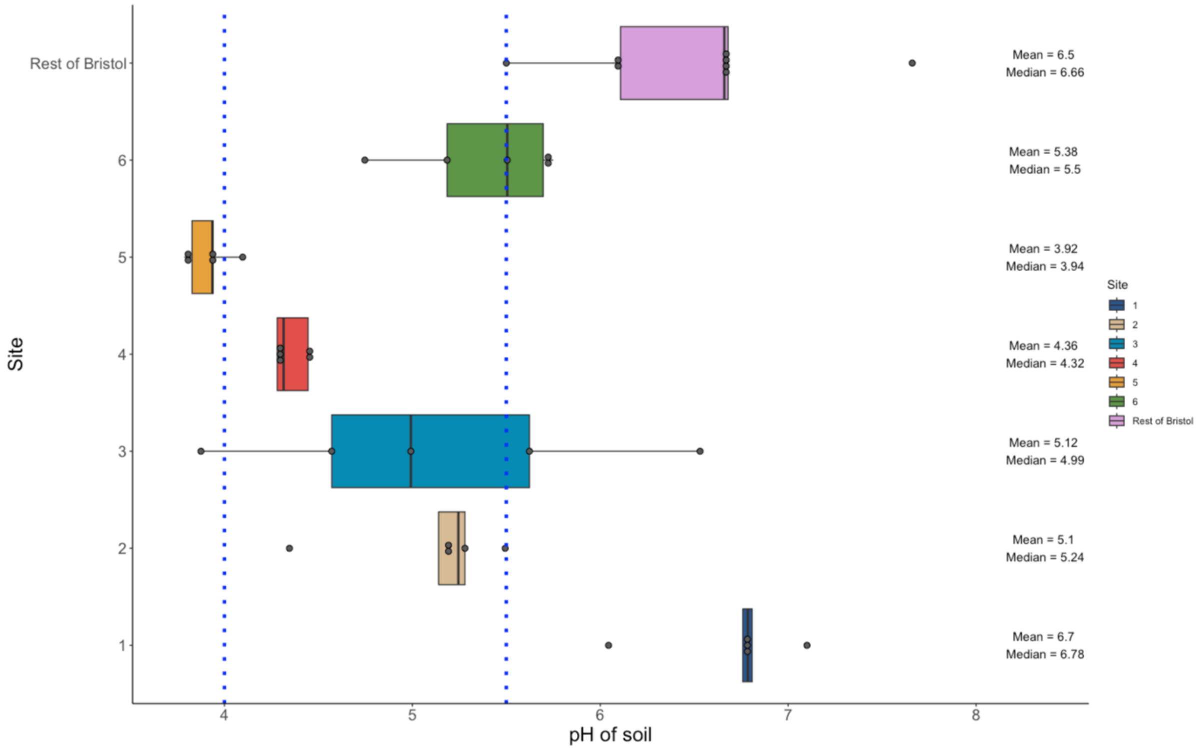


Figure 2: *A comparison of soil pH between sites on Troopers Hill, and soil pH data for other areas around Bristol. Secondary data incorporates soil pH readings for areas within and around the Bristol city centre including Clifton and Stokes Park. (Blue dotted lines indicate the average pH range for a heathland environment). (Centre for Ecology and Hydrology, 2007) and (Maddock, 2008).*

Secondary soil pH data were used to create a seventh boxplot, highlighting how Troopers Hill soil appears to be particularly more acidic than other surrounding areas of Bristol. The average pH range for a heathland environment indicated in **Figure 2,** demonstrates that parts of the Troopers Hill site can be defined as heathland environments.

Soil at Site 1 is more alkaline than the rest of the Troopers Hill data. Average soil pH for Bristol is 6.5, compared to a mean pH of 5.1 for soil on Troopers Hill, with a t-test demonstrating a significant difference between these means. A t-test was also found that the mean pH values of Site 1 and the Bristol data were statistically similar as the p value was above the significance level of 0.05. A Tukey test revealed there were significant differences between the mean pH values of Site 1 and the five other sites. The greatest difference was between Site 1 and Site 5, whereas Site 3 and Site 2 were the most statistically similar.

4.2. Influence of CO_3

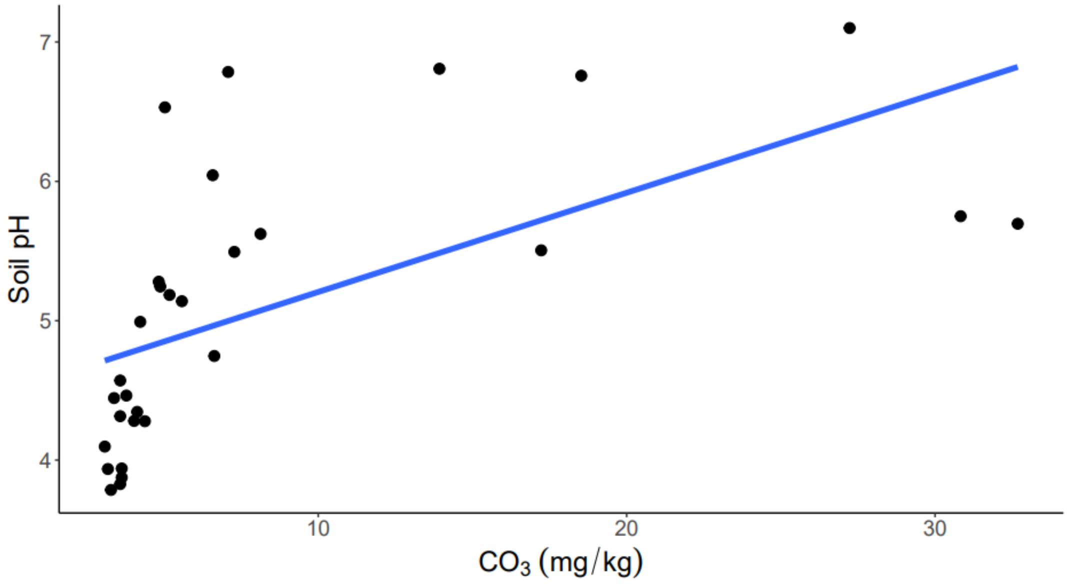


FIGURE 3: A LINEAR REGRESSION PLOT TO DEMONSTRATE THE RELATIONSHIP BETWEEN CO_3 (MG/KG) AND SOIL PH.

The p-value for this linear model is less than 0.05, illustrating that the relationship between CO_3 and pH is statistically significant. Despite this, a relatively low multiple R^2 value suggests that approximately only 33% of the variance in soil pH can be explained by the levels of CO_3. Notwithstanding this, it can be suggested that with more data points, a relationship with a higher R^2 value would likely present itself. This relationship also exhibits homoscedasticity, proven by the Breusch Pagan test.

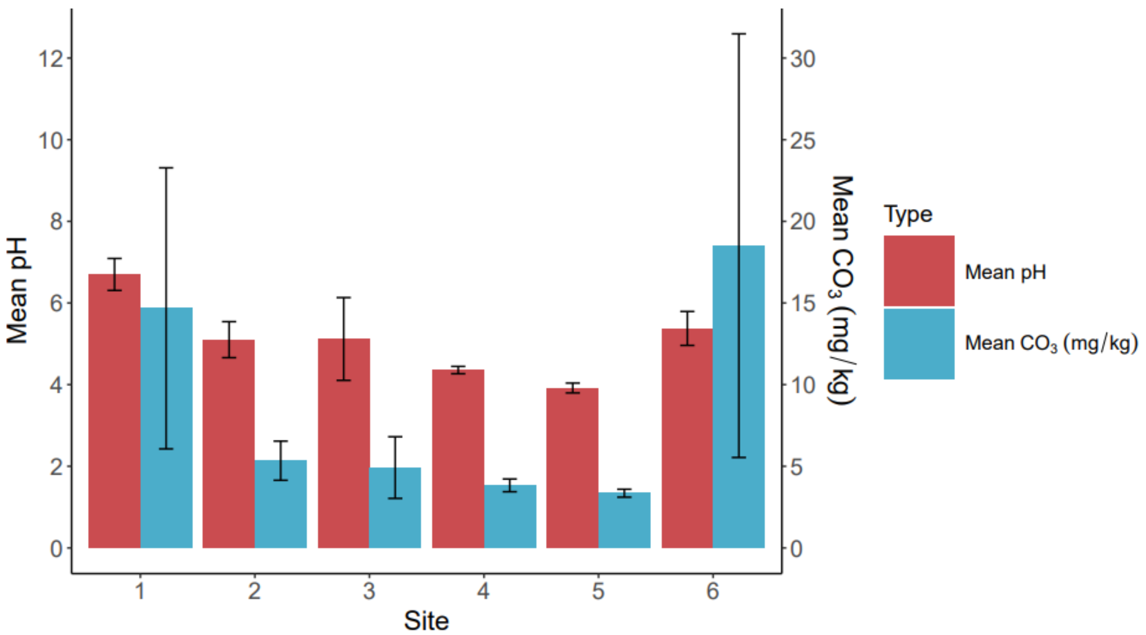


FIGURE 4: A COMPARISON BETWEEN MEAN SOIL PH AND CO_3 LEVELS FOR EACH SITE SAMPLED ACROSS TROOPERS HILL. (VERTICAL BLACK BARS REPRESENT STANDARD DEVIATION).

