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MANOR WOODS VALLEY GROUP

IMPACT OF LANDFILL ON SOIL PROFILES AND DRAINAGE PATTERNS IN A WILDFLOWER MEADOW

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Abstract

The effect of landfill on agricultural soils and drainage patterns has been widely studied, yet a gap exists in the examination of how landfill underneath recreational land may be affecting this environment. Unexplored landfill on recreational land is a necessary area of investigation, due to possible environmental and social detriment of leachate from below the ground surface. Analysis of grainsize, organic matter content, nutrient content, pH, soil moisture and heavy metal content were all investigated in a wildflower meadow in Bristol, UK to look at soil properties and drainage patterns of the site. Zinc was the heavy metal found in the highest quantity, 350.31ppb, though this was over 200 times lower than the UK average of 82,000ppb. The same trend applied to the other heavy metals, which were significantly incomparable with average UK results. Nitrate levels were healthy, below 20μg/l at all but 4 sites. This suggested the landfill was having no impact on the nutrient content of the soil at down to 30cm depth. Unusually, soil moisture levels decreased downslope, and it was concluded that compaction due to heavy machinery used during the construction of the landfill was a contributing factor. This paper highlights the need for more research to be done looking at the environmental impact of landfill, especially on land that isn't of agricultural purpose.

Contents:

1. Introduction

"The world generates 2.01 billion tonnes of municipal solid waste annually with at least 33% of that…not managed in an environmentally safe manner" (Kaza, et al., 2018) and every year, the UK sends around 7.4 million tonnes of biodegradable municipal waste into landfills, every tonne of which has adverse effects on the surrounding environment (DEFRA, 2019). Landfill efforts are believed to have started in the early 20th century but became particularly popular in the 1960s and 1970s to limit the occurrence of open dumps and unsanitary dumping practices (Curran, 2006). In an attempt to stop the waste interacting with the environment, a clay liner or cap can be used to create an impermeable barrier on top of or surrounding the waste site, preventing leachate (any substance that leaches out of the landfill layer) entering soil and water systems, although this is not a guaranteed method of prevention. Leachate typically consists of high percentages of heavy metals, methane and ammonia (Kjeldsen & Christophersen, 2001), all of which have negative consequences on the environment, affecting the ability of plants to uptake nutrients, polluting essential water systems used by animals and in some cases, creating air pollution from harmful fumes. There has been a wide array of studies on the impact of landfill on the environment. The studies have looked at how the impact is linked to three different factors:

1. The type of waste e.g. household, municipal, industrial
2. The scale of the landfill site
3. The type of surrounding environment (end use of landfill)

We have identified a gap in the literature referring to the impact of landfill on recreational land, as much of the coverage is based on agricultural and residential areas that are situated on top of historic landfill. However, in Sharma and Reddy's 2004 book, "Geoenvironmentel Engineering" they stated, "The most common end use of landfills in developing the land for recreational use." (Sharma & Reddy, 2004). Despite the majority of landfill being converted to recreational land, there are very few studies looking at its effect on this environment, therefore there's a notable imbalance between which land is affected by landfill, and which of these land uses are more widely studied. Recreational land is an essential green space used by local communities across the world and a deeper analysis of the impact of landfill it's sitting on demands investigation.

Sharma and Reddy defined recreational use as nature parks, golf courses, parkland and other green spaces (Sharma & Reddy, 2004). In the UK, urban recreational land constitutes 2.5% of the country, and wildflower meadows specifically make up almost 3.1 million hectares of this green space (Dines, 2018), providing a haven for a wide variety of flora as well as mammals and insects. Our investigation focused on wildflower meadows, which are characterised by low organic content (Forest Research, 2014) allowing them to develop in unhealthy or disturbed soils and are easy to manage by local conservation groups, only needing to be mown for hay once a year (Loy-Hancocks, 2020).

Our research area was based in Manor Woods Valley, a local nature reserve in South Bristol. The whole reserve spans around 1km in length, and the Malago river flows in the southern half of the site. In the northern part of the site, there is an extensive wildflower meadow, which is believed to be situated above landfill deposited from 1945. (Environment Agency, 2019). The Malago river is intercepted by the South Bristol Storm Drain in the south east corner of the meadow, which was built between 1971-1974 following storms in 1968. It reduces flood risk in the Bedminster Down area, and its construction created several tonnes of arisings, likely to have been deposited on top of the landfill underneath the meadow and surrounding amenity grassland.

As seen in Figure 1, the wildflower meadow occupies an estimated two thirds of the northern part of the site. This landfill beneath is believed to be household category (bricks, window frames, piping etc.), and has created a hill over 200m long and 30m deep. According to local records shown in Figure 2, this area was playing fields in the 1920's (Digimap 2020) suggesting it was very flat in nature – a stark contrast to the slope it is today.

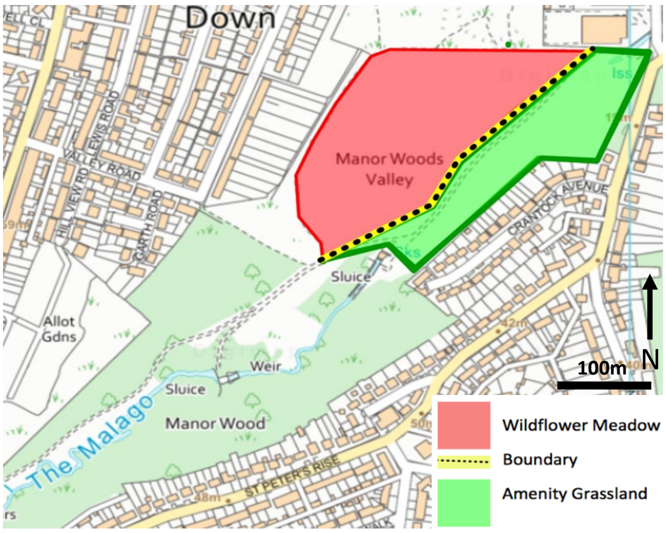

Figure 1. *Northern Manor Woods Valley, showing the wildflower meadow and surrounding area.* (Digimap , 2020)

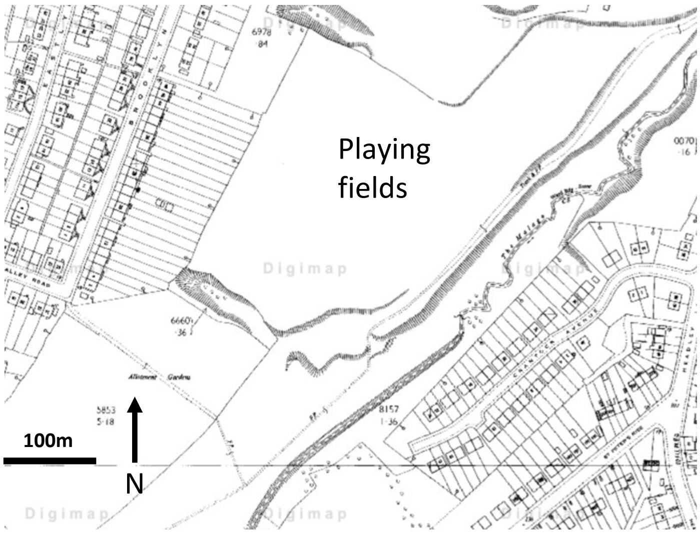

Figure 2. *Map from early 20th century depicting playing fields on site now occupied by wildflower meadow. Digimap 2020.*

This report is focused on how these inputs of landfill could have an impact on both the soil properties and the drainage pattern of the site. Our investigation looked at both the trend downslope, and the variability within different depths of soil, and follows on from a previous investigation at this site, carried out by students at the University of Bristol in 2019 (GroupN, 2019) . The site and transect chosen for this study were in line with theirs, which concentrated on the properties of the topsoil layer (surface soil to 10cm depth), so as a continuation to that, our investigation looked at soil depths of 10-30cm, along a similar transect for comparability and scientific consistency.