Figure 4 demonstrates little observable correlation between pH and CO_3. However, site 1 and site 6 have the highest pH values and the highest CO_3 concentrations. The standard deviation is also highest at Sites 1 and 6, overlapping with the standard deviation bars for the other sites, suggesting that the larger CO_3 concentrations shown by **Figure 4** are potentially due to error.

4.3. Soil Moisture

TABLE 1: AVERAGE SOIL MOISTURE MEASURED IN-SITU, COMPARED WITH AVERAGE SOIL MOISTURE MEASURED IN THE LAB, FOR EACH SAMPLE SITE

Site	Mean in situ soil moisture (%)	Mean soil moisture measured in lab (%)
1	31.64	29.53
2	45.62	28.39
3	28.4	22.64
4	32.1	26.67
5	40.46	41.51
6	33.98	17.23

In situ soil moisture varied greatly across the hill and within sites. The mean in situ soil moisture across the sites was 35.4 and the range was 32.7, with the largest variation occurring at site 1 and 3. Sites 6 and 4 have the mean values closest to the mean of all the data. The field moisture data was normally distributed, and an ANOVA test identified significant differences in means between at least 2 of the groups. A Tukey test identified the largest differences in means were between Site 2 and Sites 1,3 and 4. Additionally, moisture was also measured in the lab. Both moisture results were normally distributed, allowing a t-test to be performed. The t-test returned a p-value with a value lower than the significance level of 0.05, meaning that there was a significant difference between the mean values of the data measured in the field and that which was measured in the lab.

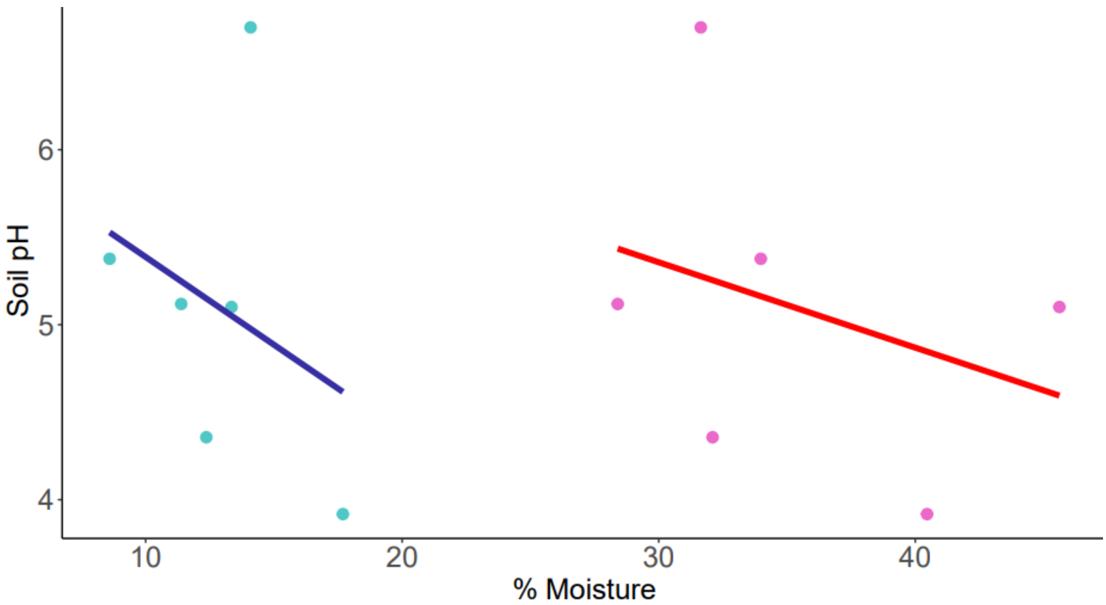


FIGURE 5: A LINEAR REGRESSION PLOT SHOWING MEAN IN SITU MOISTURE (RED) AND LAB MOISTURE (BLUE), AGAINST MEAN SOIL PH ACROSS THE SITES

Figure 5 demonstrates that, with both the field and lab moisture measurements, there is a negative correlation between soil moisture content and soil pH. However, the significant differences between means, shown by the t-test, are also evident in this figure. The R^2 value is 0.116 for in situ moisture and 0.125 for lab moisture, illustrating very weak correlations for both regression lines. Additionally, the p-value is above the significance value for both measurements, indicating that there is no significant correlation between the variables.

4.4. Loss on Ignition

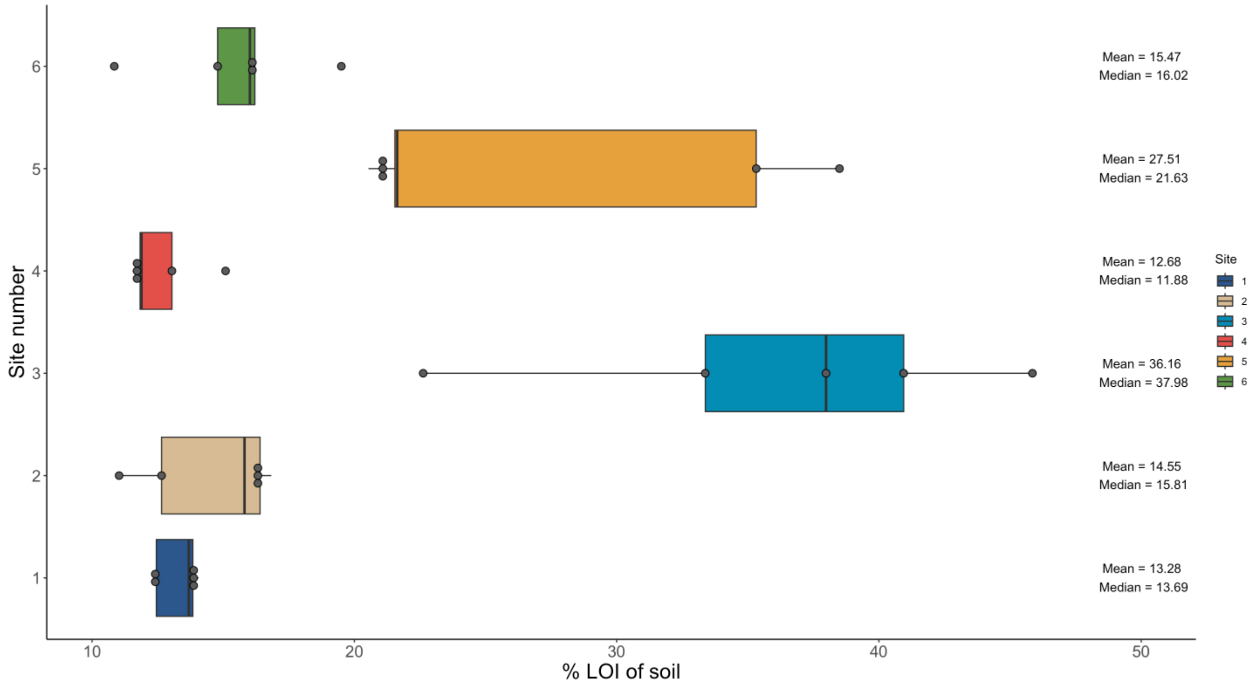


Figure 6: *A comparison between sites visualising the percentage loss of organic matter from the soil after ignition.*

Figure 6 shows a large variation in percentage loss on ignition across the Sites. Site 3 has the highest mean at 36.16% and site 4 has the lowest at 12.68%. Generally, the means demonstrated by **Figure 6** look quite similar for Sites 1, 2, 4 and 6. The data are not normally distributed, but a Kruskal Wallis test identified that there is a significant difference between the means of at least 2 of the sites.