This report will explain the field and laboratory methods we chose to obtain an extensive data set as well as providing a justification for these methods. The results will be presented and discussed, and limitations of the investigation considered. Investigation improvements and future research ideas will be debated, and conclusions will be drawn concerning the variability of our soil properties results, as well as possible explanations of the drainage pattern found.

2. Methodology

2.1. Sampling Methodology

A preliminary trip to the sampling site took place of Friday 17th January 2020 where 5 soil cores were taken along the transect, aiming to determine the presence of a possible clay cap. We found evidence of clay, leading us to believe a clay cap was present, therefore we commenced with our main sampling on Monday 20th January 2020.

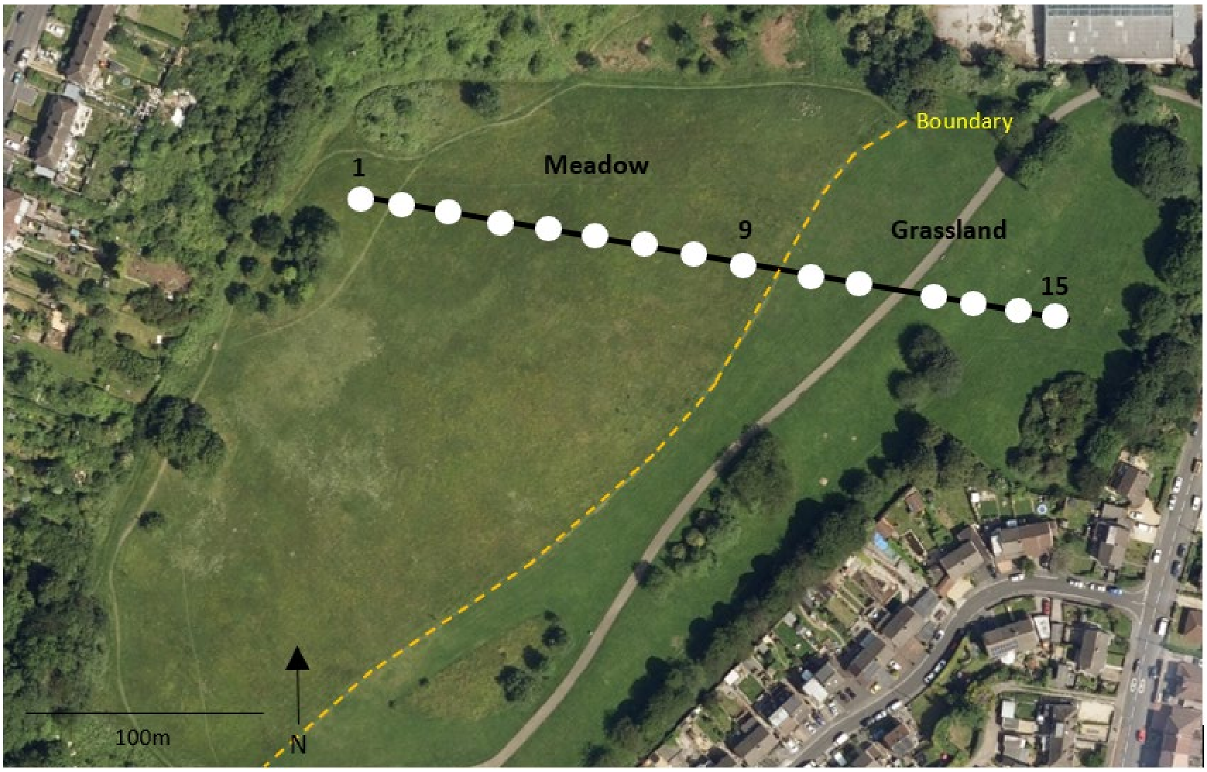

Figure 3. *Aerial map of Manor Woods Nature Valley Reserve, containing the Wildflower Meadow (left of the boundary), and the grassland (right of the boundary). The transect (black) and site points (white) are also indicated.* (Digimap , 2020)

A transect spanning 238m through the wildflower meadow and amenity grassland was laid out using a tape measure. At equal intervals of 17m, 15 points along the transect were marked with flags. As seen in Figure 3, sites 1-9, 0-136m along the transect, were in the wildflower meadow and sites 10-15, 153-238m along the transect, were in the grassland. It is important to note here that site 1 was at the top of the mound, and site 15 at the bottom – elevation therefore decreased along the transect. At each site, the GPS location was recorded, 3 theta-probe soil moisture readings, and 2 soil cores were taken. The soil cores were taken from 2 depths at each site. Firstly, at a depth of 10-20cm (referred to as upper layer), and secondly at a depth of 20-30cm (referred to as lower layer). Due to frozen ground conditions on the day the data was collected, the deeper soil core at site 15 was unable to be obtained and is missing from our results. The 3 soil moisture readings were then averaged for each site.

To ensure consistency was applied to technique, the same person took all the soil cores and soil moisture readings. The same GPS recorder was used at each site to enable precise recordings and a transect to be plotted and mapped later in ArcGIS. To limit the possibility of contamination, the soil corers were cleaned with a brush and paper tissue between each sample, however, the corers were not able to be completely free from contamination.

2.1.1 Sample Analysis

To note, the phosphorus, nitrogen and heavy metals laboratory analysis took place externally. We were unable to obtain precision results for the Mastersizer as blanks are not run through the machine frequently enough to obtain a value. The Mastersizer runs each sample 5 times which gave us the ability to calculate the standard deviation for each sample. For the upper layer of soil, the average standard deviation was 0.0461. This shows the Mastersizer is very accurate because there is very little spread of values around the mean. The error of the pH reader was 0.01 so we can conclude that the probe was highly accurate, and therefore the error of the pH reader is not something of a concern. Due to the error being so small it was not feasible to plot these error bars on the pH graphs.

2.2. Laboratory Methodology

2.2.1. Nutrients: Nitrate and Phosphate

The quantities of phosphorus and nitrogen found within soils are key indicators of the quality of plants (Muhammad Razaq, 2017) (Parent, 2000). We therefore decided to investigate phosphorous and nitrogen levels to see if the suspected landfill was leaching into the soil and therefore having any impacts on the quality of the wildflower meadow (Tfi.org, 2014). With the aim of discovering the abundance of nitrogen and phosphorus in our soil samples we undertook a digest following the methodology in the University of Bristol 'Teaching Laboratories Manual of Field and Laboratory Methods' (Cobb, 2019, pp. 24-25). We chose to do this digest because it is also a method used to determine the abundance of different heavy metals in soil. The soil samples were dried out over night to make sure all water was removed from the sample. Once dried, the soil samples were ground down using a pestle and mortar and sieved through a 2mm sieve. Approximately 0.2g of this soil was weighed and added to a 100mL conical flask. We repeated this for all 28 samples. After adding 4.4mL of digest (see Appendix 9) to each tube, we placed the 28 digest tubes on a hot plate that was preheated to 360°**C** and left them for approximately 2 hours. After the 2 hours, the solution was colourless, and any soil was white in colour. We then removed the samples from the hot plate and left them to cool. Once cool enough to handle we added 50mL of Milli-Q water and mixed until there was no sediment left. Then each sample was filter through a Whatman No. 1 filter paper in a conical flask and Milli-Q water was used to make to sample up to 100mL. We then re-filtered each of the 28 samples through a 0.2μm Cellulose Nitrate Membrane filter into 5mL test tubes and sent the test tubes off to an external lab for analysis. We were not provided with results for the upper sample of site 15 (238m).

2.2.2. Organic Matter Content

Loss on ignition was the chosen methodology to measure organic matter content within the soil (Cobb, 2019, p. 46). We had organic matter data from a previous study for the top layer of soil along a similar transect in the same area, so it was interesting to see if there was any variance in the layers of soil. Firstly, the soil samples were dried overnight so any moisture was removed. We then ground down the samples and sieved them through a 2mm sieve. For each sample, we started by weighing the crucible and recording its weight, then adding approximately 5g of dried and sieved soil and recorded the overall weight. The samples were then placed in a furnace, that was heated to 805°C for 2 hours – chosen to ensure full removal of organic matter. Once the samples were finished in the furnace, we reweighed each crucible to work out the percentage loss of organic matter (Appendix 8). There is a possibility that structural water from clay rich soils in our samples could have been lost during the Loss on Ignition process, and this possibility is not accounted for in the organic matter calculations. Therefore, the % organic matter results may be an overestimate of total organic matter in the sample.

2.2.3. Grainsize

Grainsize is an important factor to look at, as it can heavily affect the drainage patterns of soil. We used the soil samples that had been through the steps of loss on ignition as this soil is now in the correct form for the Mastersizer. All organic matter must be removed from the soil as organic matter can bind together soil particles and affect the Mastersizer results as soil particles would appear bigger than they are. The first step was to turn on the machine and allow it to take a background measurement with a clean beaker of water. Then, the sample could be added to the beaker with a spatula. It is important to note that the sample had to be added to the beaker slowly to allow the Mastersizer to measure the grainsize accurately. The obscuration value must range between 10 and 15%. Once this value had equalized to a steady value, measurements could be taken and recorded. Once the Mastersizer had completed taking the measurements, the beaker contaminated with soil water was removed and the Mastersizer was cleaned by allowing the system to drain and running it through with three beakers of fresh water (Cobb, 2019, pp. 85-86). This process was repeated for all 28 samples.

2.2.4. pH

We decided to determine the pH of our soil samples to see if any leachate from the landfill was coming into the soils. Landfill leachate is generally alkaline so we were looking for our soils to also be alkaline **(Muhammad Umar, 2010, p. 2)**. To determine the pH of the soil, we used the soil samples that had been dried overnight. For each of the 28 soil samples, we weighed out 5g, added it to a 50mL test tube, added 45mL of Milli-Q water and shook vigorously for 10 seconds. After shaking, we left the samples to stand for 10 minutes and then used a calibrated pH meter to take the readings. This is following the same methedology in Simon Cobb's lab guide **(Cobb, 2019, p. 68)**.

2.2.5. Heavy Metals

From reading literature on the effects of landfill on soil, we decided to look at the quantities of zinc, lead, chromium, copper, nickel and cadmium as the abundance of these metals had been recorded in similar studies to ours so we had values to compare to (Fethi Bouzayani, 2014) (Gandhimathi, 2012). To find the quantity of heavy metals in our samples we undertook the same methodology as we did for phosphorus and nitrogen and sent off the samples to an external laboratory for analysis.

2.3 Statistical Tests

To analyse the data from this investigation statistically, a t-test was used between variables. A t-test has been used to determine if there is a significant relationship between any of the variables in the investigation. The t-tests have been done to 95% confidence level. It is important to note that as sample size is so small, results will not be extremely reliable as a robust analysis cannot take place.

3. Results

3.1. Nutrients: Phosphate & Nitrate

Quantities of phosphate and nitrate in the soil samples were investigated to determine the quality of plant health (Muhammad Razaq, 2017) (Parent, 2000). As shown in Figure 4, the quantity of nitrate was generally lower than that of phosphate, but both exhibited similar trends, with nitrate peaking at the same points as phosphate. There is a clear peak in both nutrients at 102m in both the upper (A) and lower (B) soil samples, with a quantity of 281.51µg/l phosphate and 46.43µg/l nitrate, the highest along the whole transect. Graph B shows a second peak in nutrients at 170m for the lower soil, which is not mirrored in the upper soil results shown in graph A. Nutrient quantities for both phosphate and nitrate indicate no significant distinction between the meadow, which ends at 136m, and the grassland.