4.5. Nutrients

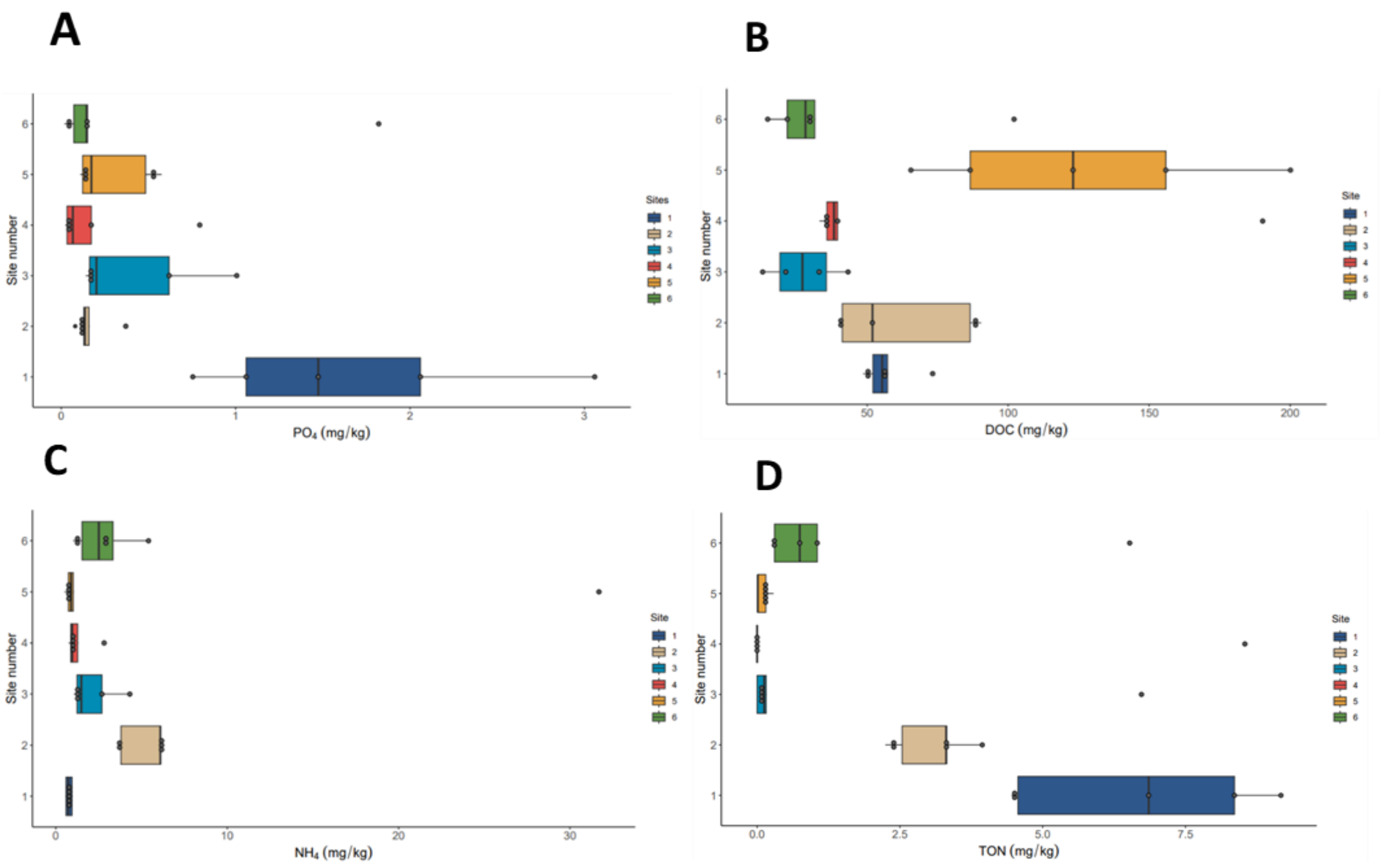


Figure 7: Boxplots comparing nutrient levels within soil samples from sites across Troopers Hill (A: Phosphate (PO_4), B: Dissolved Organic Carbon (DOC), C: Nitrate (NO_3), D: Total Oxidisable Nitrogen (TON)).

Figure 7A demonstrates that for most of the sites, PO_4 concentrations remain reasonably similar. The exception to this is group 1, where the largest range is also present. The mean of group 1 is also 2.8 times larger than the means of the rest of the sites. When ANOVA was applied to logged phosphate data, significant differences between at least two means were identified. The more significant differences were between Site 1 and the rest of the sites. The biggest of these differences was between Site 1 and Site 4. The exception to this is that Site 1 and Site 3 have statistically similar mean PO_4 concentrations.

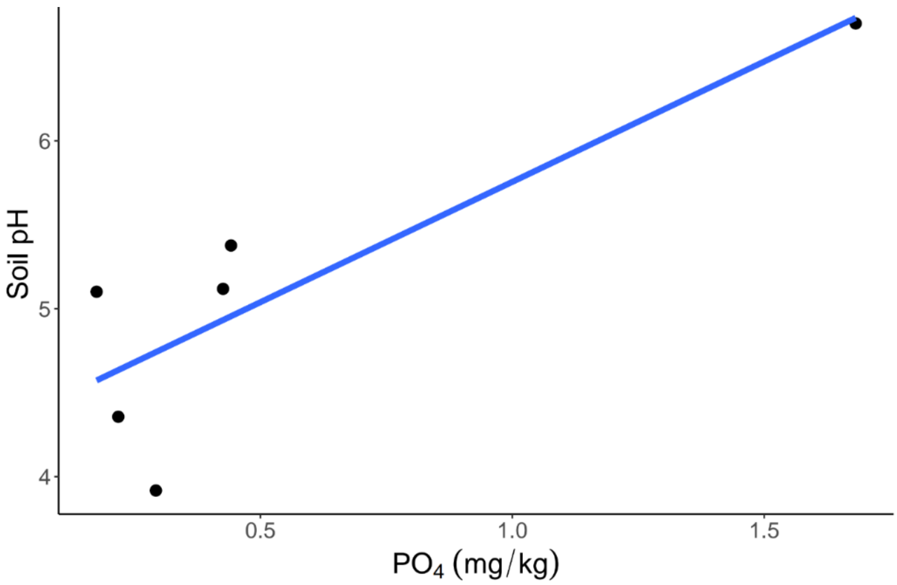


FIGURE 8: A LINEAR REGRESSION PLOT SHOWING THE MEAN PO4 CONCENTRATIONS PLOTTED AGAINST THE MEAN SOIL PH AT EACH SITE.

Figure 8 shows that most of the mean PO_4 concentrations were below 0.5 g/g, and most of the mean pH values were below 6. Site 1 is also identified as an outlier in **Figure 8**. Overall, **Figure 8** highlights that as PO_4 increases, so does pH. This is confirmed by an adjusted r squared value of 0.6596, indicating a moderate correlation between the 2 variables. Additionally, this correlation is statistically significant due to the p value being lower than the alpha value. Consequently, the null hypothesis stating that there is no significant correlation between the 2 variables must be rejected.

Figure 7B identified that most of the sites have similar concentrations of DOC. However, site 5 has the highest mean concentration of DOC at 122 mg/kg, compared to the overall mean of 64.57 mg/kg. The ANOVA/Tukey test result confirmed that Site 5 had a statistically different mean value compared to Sites 3 and 6. However, the rest of the sites had statistically similar means.

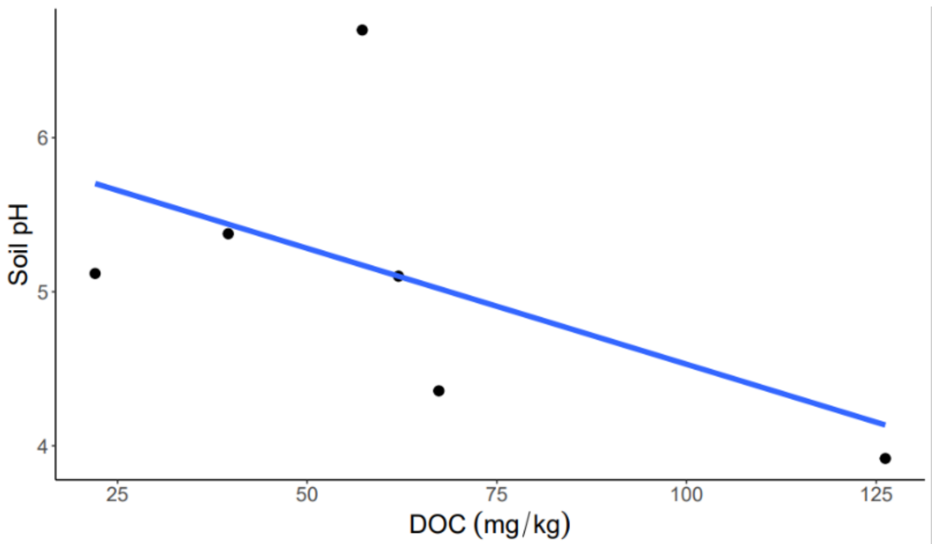


FIGURE 9: A REGRESSION PLOT TO DEMONSTRATE THE CORRELATION BETWEEN MEAN DOC AND SOIL PH AT EACH SITE.

Figure 9 shows a negative correlation between DOC concentration and soil pH. The adjusted R^2 value for this regression plot is 0.1375, showing that the correlation is extremely weak. This correlation is also not significant as the p value is above the significance value of 0.05. It can be inferred there is no significant correlation between DOC and pH across Trooper's Hill and the null hypothesis must be accepted.

Additionally, **Figure 7C** shows that NH_4 concentrations across the site are relatively consistent. The mean across all the sites is 3.19 mg/kg, however the median value is lower at 1.26 mg/kg, 2.5 times lower than the mean value. This may be due to the large outlier in Site 5. These data are not normally distributed, so when a Kruskal Wallis test was applied it showed that there was significant differences between the means of at least 2 of the groups.

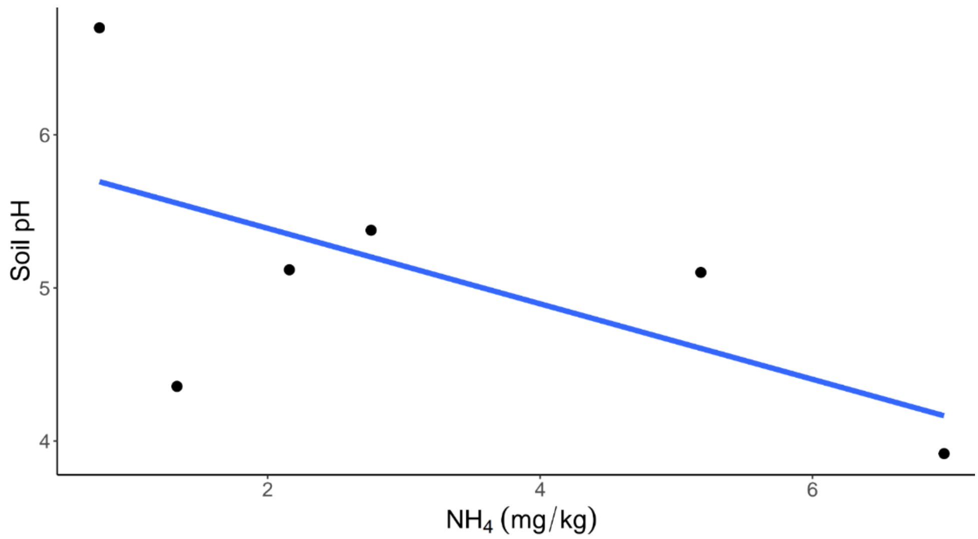


FIGURE 10: A REGRESSION PLOT TO DEMONSTRATE THE CORRELATION BETWEEN NH4 AND SOIL PH AT EACH SITE.