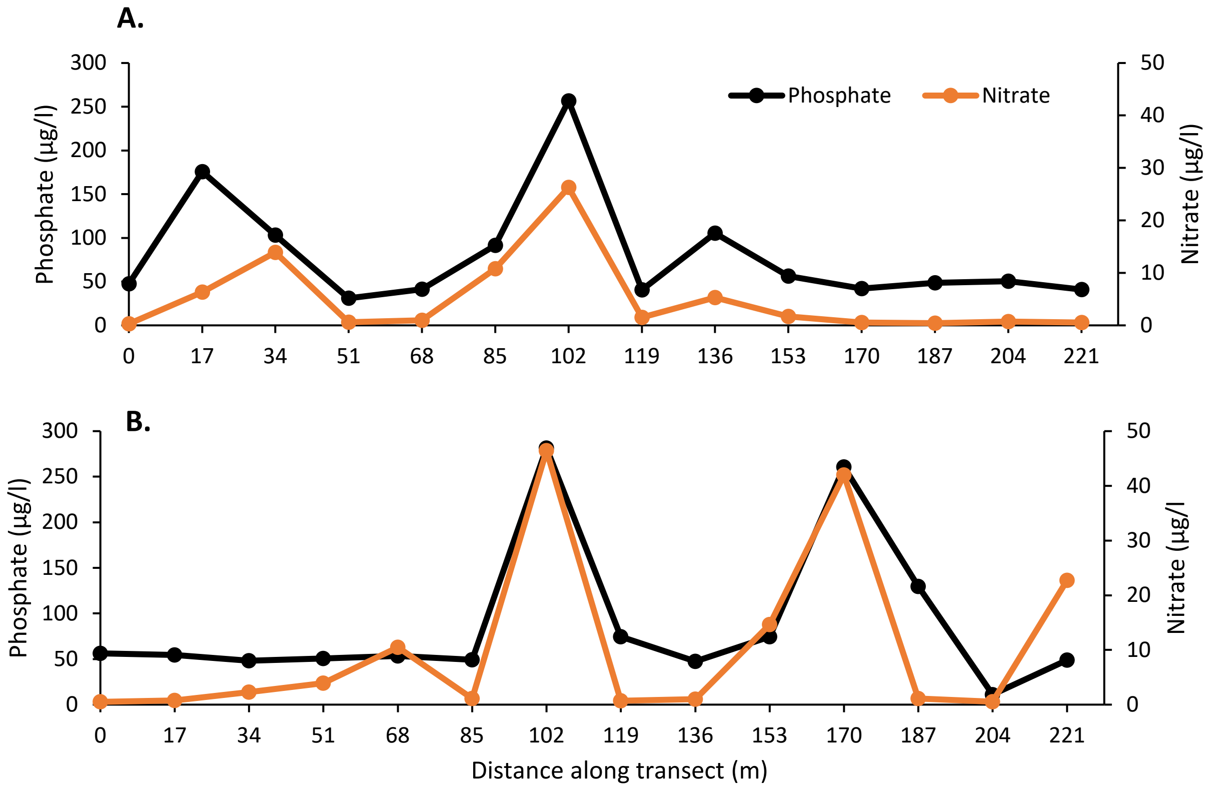

Figure 4. *Graph showing Phosphate and Nitrate quantities found at each site in the upper (A) and lower (B) samples*

3.2. Organic Matter Content

Figure 5 shows an increasing trend in soil organic content moving down the transect to 187m, from the meadow into amenity grassland. As Figure 5 shows, there was a major decrease in organic content in the lower soil at 204m along the transect, which corresponded with a visible dip in topography. The average organic content for the wildflower meadow is 11.4%, which is 1% lower than the average of 12.4% for the grassland. The upper and lower soil values have similar variation with values ranging from 7-18%.

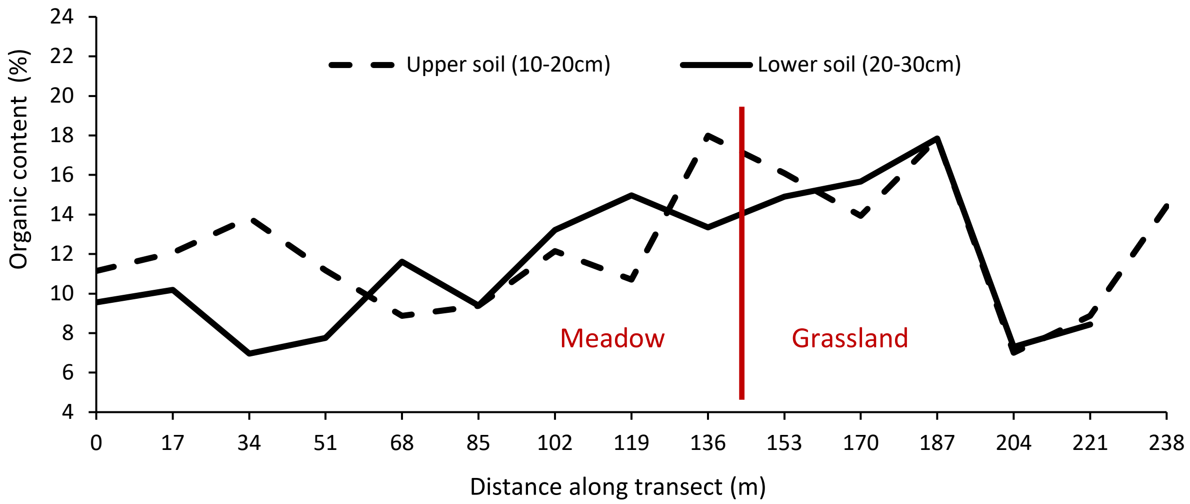

Figure 5. *Line graph of organic content (%) in upper and lower soil samples at distances along the transect*

3.3. Grain Size

Mastersizer results revealed trends in grainsize in the upper and lower soil samples (see Figure 6). Both upper and lower samples exhibited low sand content, with percentage volume below 12% for all sites. Both samples also revealed a general increase in clay and decrease in silt as distance downhill along the transect increased. The lower soil samples (Figure 6b) exhibited less variation than the upper samples (Figure 6a), suggesting the lower samples were more homogenised.

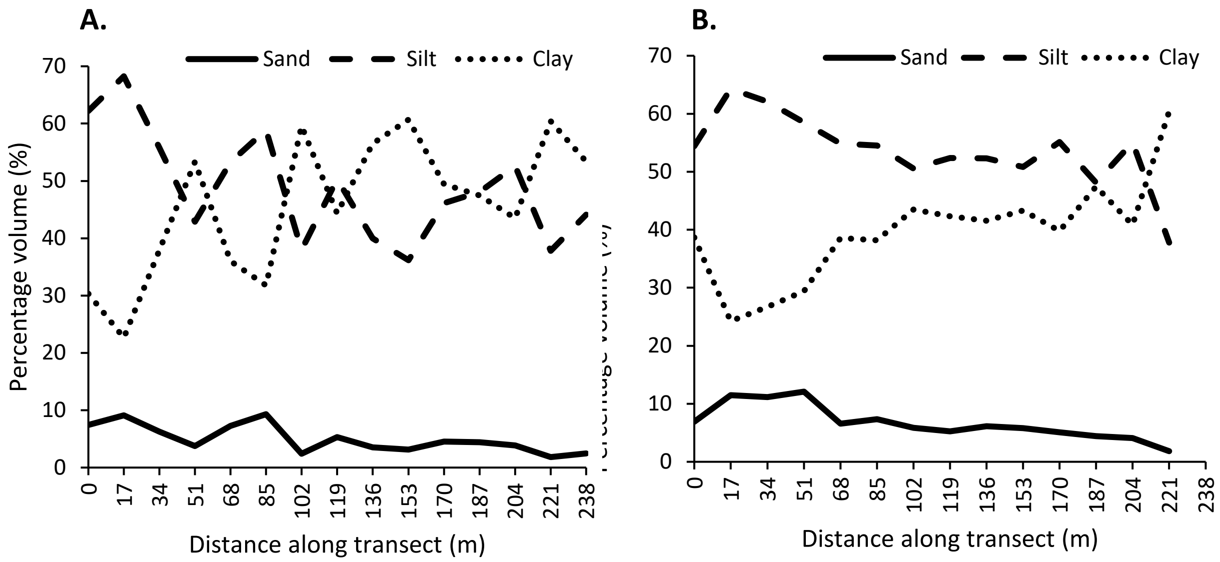

Figure 6. *Graphs showing percentage volumes of sand, silt and clay found in upper (Graph A) and lower (Graph B) soil samples*

As shown in Figure 7, the overall textural classification of our upper soil samples was silty clay, containing 48.96% silt, 45.82% clay and 4.98% sand. The lower soil was slightly different, classified as silty clay loam, with proportions of 53.62% silt, 39.64% clay and 6.72% sand. These results show us that silt was the dominant grainsize in both samples and that the differences between the upper and lower soil grainsize is minor, varying by only a few percent.

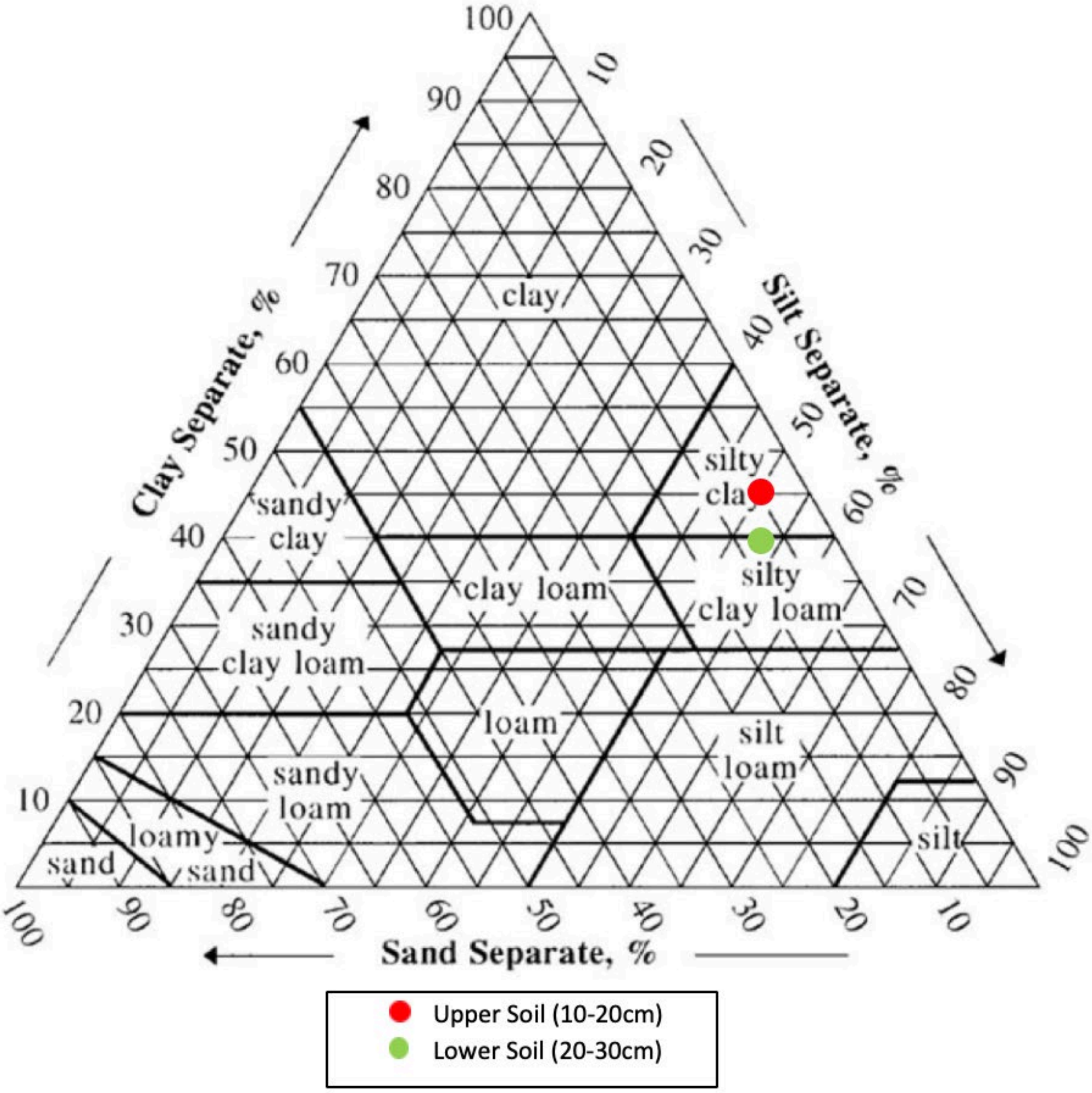

Figure 7. *Textural classification of soils. Average upper soil classification shown by red dot and average lower soil classification shown by green dot.* (Natural Resources Conservation Service Soils, 2020)

3.4 Soil Moisture

Figure 8 shows soil moisture plotted against the elevation of each site, and a negative correlation can be observed, whereby soil moisture decreases with elevation. This unusual result was also found by a research group who carried out a similar investigation at the same location last year (GroupN, 2019). The highest soil moisture values were generally found in the wildflower meadow, where elevation was at its highest, with an average of 53.4% compared to 45.8% in the amenity grassland. As Figure 8 shows, there was a significant peak in soil moisture to 74.63% at 68m, and a smaller peak of 54.3% at 204m.

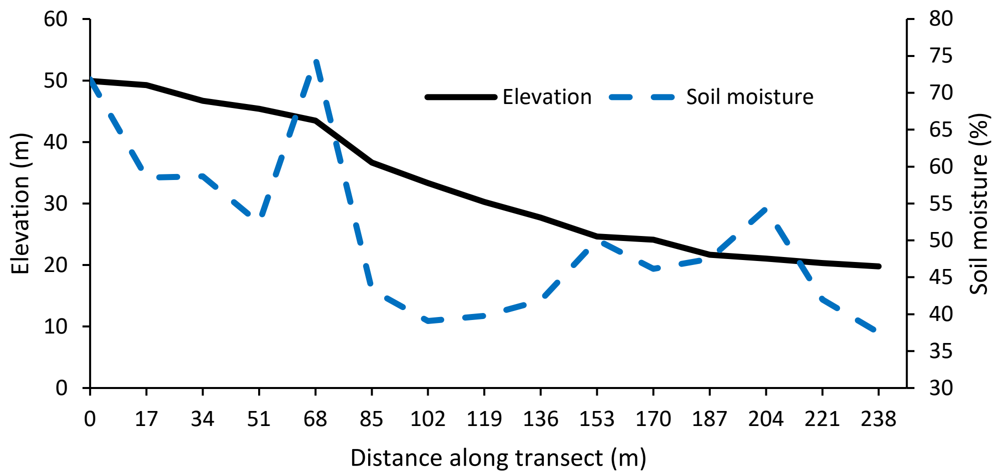

Figure 8. *Graph showing elevation and soil moisture changes along the transect*

3.5. pH

According to previous research which has taken place at this location, the soil in both the wildflower meadow and the amenity grassland was expected to read close to neutral, pH 7 (GroupN, 2019). However, as seen in Figure 9, pH readings at our sites were consistently between 8-10, highlighting a slight alkalinity to the soils which is unusual (Gazey, 2018).