Figure 10 shows a weak negative correlation between nitrate concentration and soil pH. The adjusted R^2 value for this regression is 0.227, indicating a very weak correlation. Additionally, the p value is above the significance value of 0.05, meaning that there is no statistically significant correlation between the variables.

Figure 7D also identifies site 1 as an outlier compared to other sites regarding TON concentration, with a mean of 6.55 mg/kg, compared to the overall mean of 2.46 mg/kg. Additionally, sites 6, 4 and 3 are shown to have large outliers compared to the IQR of the rest of the measurements. Site 2 is also shown to have a larger median (2.54 mg/kg) than the average (0.526 mg/kg). The TON data could not be made normally distributed by a log function, therefore a Kruskal Wallis test was applied. This presented a p value smaller than the significance level of 0.05 meaning that there is a statistically significant difference in means between at least 2 of the sites.

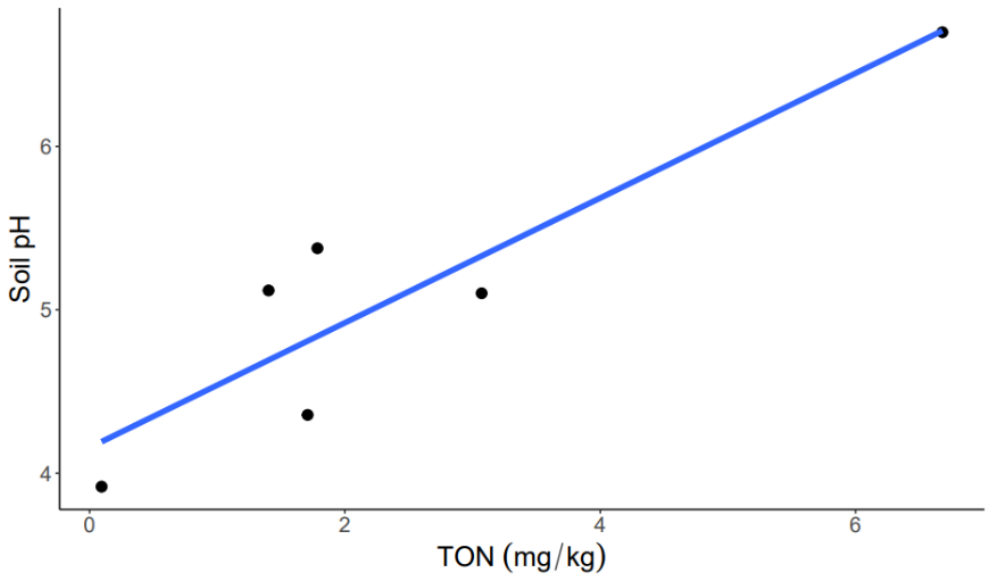


FIGURE 11: A REGRESSION PLOT TO DEMONSTRATE THE CORRELATION BETWEEN MEAN TON CONCENTRATION AND

Figure 11 shows a positive correlation between TON and soil pH across Trooper's Hill. This relationship produced an R^2 value of 0.78, demonstrating a moderate correlation between the 2 variables. This correlation is also significant due to the p-value being lower than the significance value, meaning that the null hypothesis of no correlation between the 2 variables must be rejected. The highest value of TON and pH can be identified as Group 1, remaining the most different in terms of characteristics to the other sites.

5. Discussion

5.1. What factors are influencing soil pH variations across selected sites at Troopers Hill?

Across Troopers Hill, Site 1 has the most significant difference in pH compared to the other sites, as shown in **Figure 2**. This may be due to Site 1 being in a woodland environment, compared to the other sites being characterised by a heathland environment. Additionally, pH similarity between Site 1 and the Bristol data may be due to Bristol pH measurements being taken at sites with characteristics more like those observed at Site 1 than the rest of the Troopers Hill sites.

pH in the soil at Troopers Hill varies; to characterise the soil and identify potential factors influencing pH, different factors were measured at each sample site. Soil nutrient data were collected and no significant correlations between DOC and soil pH, and NH_4 and soil pH could be found. However, statistically significant relationships between soil pH and PO_4 and TON were found (**Figures 7, 8, 9, 10 and 11**). The significant correlation observed in **Figure 8** suggests that soil PO_4 levels are influencing soil pH levels across the sample sites. Soil pH isn't typically impacted by levels of PO_4, but it can be influenced by phosphate fertilisers, (Saunders, 1958) However, according to 'Friends of Troopers Hill' fertilisers have never been used on any parts of the site. Phosphorus does affect nitrification (Deforest and Otuya, 2020) and therefore nitrate levels of soil. Nitrogen in soil causes acidification if leached (Ste-Marie and Paré, 1999) which means soil pH is influenced by TON. This matches the relationship illustrated in **Figure 11**. This means that PO_4 levels on Troopers hill indirectly influence soil pH. In addition, **Figure 5** illustrates how soil moisture has no impact on soil pH, therefore soil moisture can also be discounted.

5.1.1. Variations in pH at Site 1

Figure 2 shows how soil pH varies between the chosen sample sites across Troopers Hill; a Tukey test revealed that soil pH at Site 1 was significantly different to the soil pH for the rest of the sites. The soil pH at this site was less acidic than the other sites, which explains the observed presence of Ploughman's Spikenard, a plant which requires higher pH soil conditions for growth. The brief provided by 'Friends of Troopers Hill' discussed a recently installed limestone path located adjacent to Site 1. Limestone is primarily composed of $CaCO_3$, a basic compound known to have alkaline properties (Wang *et al.*, 2015). **Figure 3** illustrates a statistically significant relationship between levels of CO_3 and soil pH. Higher levels of CO_3 in the soil at Site 1 suggest the limestone path is releasing $CaCO_3$ into the soil and increasing the soil pH. It can be argued that the presence of the limestone path is likely influencing the levels of CO_3, and therefore the pH, in the soil for this area of Troopers Hill.

Despite this, there is no secondary data to corroborate this argument. No soil pH readings took place at this location before the addition of the limestone path. Without historical soil pH readings taken prior to the path's construction, it is difficult to understand the path's true influence on the carbonate and pH levels of the soil. It is important to acknowledge that there are several other factors which could influence the levels of CO_3 at Site 1, for example, the underlying bedrock. Despite this, it can still be argued that the presence of the adjacent limestone path is likely creating a significantly more alkaline soil environment, when compared to the rest of the sites sampled across Troopers Hill.

5.1.2. Variations in pH at Site 2

It is important to note that Site 2 is also located close to another limestone path on Troopers Hill, but higher pH values were not recorded. **Figure 2** shows that the pH values sit within the heathland pH range, but this site is one of the few parts of Troopers Hill which cannot be classified as a heathland environment. Despite this, the physical sample location for the quadrat was located further from the path than the proximity of the quadrat to the path at Site 1. There are several elements here which require further analysis to understand the factors and processes influencing the soil pH at Site 2.

5.1.3. Variations in pH at Site 5

The data showed that soil samples at Site 5 were the most acidic. In fact, the soil here falls below the expected pH range for a heathland environment. It can be argued there is likely an additional factor influencing soil pH in this area; exposed coal spoils were observed at this site. To corroborate this, high levels of DOC recorded at Site 5 strongly suggest the presence of coal (**Figure 7**). As the coal is exposed at the surface, it is likely that the spoils are oxidising. It is known that when coal oxidises it forms sulfuric acid (Aguilar *et al.*, 2004). As a result, it can be suggested the presence of exposed coal spoils at this site is generating an acidic soil environment, through the process of oxidation and the production of sulfuric acid. Further research is required to understand the specific types of coal which may reside within the soils of Troopers Hill, for example by analysing the soil sulphur content. It is important to confirm that the presence of the exposed coal is indeed influencing the pH of the soil in this area.

5.1.4. Variations in pH at Site 6

Along with Site 1, Site 6 was found to be slightly less acidic than the other sites. Site 6 was not statistically significantly less acidic, but the mean soil pH at this site is higher. Primary data collected during this broad investigation have raised several theories for this pH shift, but more research is required at this site to determine a precise cause for this apparent increase in pH. **Figure 4** shows a clear presence of alkaline compound CO_3 at Site 6, in addition to clearly raised pH levels, suggesting that this is likely a factor raising pH levels in the soil. **Table 1**, showing soil moisture data from the lab, suggests that soil at Site 6 is drier and well-drained. The site itself is also located on a high point of Troopers Hill, adjacent to a steep sided cliff. This explains the observed presence of the Ribwort plant which thrives in well-drained, less acidic soil, corroborating the CO_3 data. Detailed future research must determine a precise explanation for the raised levels of CO_3 at this site.

Site 6 is an area with high foot-traffic. It could be theorised that limestone particulates, originating from multiple limestone paths present on the hill (**Map 2**), embed themselves into the shoes of pedestrians, encouraging a build-up of limestone within the surface soil, over time, altering the pH of the soil in the area. To corroborate this theory, future investigations must test adjacent areas of the hill for carbonates. Alternatively, the abnormally higher CO_3 could suggest that the soil here has been moved from another location. However, this cannot be confirmed without further investigation.