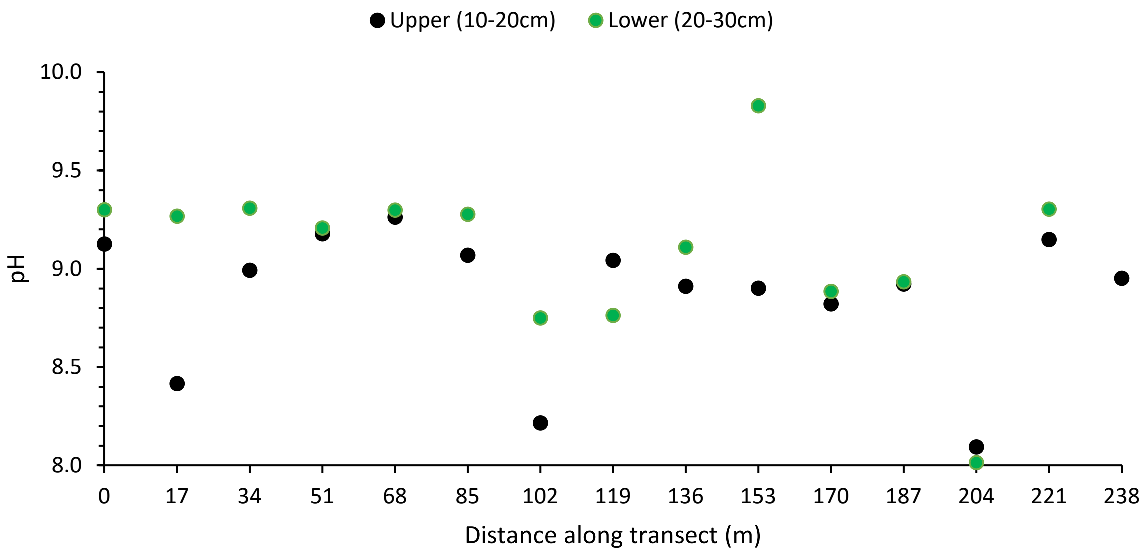

Figure 9. *Scatter plot showing pH values of upper (black) and lower (green) soil samples along the transect*

At 204m along our transect, the lowest pH for both sites were recorded with both under a pH of 8.1. At 153m along our transect, the highest pH reading for the lower soil was recorded with a pH of 9.8, whereas at 68m the highest pH for upper soil was recorded with a pH of 9.3.

3.6. Heavy Metals

As previously stated, the soil samples were measured for heavy metals externally. The metals analysed were cadmium, nickel, copper, chromium, lead and zinc. Zinc and lead were the heavy metals found in the highest quantities. Overall there were higher concentrations of each heavy metal in the lower soil than the upper soil. Zinc and lead had the highest values at 170m along the transect in the lower soil with 1467.58ppb and 449.83ppb respectively. Cadmium had the lowest concentrations found in the soil samples with 0.13ppb in the lower soil at 85m along the transect. The most striking result from the heavy metals was the extremely low values found for all the metals compared to a UK national average (Appendix 4), (Nicholson & Chambers, 2007). For example, we found 47.22ppb of chromium in the upper soil whereas the UK average value for chromium in soils is 23,000ppb. However previous investigations into the heavy metal content of the soil in this location also had the same results (GroupN, 2019).

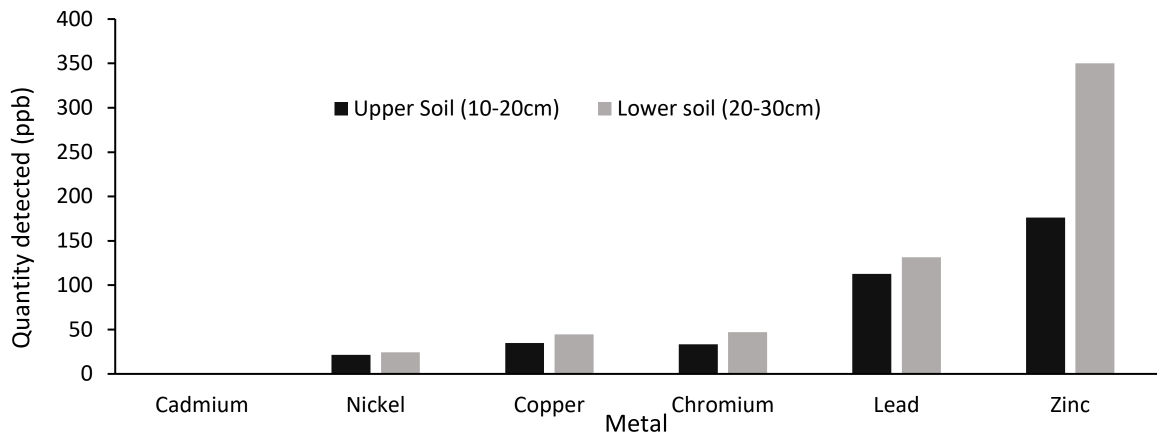

Figure 10. *Quantity of heavy metals detected in upper (black) and lower (grey) soil samples, averaged across 15 sites.*

4. Discussion

4.1. Nutrients: Nitrate and Phosphate

Phosphate is an important macronutrient that promotes root development and energy transfer essential for plant growth, therefore is an important factor in the dynamics of a wildflower meadow (Brunings, 2005). Phosphate quantities recorded during our investigation provided a significant range of data (see Figure 4). The lowest value of phosphate, 11.08µg/l, was recorded at 204m in the upper soil and the highest, 281.51µg/l, at 102m in the lower soil. Nitrate is another macronutrient, also essential for plant productivity as a key component of proteins (Morgan, 2013). Nitrate quantities recorded also provided a large range of results, from 0.29µg/l at 0m in the upper soil, to 46.43µg/l at 102m in the lower soil. This large range of nutrient quantities seen in Figure 4 indicate that soil nutrients are not consistent along our transect. However, there is no clear distinction between the wildflower meadow and the grassland. This is supported by Group N who found that the nutrient quantities in the topsoil was no different across the two areas (GroupN, 2019). Additionally, the average quantity of both nutrients was higher in the lower soil samples, phosphate by 7.8% and nitrate by 5.6%, which could be a result of drainage patterns causing nutrients to leach out of upper soils (Lehmann & Schroth, 2003).

Nitrate was found in much lower quantities than phosphate, which was expected as nitrate quantities under 20µg/L in soil are the most ideal for plant growth (Fieldhouse, 2008). 24 of the 28 samples collected provided nitrate values under 20µg/l, suggesting that the nitrate level in the soil across the meadow and grassland is not limiting plant growth.

The largest peak in both nitrate and phosphate occurred at 102m in the lower sample, mirrored by a similar, slightly smaller peak in the upper sample, which could be an indicator that this area of soil along our transect was most nutrient rich. Dog walkers are regular users across the wildflower meadow and grassland, which has an impact on phosphate levels within the soil, as dog faeces contains about 0.25% phosphate that can accumulate over time (Jaber, 2012). This peak therefore may be a result of dog faeces at this location along the transect, however, there was no distinct visible evidence of this. Plant decay also impacts nutrient density so studying this site in summer months could help to show whether a greater density/variety of plants grow at this location along the transect, which would help understand why the nutrient content spiked.