5.1.5. Variations in pH at other sites

For the other sites sampled, no factors could be attributed to the variations in pH. Sites 3 and 4 had pH values typical for heathland environments. A question was specifically posed, asking if Site 4 is more acidic than expected, however this was not suggested in our results.

5.2. How do other soil characteristics vary between those sites?

As well as attempting to measure potential factors influencing soil pH, the investigation also set out to create a general characterisation of Troopers Hill soils.

Within the brief, 'Friends of Troopers Hill' specified Site 3 as an area of special interest. The project partners suggested that this could have been an area where bonfires occurred in the past. Bonfires can impact soil pH in numerous ways, particularly impacting nutrient, and organic matter content in the soil (DeBano, 1991). **Figure 6** shows high organic matter levels in the soil at Site 3. Despite this, nutrient levels at Site 3 do remain relatively low, but they do not greatly differ to the rest of the sites. As a result, there is no evidence to suggest that bonfires have ever taken place at this site. Precise timeframes are difficult to determine with the primary data collected. Future investigations must take deeper soil cores to build an accurate profile of the soil characteristics here.

Figure 7 illustrates Site 2 as having relatively raised NH_4 and TON levels. This is an area of cut grass and high footfall, located close to one of the nature reserve entrances. It is likely that these results can be attributed to the presence of dog urine and faeces in the soil.

Within the project brief, the project partners were curious to understand if soil had potentially been moved from other parts of Troopers Hill or external sites. To accurately answer questions like this would likely require a large-scale project involving potential excavation and taking large amounts of deep soil cores from across Troopers Hill and the surrounding areas. Therefore, due to the small scale of this investigation and our limitations, we would unlikely be able to conclude on this. Despite this, the fact that there are not huge amounts of variation between most of the sites could suggest that the soil from the sampled sites does not originate from other locations. Notwithstanding this, it was suggested that raised levels of CO_3 at Site 6 could potentially be explained by this.

6. Limitations:

Although this study has postulated many conclusions surrounding the variation of soil pH on Troopers Hill and why variation occurs, these findings are inevitably limited by the amount of data collected, resources available, methods chosen and more. Unpacking these limitations allows the results explored within this study to be put into context.

The most considerable limitation was the amount of data points recorded during fieldwork due to time constraints and chosen methods. Using a selective sampling strategy was limiting as not all areas of the hill were examined equally, possibly skewing knowledge of the hill's soil variation. For instance, the low soil moisture anomaly at Site 6 suggests increasing moisture downslope and therefore nutrients and other soil features being washed down the hill as a result. However, data would need to be recorded along a downwards transect to confirm whether soil is being affected.

Similarly, sparse data points also limit the understanding of why high pH anomalies occurred at Site 1 and Site 6. This study proposed an explanation for this being high footfall transferring limestone particles from the nearby footpath and increasing $CaCO_3$ levels. Nonetheless, without data points mapping out the variation of $CaCO_3$ levels between these points of interest, it can't be said for certain whether this is the case. Additionally, a lack of secondary data on $CaCO_3$ levels prior to the installation of the path is another factor limiting these conclusions.

The site conditions also restricted findings as frosted soil as well as rocks underlying a very shallow level of soil at certain locations prevented the soil corer from reaching 10cm at all sites. Taking samples in warmer conditions or collecting shallower samples at each site may have increased consistency, possibly improving the accuracy of findings.

Additionally using a theta probe was found to not be the most accurate measure of soil moisture because results varied greatly from site to site, as well as being inconsistent with lab measurements of soil moisture. However, as a negative correlation was found between soil moisture and pH, this was not a factor of high relevance. Statistical tests on other variables such as DOC and NH_4 also lacked any correlation with pH. Therefore, this again points to the limitation of sample size as having more data points may have resulted in more variables displaying a correlation with pH.

7. Future Study Recommendations

Exploring the limitations of this study has informed numerous new areas for investigation. Altering data collection methods and focusing further into specific areas of study could create a more precise understanding of Troopers Hill soil properties.

Increasing data points would be a huge area of focus for future studies recording data along multiple transects down the hill. Similarly, due to the shallow depth of soil found during fieldwork, exploring the depth of soil above the underlying pennant sandstone in relation to locations of coal spoils, areas of annual scrub clearing, and areas of acidity could aid understanding of where soil maintenance is necessary.

Due to this study's findings that the exposed coal spoils at Site 5 are likely to be affecting soil acidity, this component would be of particular interest. Carrying out data collection on soil sulphur content as well as the types of coal residing on Troopers Hill could help substantiate these conclusions.

In addition, mapping out the variation of CaCO3 levels between Site 1, Site 6, and the limestone footpath by conducting increased data collection in this region, would be valuable for understanding whether the implementation of man-made elements, such as this footpath, can significantly alter soil qualities.

8. Conclusion

This investigation attempted to create a general characterisation of the soil on Troopers Hill, with a focus on variations in soil pH and possible factors which were influencing those variations. The results showed that soil on Troopers Hill was acidic, corroborated by secondary data collected in the past. Two sample sites were found to be less acidic than the others. It was suggested that at one of these sites, the presence of a limestone path was raising carbonate levels in the soil generating alkaline soil conditions. In another area on top of the hill, carbonate levels in the soil were also found to be raised, likely influencing soil pH, but the investigation failed to determine precise reasons for this, perhaps an area of interest for future studies. Another sample site with exposed coal spoils showed lower pH than other sites. It was suggested that the coal was oxidising and creating a more acidic soil environment, however, future investigations must determine if there is a direct correlation between the coal presence and low pH. In addition to this the project partners suggested one of the sites could have been the location of bonfires. Results suggested that no bonfires had ever taken place at this site, however precise timeframes were difficult to determine and deeper soil cores at this location are required to investigate this further.

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10. Appendix

Table 2: In situ moisture probe

Site/Sample Number	Moisture (%)
G13S1R1	36.6
G13S1R2	22.8
G13S1R3	22.2
G13S1R4	38.7
G13S1R5	37.9
G13S2R1	44.6
G13S2R2	39.8
G13S2R3	46.6
G13S2R4	44.6
G13S2R5	52.5
G13S3R1	38.6
G13S3R2	22.4
G13S3R3	19.8
G13S3R4	35.3
G13S3R5	25.9
G13S4R1	25.8
G13S4R2	30.1
G13S4R3	41.4
G13S4R4	33.6
G13S4R5	29.6
G13S5R1	39.7
G13S5R2	43.6
G13S5R3	45.6
G13S5R4	30.1
G13S5R5	43.3
G13S6R1	26.7
G13S6R2	31.9
G13S6R3	33.5
G13S6R4	42
G13S6R5	35.8

Table 3: Lab moisture content

Site/Sample Number	Weight of boat (g)	Wet weight (g, not including boat)	Dry weight (g, including boat)	Dry weight (g, not including boat)	% weight loss
G13S1R1	1.0965	49.4785	35.2173	34.1208	31.03913821
G13S1R2	1.0982	45.9372	32.8223	31.7241	30.94028369
G13S1R3	1.0899	41.3862	31.6171	30.5272	26.23821467
G13S1R4	1.1015	52.7851	39.8775	38.776	26.53987584
G13S1R5	1.1025	48.6508	33.7389	32.6364	32.91703322
G13S2R1	1.0863	50.1956	34.9897	33.9034	32.45742655
G13S2R2	1.0868	42.9734	30.9552	29.8684	30.49560891
G13S2R3	1.1115	48.0501	36.4559	35.3444	26.44260886
G13S2R4	1.0952	45.6291	33.2918	32.1966	29.43845046
G13S2R5	1.0861	48.4707	38.3594	37.2733	23.10137877
G13S3R1	1.0886	49.7015	37.0215	35.9329	27.70258443
G13S3R2	1.0899	50.4503	42.9631	41.8732	17.0010882
G13S3R3	1.0887	50.3935	38.6449	37.5562	25.47411869
G13S3R4	1.1065	50.5351	41.4453	40.3388	20.17666929
G13S3R5	1.1034	50.5015	40.0599	38.9565	22.86070711
G13S4R1	1.0839	45.2197	36.1569	35.073	22.43867164
G13S4R2	1.0915	45.4761	34.5491	33.4576	26.42816776
G13S4R3	1.0858	46.4753	35.2596	34.1738	26.46889853
G13S4R4	1.0792	48.2767	35.7487	34.6695	28.18585363
G13S4R5	1.0948	46.0859	33.4325	32.3377	29.83168388
G13S5R1	1.0327	43.9588	24.191	23.1583	47.31817065
G13S5R2	1.0268	44.2955	30.7392	29.7124	32.92230588
G13S5R3	1.0021	45.1701	31.8041	30.802	31.80887357
G13S5R4	1.0173	40.5272	21.5735	20.5562	49.27801575
G13S5R5	1.0118	40.4956	22.7871	21.7753	46.22798526
G13S6R1	1.0183	47.8883	38.5977	37.5794	21.52697005
G13S6R2	1.009	51.2099	41.5083	40.4993	20.9150965
G13S6R3	1.0179	50.8291	42.5684	41.5505	18.25450382
G13S6R4	1.0133	51.019	44.4711	43.4578	14.82036104
G13S6R5	1.0107	48.2704	44.1579	43.1472	10.6135437

Table 4: pH

Site/Sample Number	Weight of tube (g)	Weight of soil (g)	pH
G13S1R1	13.2396	10.1749	6.044
G13S1R2	13.2314	10.0694	6.808
G13S1R3	13.2161	10.4623	7.1
G13S1R4	13.8041	10.1266	6.758
G13S1R5	13.0399	10.0989	6.785
G13S2R1	13.7395	10.0553	5.245
G13S2R2	13.2015	10.1465	5.14
G13S2R3	13.1837	10.1125	5.28
G13S2R4	13.0807	10.1497	5.494
G13S2R5	13.2144	10.0835	4.346
G13S3R1	13.19	10.1006	4.992
G13S3R2	12.9803	9.9825	3.875
G13S3R3	13.0773	9.9495	6.531
G13S3R4	13.0913	10.0049	5.623
G13S3R5	13.0178	10.1517	4.571
G13S4R1	13.2124	10.0566	4.463
G13S4R2	13.2391	10.0269	4.315
G13S4R3	13.2512	10.0151	4.279
G13S4R4	13.7317	10.4236	4.445
G13S4R5	13.7409	10.2454	4.281
G13S5R1	13.7464	10.023	3.828
G13S5R2	13.7699	9.975	3.94
G13S5R3	13.6895	9.97	3.786
G13S5R4	13.7326	10.0802	3.936
G13S5R5	13.6689	10.0047	4.097
G13S6R1	13.5174	10.0633	4.747
G13S6R2	13.7103	10.0641	5.505
G13S6R3	13.7162	9.9743	5.185
G13S6R4	13.7946	10.069	5.75
G13S6R5	13.4629	10.0699	5.696

Table 5: Loss on ignition

Site/Sample Number	Crucible number	crucible weight (g)	Start weight (not including crucible)	end weight (including crucible)	End weight (not including crucible)	LOI (g)	% LOI
G13S1R1	85	29.2601	10.0291	37.901	8.6409	1.3882	13.84172
G13S1R2	96	25.9488	10.0542	34.6267	8.6779	1.3763	13.68881
G13S1R3	47	26.7959	10.0758	35.6173	8.8214	1.2544	12.44963
G13S1R4	12	28.0395	10.0361	36.8341	8.7946	1.2415	12.37034
G13S1R5	73	29.6899	10.0267	38.307	8.6171	1.4096	14.05846
G13S2R1	15	26.9112	10.0772	35.292	8.3808	1.6964	16.83404
G13S2R2	74	28.3673	10.0336	36.755	8.3877	1.6459	16.40388
G13S2R3	92	27.0493	10.0437	35.8225	8.7732	1.2705	12.64972
G13S2R4	42	28.1673	10.0858	36.6583	8.491	1.5948	15.81233
G13S2R5	56	23.6674	10.0455	32.6048	8.9374	1.1081	11.03081
G13S3R1	68	25.5393	10.0754	31.4894	5.9501	4.1253	40.94428
G13S3R2	89	25.5376	10.083	33.3394	7.8018	2.2812	22.62422
G13S3R3	99	26.2955	10.0569	32.9954	6.6999	3.357	33.38007
G13S3R4	87	26.5381	10.0285	32.7573	6.2192	3.8093	37.98474
G13S3R5	61	27.0866	10.0619	32.5348	5.4482	4.6137	45.85317
G13S4R1	2	27.7944	9.9042	36.5216	8.7272	1.177	11.88385
G13S4R2	64	25.0283	10.099	33.9325	8.9042	1.1948	11.83087
G13S4R3	41	29.5974	10.0336	38.4726	8.8752	1.1584	11.54521
G13S4R4	72	26.6705	9.9026	35.2812	8.6107	1.2919	13.04607
G13S4R5	58	27.8753	9.9719	36.3424	8.4671	1.5048	15.0904
G13S5R1	29	27.615	9.7304	35.2404	7.6254	2.105	21.63323
G13S5R2	7	23.9917	9.9991	31.9373	7.9456	2.0535	20.53685
G13S5R3	34	26.4909	9.9289	34.2805	7.7896	2.1393	21.54619
G13S5R4	37	26.8897	6.7759	31.0572	4.1675	2.6084	38.49526
G13S5R5	27	27.2485	7.6988	32.2279	4.9794	2.7194	35.32239
G13S6R1	9	24.7261	10.0848	33.3197	8.5936	1.4912	14.78661
G13S6R2	25	26.6129	10.0695	34.7185	8.1056	1.9639	19.50345
G13S6R3	24	26.77196	10.0214	35.1881	8.41614	1.60526	16.01832
G13S6R4	17	26.6317	10.1582	35.1436	8.5119	1.6463	16.20661
G13S6R5	31	28.831126	10.027	37.7704	8.939274	1.087726	10.84797

Table 6: Carbonates

Site/Sample Number	Pressure (psi)	Weight of vial (g)	Weight of soils (g)	CaCO3 (g/kg)	CaCO3 (mg/kg)
G13S1R1	13.1	85.0635	2.0778	0.00658	6.58
G13S1R2	27.8	89.9956	2.0874	0.01393	13.93
G13S1R3	54.4	88.3169	1.9939	0.02723	27.23
G13S1R4	37	90.2378	2.0181	0.01853	18.53
G13S1R5	14.1	87.4267	2.0342	0.00708	7.08
G13S2R1	9.7	89.8726	2.0184	0.00488	4.88
G13S2R2	11.1	90.1924	1.9555	0.00558	5.58
G13S2R3	9.6	89.2223	1.9668	0.00483	4.83
G13S2R4	14.5	89.5729	1.9824	0.00728	7.28
G13S2R5	8.2	89.7617	2.0909	0.00413	4.13
G13S3R1	8.4	90.0305	2.0324	0.00423	4.23
G13S3R2	7.2	90.0994	2.0808	0.00363	3.63
G13S3R3	10	90.5317	2.0783	0.00503	5.03
G13S3R4	16.2	87.3414	2.0737	0.00813	8.13
G13S3R5	7.1	90.0918	2.0435	0.00358	3.58
G13S4R1	7.5	89.3357	2.0291	0.00378	3.78
G13S4R2	7.1	86.862	2.0162	0.00358	3.58
G13S4R3	8.7	89.844	2.0269	0.00438	4.38
G13S4R4	6.7	88.7361	2.0752	0.00338	3.38
G13S4R5	8	89.7506	2.0706	0.00403	4.03
G13S5R1	7.1	90.1154	2.0737	0.00358	3.58
G13S5R2	7.2	88.7955	2.0853	0.00363	3.63
G13S5R3	6.5	89.9528	2.0307	0.00328	3.28
G13S5R4	6.3	89.5427	2.0496	0.00318	3.18
G13S5R5	6.1	89.5887	2.0369	0.00308	3.08
G13S6R1	13.2	87.4865	2.0689	0.00663	6.63
G13S6R2	34.4	89.4844	2.0043	0.01723	17.23
G13S6R3	10.3	90.3458	2.0644	0.00518	5.18
G13S6R4	61.6	89.7589	2.0352	0.03083	30.83
G13S6R5	65.3	89.7365	2.0589	0.03268	32.68
Standard 1	208	86.7024	0.1031		
Standard 2	210	89.7265	0.1013		
Standard 3	214	90.2669	0.0996		