At every peak in Figure 4, both nitrate and phosphate mirror each other, therefore a parametric t-test was run to establish whether the correlation between nitrate and phosphate was consistent along the whole transect. However, a p-value of 0.238 illustrated a poor relationship between the two variables, suggesting they are not interlinked. Therefore, evidence of landfill impacts on nutrient content within the wildflower meadow were not found within our investigation.

4.2. Organic Matter Content

Organic content exhibits an increasing trend with distance along the transect, moving from the wildflower meadow to the amenity grassland. This may be linked to the different plant types that grow across the wildflower meadow, but research in the summer months would be needed to investigate this further. Wildflower meadows are characterised by low organic content (Forest Research, 2014), which explains why the lowest organic content values are found in the meadow area at the top of the transect. Despite this, a t-test calculated a p-value of 0.666 indicating no significant difference in organic content between the meadow and the grassland. This lack of difference could suggest that landfill is not influencing the organic content of the meadow and grassland area, however, we have no further evidence to back this theory up so further investigation is needed. The sharp dip in organic content at 204m, shown on Figure 5, can be explained by shallow soil as a result of the South Bristol Storm Drain running underneath, which reduces scope for plant growth and nutrient cycling, hence reducing organic content.

Comparing our data to topsoil data (GroupN, 2019) collected along a similar transect, shows that topsoil contains the highest organic content with an average of 16.25% (see Appendix 6). This is expected as the topsoil is first to receive nutrients from plants and rainfall that infiltrates the ground. Upper soil content from our investigation showed a lower level of organic content, which is expected due to loss of nutrients with depth in the soil. However, there is only 0.85% difference between organic content in the upper 12.36% and lower 11.51% samples. The high organic content in the topsoil increases soil aggregation, improving soil permeability (Funderburg, 2001). Heavy rainfall the week before our data collection (see Appendix 7), paired with increased infiltration due to soil aggregation and possible macropores, allows nutrients to reach the deeper soil, which explains why the difference between average upper and lower soil results is so small.

Organic matter can hold up to 90% of its weight in water (Funderburg, 2001), therefore, we expected soil moisture to increase with organic content. However, Figure 11 shows that there is close to no correlation between the two factors for both the lower and upper soil samples, with R^2 values of 0.0831 and 0.1234.
Overall, our results provided no significant evidence that the underlying landfill has any impact on the organic content of the upper or lower soils in the wildflower meadow as all trends can be explained by other influencing factors.

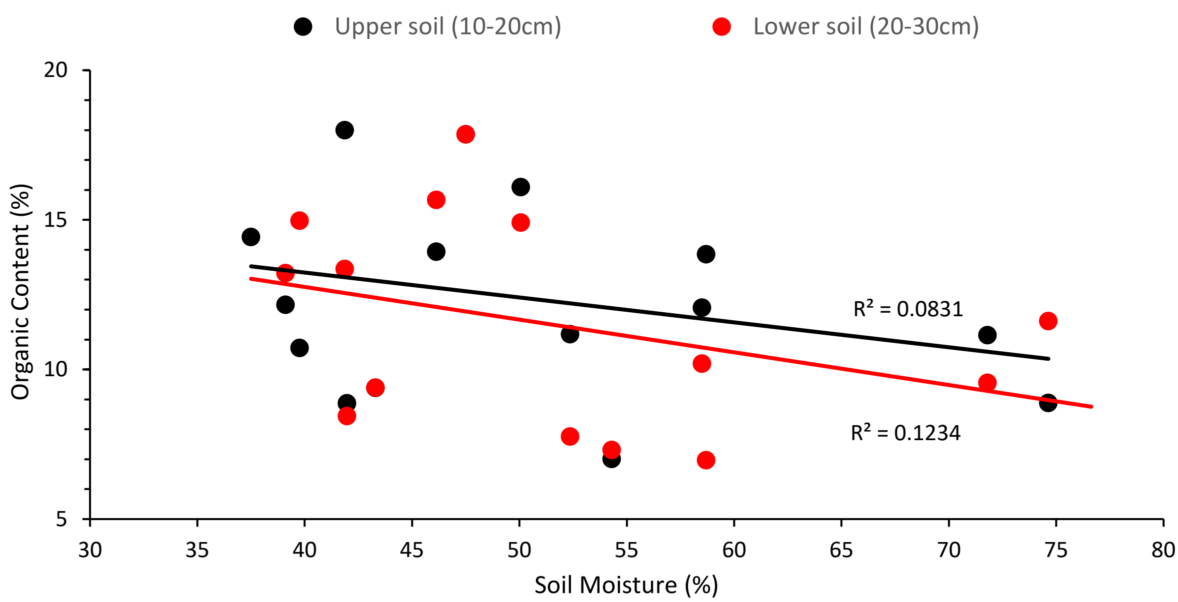

Figure 11. Cross plot of organic content and moisture for upper (black) and lower (red) soil samples, including linear trendlines and R^2 values

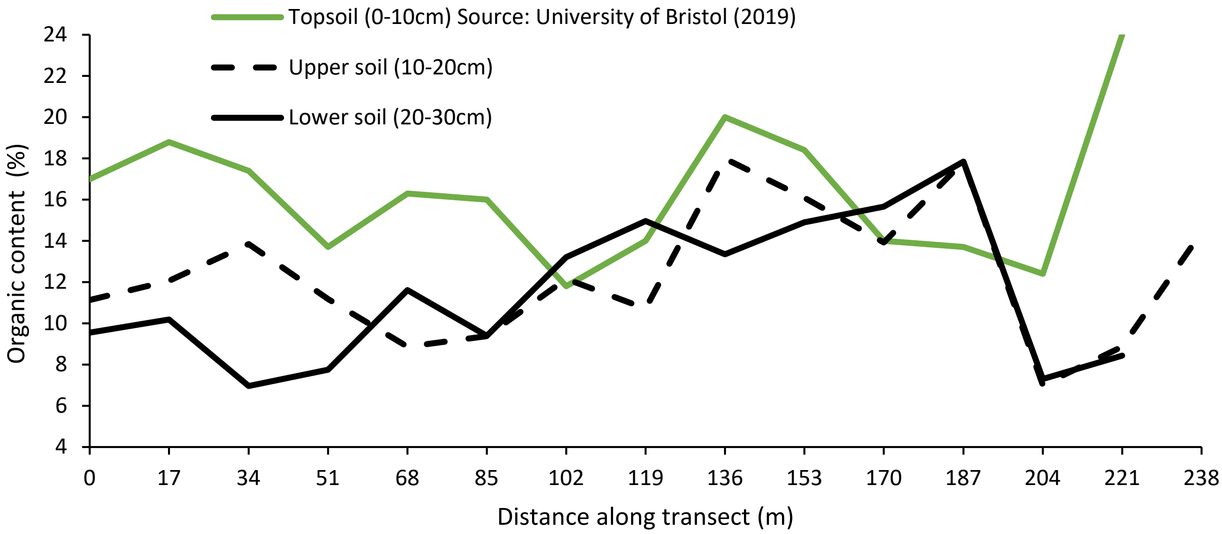

Figure 12. *Graph comparing upper and lower soil organic content to secondary topsoil data (shown in green)* (GroupN, 2019) *along the transect.*

4.3. Grain Size

Grainsize is a key component of soil profiles and heavily impacts drainage patterns, making it an important variable to look at in this investigation. Sand content was noticeably low in both the upper and lower soils (see Figure 6). This is due to the prevailing geology being Mercia Mudstone (Digimap , 2020), which as a group is typically characterised by a sequence of clays, with occasional beds of silts and sands, so sand is expected to be in lower quantities (Hobbs P. , 2002).