Table 7: NH_4-N

Sample/ctrl ID	Result	Adjusted values	Adjusted Value (µg/mL)	Weight of sample not including centrifuge tube (g)	NO3 in Moist soil (µg/g)	NO3 in Moist soil (g/kg)	Original weight (g)	New Weight	Moisture Factor	NH4 in dry soil (g/kg)	NH4 in dry soil (mg/kg)
AP G13 B1	2.958	n/a									
AP G13 B2	5.551	n/a									
AP G13 B3	5.726	n/a									
AP G13 S1R1	138.4	133.6353	0.1336353	5.1453	0.649307621	0.000649308	49.4785	34.1208	1.450097888	0.00094156	0.941559609
AP G13 S1R2	108.8	104.0425	0.1040425	5.1276	0.507267045	0.000507267	45.9372	31.7241	1.448022166	0.000734534	0.734533925
AP G13 S1R3	89.14	84.39082	0.08439082	5.0239	0.419946755	0.000419947	41.3862	30.5272	1.355715559	0.000569328	0.569328349
AP G13 S1R4	96.84	92.09887	0.09209887	5.2556	0.438098742	0.000438099	52.7851	38.776	1.361282752	0.000596376	0.596376262
AP G13 S1R5	150.5	145.7962	0.1457962	5.5226	0.659998008	0.000659998	48.6508	32.6364	1.490691375	0.000983853	0.983853338
AP G13 S2R1	922	917.2759	0.9172759	5.4394	4.215887322	0.004215887	50.1956	33.9034	1.480547674	0.006241822	6.241822167
AP G13 S2R2	863.9	859.1663	0.8591663	5.0505	4.252877438	0.004252877	42.9734	29.8684	1.438758019	0.006118862	6.118861515
AP G13 S2R3	893.1	888.3408	0.8883408	4.947	4.489290479	0.00448929	48.0501	35.3444	1.35948269	0.006103113	6.103112698
AP G13 S2R4	524.5	519.7062	0.5197062	5.0614	2.56700814	0.002567008	45.6291	32.1966	1.417202438	0.00363797	3.637970193
AP G13 S2R5	597.6	592.8791	0.5928791	5.0719	2.922371794	0.002922372	48.4707	37.2733	1.300413433	0.003800292	3.800291536
AP G13 S3R1	580.6	575.8846	0.5758846	4.6124	3.121393418	0.003121393	49.7015	35.9329	1.383175307	0.004317434	4.3174343
AP G13 S3R2	210.7	205.9872	0.2059872	5.0083	1.02822914	0.001028229	50.4503	41.8732	1.204835074	0.001238847	1.238846531
AP G13 S3R3	417.8	413.0809	0.4130809	5.1447	2.007312866	0.002007313	50.3935	37.5562	1.341815732	0.002693444	2.693443983
AP G13 S3R4	260.3	255.5052	0.2555052	5.3696	1.189591403	0.001189591	50.5351	40.3388	1.252766567	0.00149028	1.490280339
AP G13 S3R5	166.8	162.0554	0.1620554	4.9722	0.814807329	0.000814807	50.5015	38.9565	1.296356192	0.001056281	1.056280526
AP G13 S4R1	112.3	107.5296	0.1075296	4.6203	0.581832349	0.000581832	45.2197	35.073	1.289302312	0.000750158	0.750157792
AP G13 S4R2	142.7	137.9209	0.1379209	5.3521	0.644237309	0.000644237	45.4761	33.4576	1.359215843	0.000875658	0.875657557
AP G13 S4R3	394.3	389.6029	0.3896029	4.6973	2.073547038	0.002073547	46.4753	34.1738	1.359968748	0.002819959	2.819959169
AP G13 S4R4	191	186.2782	0.1862782	5.0999	0.913146336	0.000913146	48.2767	34.6695	1.392483307	0.001271541	1.27154103
AP G13 S4R5	136.4	131.6261	0.1316261	4.9182	0.669076593	0.000669077	46.0859	32.3377	1.425144645	0.000953531	0.953530924
AP G13 S5R1	84.87	80.12357	0.08012357	5.181	0.386622129	0.000386622	43.9588	23.1583	1.898187691	0.000733881	0.733881366
AP G13 S5R2	128.2	123.481	0.123481	5.1779	0.596192472	0.000596192	44.2955	29.7124	1.490808551	0.000888809	0.888808835
AP G13 S5R3	72.18	67.43409	0.06743409	4.9416	0.341155142	0.000341155	45.1701	30.802	1.466466463	0.000500293	0.500292575
AP G13 S5R4	104.7	99.9669	0.0999669	4.8481	0.515495246	0.000515495	40.5272	20.5562	1.971531703	0.001016315	1.01631522
AP G13 S5R5	3444	3439.692	3.439692	5.0462	17.04100115	0.017041001	40.4956	21.7753	1.859703425	0.031691208	31.69120821
AP G13 S6R1	405.3	400.5981	0.4005981	5.0868	1.968811925	0.001968812	47.8883	37.5794	1.274323166	0.002508903	2.508902646
AP G13 S6R2	927.3	922.533	0.922533	5.3901	4.278830634	0.004278831	51.2099	40.4993	1.26446383	0.005410427	5.410426572
AP G13 S6R3	539.1	534.3672	0.5343672	4.8935	2.729984674	0.002729985	50.8291	41.5505	1.223308985	0.003339615	3.339614781
AP G13 S6R4	276.2	271.4139	0.2714139	5.1952	1.306080132	0.00130608	51.019	43.4578	1.173989479	0.001533324	1.533324334
AP G13 S6R5	183.3	178.5314	0.1785314	4.9701	0.898027203	0.000898027	48.2704	43.1472	1.118737716	0.001004657	1.004656902

Table 8: TON

Sample/ctrl ID	Result	Adjusted values	Result unit	Adjusted Value (µg/mL)	Weight of sample not including centrifuge tube (g)	TON in Moist soil (µg/g)	TON in Moist soil (g/kg)	Moisture	TON in dry soil (g/kg)	TON in dry soil (mg/kg)
AP G13 B1	6.19253	n/a	µg/l							
AP G13 B2	0.66999	n/a	µg/l							
AP G13 B3	6.00281	n/a	µg/l				0.003148616			
AP G13 S1R1	652.3115	648.023057	µg/l	0.648023057	5.1453	3.14861649	0.00633258	1.450097888	0.004565802	4.56580212
AP G13 S1R2	1303.126	1298.837557	µg/l	1.298837557	5.1276	6.332580335	0.005055995	1.448022166	0.009169717	9.169716694
AP G13 S1R3	1020.321	1016.032557	µg/l	1.016032557	5.0239	5.055995128	0.003269288	1.355715559	0.006854491	6.85449126
AP G13 S1R4	691.5712	687.282757	µg/l	0.687282757	5.2556	3.269287793	0.005605931	1.361282752	0.004450425	4.450425085
AP G13 S1R5	1242.661	1238.372557	µg/l	1.238372557	5.5226	5.605930889	0.002662121	1.490691375	0.008356713	8.356712826
AP G13 S2R1	583.502	579.213557	µg/l	0.579213557	5.4394	2.662120625	0.002306741	1.480547674	0.003941396	3.941396498
AP G13 S2R2	470.2963	466.007857	µg/l	0.466007857	5.0505	2.306741199	0.001650706	1.438758019	0.003318842	3.318842397
AP G13 S2R3	330.9301	326.641657	µg/l	0.326641657	4.947	1.650705766	0.002335178	1.35948269	0.002244106	2.244105916
AP G13 S2R4	477.0593	472.770857	µg/l	0.472770857	5.0614	2.335178296	0.001953087	1.417202438	0.00330942	3.309420372
AP G13 S2R5	400.5229	396.234457	µg/l	0.396234457	5.0719	1.953086895	-5.4442E-05	1.300413433	0.00253982	2.539820434
AP G13 S3R1	-5.75588	-10.044323	µg/l	-0.010044323	4.6124	-0.054441955	0.005584308	1.383175307	-7.53028E-05	-0.075302768
AP G13 S3R2	1123.004	1118.715557	µg/l	1.118715557	5.0083	5.584307834	0.00011761	1.204835074	0.00672817	6.72816994
AP G13 S3R3	28.49117	24.202727	µg/l	0.024202727	5.1447	0.117610002	9.87893E-05	1.341815732	0.000157811	0.15781095
AP G13 S3R4	25.5068	21.218357	µg/l	0.021218357	5.3696	0.098789281	-4.17259E-05	1.252766567	0.00012376	0.123759909
AP G13 S3R5	-4.01033	-8.298773	µg/l	-0.008298773	4.9722	-0.041725861	-5.65494E-05	1.296356192	-5.40916E-05	-0.054091578
AP G13 S4R1	-6.16256	-10.451003	µg/l	-0.010451003	4.6203	-0.056549374	-6.488E-05	1.289302312	-7.29092E-05	-0.072909239
AP G13 S4R2	-9.60132	-13.889763	µg/l	-0.013889763	5.3521	-0.064879968	0.006278684	1.359215843	-8.81859E-05	-0.08818588
AP G13 S4R3	1184.003	1179.714557	µg/l	1.179714557	4.6973	6.278684335	-5.59463E-05	1.359968748	0.008538814	8.538814474
AP G13 S4R4	-7.12437	-11.412813	µg/l	-0.011412813	5.0999	-0.055946259	-9.46745E-05	1.392483307	-7.79042E-05	-0.077904231
AP G13 S4R5	-14.33668	-18.625123	µg/l	-0.018625123	4.9182	-0.09467449	5.70014E-06	1.425144645	-0.000134925	-0.134924842
AP G13 S5R1	5.46974	1.181297	µg/l	0.001181297	5.181	0.00570014	-5.64791E-06	1.898187691	1.08199E-05	0.010819935
AP G13 S5R2	3.11867	-1.169773	µg/l	-0.001169773	5.1779	-0.005647912	0.000196499	1.490808551	-8.41996E-06	-0.008419956
AP G13 S5R3	43.1293	38.840857	µg/l	0.038840857	4.9416	0.196499398	7.64351E-05	1.466466463	0.00028816	0.288159777
AP G13 S5R4	19.11104	14.822597	µg/l	0.014822597	4.8481	0.076435083	6.3299E-06	1.971531703	0.000150694	0.150694189
AP G13 S5R5	5.56612	1.277677	µg/l	0.001277677	5.0462	0.006329897	0.00511795	1.859703425	1.17717E-05	0.011771731
AP G13 S6R1	1045.648	1041.359557	µg/l	1.041359557	5.0868	5.11795017	0.000590107	1.274323166	0.006521922	6.521922466
AP G13 S6R2	131.5179	127.229457	µg/l	0.127229457	5.3901	0.590107127	0.000860666	1.26446383	0.000746169	0.746169118
AP G13 S6R3	172.7552	168.466757	µg/l	0.168466757	4.8935	0.86066597	0.000259897	1.223308985	0.00105286	1.052860415
AP G13 S6R4	58.29704	54.008597	µg/l	0.054008597	5.1952	0.259896621	0.000264932	1.173989479	0.000305116	0.305115899
AP G13 S6R5	56.95807	52.669627	µg/l	0.052669627	4.9701	0.264932431		1.118737716	0.00029639	0.296389903

Table 10: PO_4-P

Sample/ctrl ID	Result	Adjusted values	Result unit	Adjusted value (µg/ml)	Weight of sample not including centrifuge tube (g)	PO4 in Moist soil (µg/g)	PO4 in Moist soil (g/kg)	Moisture	PO4 in dry soil (mg/kg)
AP G13 B1	0.01361	n/a	mg/l						
AP G13 B2	0.01484	n/a	mg/l						
AP G13 B3	0.015	n/a	mg/l						
AP G13 S1R1	0.12156	0.107077	mg/l	0.107077	5.1453	0.520266068	0.000520266	1.450097888	0.754436726
AP G13 S1R2	0.30625	0.291767	mg/l	0.291767	5.1276	1.422531984	0.001422532	1.448022166	2.059857845
AP G13 S1R3	0.17162	0.157137	mg/l	0.157137	5.0239	0.781947292	0.000781947	1.355715559	1.06009811
AP G13 S1R4	0.48695	0.472467	mg/l	0.472467	5.2556	2.247445582	0.002247446	1.361282752	3.059408907
AP G13 S1R5	0.23289	0.218407	mg/l	0.218407	5.5226	0.988696447	0.000988696	1.490691375	1.473841267
AP G13 S2R1	0.03783	0.023347	mg/l	0.023347	5.4394	0.107305034	0.000107305	1.480547674	0.158870218
AP G13 S2R2	0.06647	0.051987	mg/l	0.051987	5.0505	0.257335907	0.000257336	1.438758019	0.3702441
AP G13 S2R3	0.0341	0.019617	mg/l	0.019617	4.947	0.09913584	9.91358E-05	1.35948269	0.134773458
AP G13 S2R4	0.03302	0.018537	mg/l	0.018537	5.0614	0.091560635	9.15606E-05	1.417202438	0.129759956
AP G13 S2R5	0.02703	0.012547	mg/l	0.012547	5.0719	0.061845659	6.18457E-05	1.300413433	0.080424926
AP G13 S3R1	0.0414	0.026917	mg/l	0.026917	4.6124	0.145894762	0.000145895	1.383175307	0.201798032
AP G13 S3R2	0.18185	0.167367	mg/l	0.167367	5.0083	0.835448156	0.000835448	1.204835074	1.006577241
AP G13 S3R3	0.10935	0.094867	mg/l	0.094867	5.1447	0.460993838	0.000460994	1.341815732	0.618568785
AP G13 S3R4	0.03842	0.023937	mg/l	0.023937	5.3696	0.111446849	0.000111447	1.252766567	0.139616886
AP G13 S3R5	0.03945	0.024967	mg/l	0.024967	4.9722	0.125532963	0.000125533	1.296356192	0.162735434
AP G13 S4R1	0.03918	0.024697	mg/l	0.024697	4.6203	0.133633097	0.000133633	1.289302312	0.172293462
AP G13 S4R2	0.01814	0.003657	mg/l	0.003657	5.3521	0.01708208	1.70821E-05	1.359215843	0.023218234
AP G13 S4R3	0.12418	0.109697	mg/l	0.109697	4.6973	0.583830073	0.00058383	1.359968748	0.793990653
AP G13 S4R4	0.02425	0.009767	mg/l	0.009767	5.0999	0.04787839	4.78784E-05	1.392483307	0.066669859
AP G13 S4R5	0.01908	0.004597	mg/l	0.004597	4.9182	0.023367289	2.33673E-05	1.425144645	0.033301767
AP G13 S5R1	0.02637	0.011887	mg/l	0.011887	5.181	0.057358618	5.73586E-05	1.898187691	0.108877423
AP G13 S5R2	0.03846	0.023977	mg/l	0.023977	5.1779	0.115766044	0.000115766	1.490808551	0.172585009
AP G13 S5R3	0.03104	0.016557	mg/l	0.016557	4.9416	0.083763356	8.37634E-05	1.466466463	0.122836152
AP G13 S5R4	0.07108	0.056597	mg/l	0.056597	4.8481	0.291851447	0.000291851	1.971531703	0.57539438
AP G13 S5R5	0.0669	0.052417	mg/l	0.052417	5.0462	0.259685506	0.000259686	1.859703425	0.482938025
AP G13 S6R1	0.3052	0.290717	mg/l	0.290717	5.0868	1.428781356	0.001428781	1.274323166	1.820729181
AP G13 S6R2	0.03926	0.024777	mg/l	0.024777	5.3901	0.114919018	0.000114919	1.26446383	0.145310942
AP G13 S6R3	0.03867	0.024187	mg/l	0.024187	4.8935	0.123566977	0.000123567	1.223308985	0.151160593
AP G13 S6R4	0.0273	0.012817	mg/l	0.012817	5.1952	0.061677125	6.16771E-05	1.173989479	0.072408296
AP G13 S6R5	0.01777	0.003287	mg/l	0.003287	4.9701	0.016533873	1.65339E-05	1.118737716	0.018497067

Table 11: DOC

Sample Name	Result(NPOC)	Adjusted values	Unit	Adjusted value (µg/ml)	Weight of sample not including centrifuge tube (g)	DOC in Moist soil (µg/g)	DOC in Moist soil (g/kg)	Moisture	DOC in dry soil (g/kg)	DOC in dry soil (mg/kg)
AP G13 B1	2.986	n/a	mg/L							
AP G13 B2	2.824	n/a	mg/L							
AP G13 B3	2.59	n/a	mg/L							
AP G13 S1R1	9.692	6.892	mg/L	6.892	5.1453	33.48687151	0.033486872	1.450097888	0.048559242	48.55924164
AP G13 S1R2	13.172	10.372	mg/L	10.372	5.1276	50.5694672	0.050569467	1.448022166	0.073225709	73.22570943
AP G13 S1R3	11.28	8.48	mg/L	8.48	5.0239	42.19829216	0.042198292	1.355715559	0.057208881	57.20888123
AP G13 S1R4	11.338	8.538	mg/L	8.538	5.2556	40.61382145	0.040613821	1.361282752	0.055286895	55.28689464
AP G13 S1R5	10.514	7.714	mg/L	7.714	5.5226	34.92014631	0.034920146	1.490691375	0.052055161	52.05516092
AP G13 S2R1	15.508	12.708	mg/L	12.708	5.4394	58.40717726	0.058407177	1.480547674	0.08647461	86.47461042
AP G13 S2R2	15.5	12.7	mg/L	12.7	5.0505	62.86506287	0.062865063	1.438758019	0.090447613	90.44761328
AP G13 S2R3	8.796	5.996	mg/L	5.996	4.947	30.30119264	0.030301193	1.35948269	0.041193947	41.19394689
AP G13 S2R4	10.21	7.41	mg/L	7.41	5.0614	36.6005453	0.036600545	1.417202438	0.051870382	51.87038202
AP G13 S2R5	9.07	6.27	mg/L	6.27	5.0719	30.90557779	0.030905578	1.300413433	0.040190029	40.1900285
AP G13 S3R1	7.198	4.398	mg/L	4.398	4.6124	23.83791519	0.023837915	1.383175307	0.032972016	32.97201566
AP G13 S3R2	-0.1646	-2.9646	mg/L	-2.9646	5.0083	-14.7984346	-0.014798435	1.204835074	-0.017829673	-17.82967304
AP G13 S3R3	9.428	6.628	mg/L	6.628	5.1447	32.20790328	0.032207903	1.341815732	0.043217071	43.21707132
AP G13 S3R4	5.022	2.222	mg/L	2.222	5.3696	10.34527712	0.010345277	1.252766567	0.012960217	12.9602173
AP G13 S3R5	6.04	3.24	mg/L	3.24	4.9722	16.2905756	0.016290576	1.296356192	0.021118389	21.11838855
AP G13 S4R1	7.924	5.124	mg/L	5.124	4.6203	27.72547237	0.027725472	1.289302312	0.035746516	35.74651564
AP G13 S4R2	8.006	5.206	mg/L	5.206	5.3521	24.31755759	0.024317558	1.359215843	0.03305281	33.05280955
AP G13 S4R3	29.082	26.282	mg/L	26.282	4.6973	139.8782279	0.139878228	1.359968748	0.190230018	190.2300185
AP G13 S4R4	8.588	5.788	mg/L	5.788	5.0999	28.37310536	0.028373105	1.392483307	0.039509076	39.50907556
AP G13 S4R5	8.08	5.28	mg/L	5.28	4.9182	26.83908747	0.026839087	1.425144645	0.038249582	38.2495818
AP G13 S5R1	16.23	13.43	mg/L	13.43	5.181	64.80409187	0.064804092	1.898187691	0.12301033	123.0103295
AP G13 S5R2	14.82	12.02	mg/L	12.02	5.1779	58.03511076	0.058035111	1.490808551	0.086519239	86.5192394
AP G13 S5R3	11.628	8.828	mg/L	8.828	4.9416	44.66164805	0.044661648	1.466466463	0.065494809	65.49480906
AP G13 S5R4	22.482	19.682	mg/L	19.682	4.8481	101.4933685	0.101493369	1.971531703	0.200097394	200.0973937
AP G13 S5R5	19.722	16.922	mg/L	16.922	5.0462	83.83536126	0.083835361	1.859703425	0.155908909	155.9089085
AP G13 S6R1	19.098	16.298	mg/L	16.298	5.0868	80.09947315	0.080099473	1.274323166	0.102072614	102.0726142
AP G13 S6R2	8.154	5.354	mg/L	5.354	5.3901	24.8325634	0.024832563	1.26446383	0.031399878	31.39987824
AP G13 S6R3	7.3	4.5	mg/L	4.5	4.8935	22.98968019	0.02298968	1.223308985	0.028123482	28.12348235
AP G13 S6R4	6.634	3.834	mg/L	3.834	5.1952	18.44972282	0.018449723	1.173989479	0.02165978	21.65978049
AP G13 S6R5	5.42	2.62	mg/L	2.62	4.9701	13.17880928	0.013178809	1.118737716	0.014743631	14.743631