Figure 6 shows that in both the upper and lower soil samples there is an increasing proportion of clay and decreasing proportion of silt moving down the transect from the meadow to the grassland.The proportion of clay in the grassland is significantly higher in both the upper and lower soil depth in comparison to the wildflower meadow. Average clay percentage values in the upper soil are 41.39% in the wildflower meadow compared to 59.4% in the grassland. In the lower soil, clay is 35.9% in the wildflower meadow compared to 46.4% in the grassland. The proportion of silt, however, is significantly higher in the meadow than in the grassland. Silt values in the upper soil of the meadow are 52.18% compared to 44.15% in the grassland. A similar trend follows in the lower soil, with values in the meadow at 55.99% compared to 49.38% in the grassland. One explanation for this trend is that the finer clay particles are washed downslope to the grassland in wet conditions like were experienced in the weeks before conducting our investigation (see Appendix 7).

Shown on Figure 7, the average values across the transect for the upper soil places it in the silty clay classification and the lower soil in the silty clay loam classification. However, looking at the proportional differences between the upper (Figure 6a) and lower (Figure 6b) soils, reveals that variances are minor, only a few percent, which suggests the soil is well mixed. A t-test was used to analyse the statistical difference between the grainsize of the upper and lower soils and the meadow and grassland. The resulting p-values of >0.05 proved there was no significant difference between clay and silt in the upper and lower soils. Lack of distinct differences between soil layers means that no conclusion regarding the impact of underlying landfill and the possible clay cap can be made, further investigation would be needed.

Grainsize also has an effect of nutrient availability in soils. Nutrient fixation by clay in topsoil means that where clay content is high there are fewer unbound nutrients available to plants (Northland Regional Council, 2019). Figure 13 illustrates this relationship, showing that phosphate levels decrease as clay content increases down the transect. However, the low R^2 value suggests there is almost no relationship, therefore further investigation into this would be needed to confirm a correlation. As a result of this, grainsize data provides an unconvincing argument that there has been an impact of landfill on the wildflower meadow and surrounding amenity grassland.

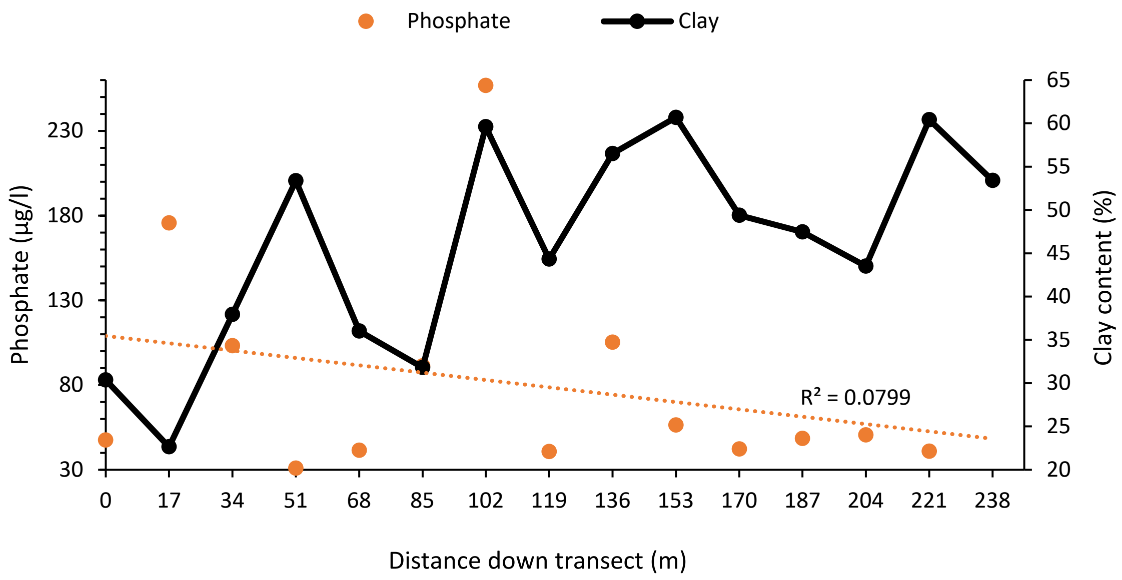

Figure 13. *Relationship between clay content (%) and phosphate content (µg/l) down the transect, including trendline and* R^2 *value for phosphate*

4.4. Soil Moisture

During precipitation events, hillslope processes of run-off, sub-surface flow and overland flow normally result in water build up at the bottom of a slope (Dunne, 1970). Therefore, we would expect soil moisture to be highest towards the end of our transect, which runs downhill. However, Figure 8 shows that soil moisture decreases as elevation decreases along the transect, the opposite to what was expected. A t-test was run to assess the significance of this correlation by comparing soil moisture to elevation, resulting in a p-value of 0.05, which shows there is a statistically significant difference, confirming there is a relationship between the two variables. On the other hand, the random nature of peaks of soil moisture content across the transect present no clear pattern, with a peak at 68m (74.64%) and a peak at 204m (54.3%). Observations made when collecting data show that these peaks coincide with areas of bog, heightened by the wet conditions preceding our investigation (Appendix 7). This shows how elevation is only one of many factors impacting soil moisture.

One explanation for the unusual drainage pattern is compaction of soil at the top of the meadow, which reduces the permeability of the ground, causing water to collect on the surface. This may have occurred as a result of heavy machinery used during the construction of the storm drain nearby. The possible dumping of arisings at the base of the hill would have improved soil drainage, which could also explain the pattern seen in the results. Also, at the majority of sites the grainsize proportions reveal large quantities of clay in the soil, which could infer a reason for water pooling at the top of the slope, due to the relatively impermeable soil.

However, Figure 14 does not provide a clear trend of this inference, instead showing a limited relationship between clay content and soil moisture. When carrying out a t-test for clay against soil moisture content, the upper soil provided a p-value of 0.01, which suggests there is a possible small relationship between the two variables. On the other hand, the lower soil against soil moisture content provided a p-value of 0.119, which suggests there is not a relationship between the two variables. This is consistent with our results, since higher clay content was found in the upper soil, so permeability of this could impact more strongly on soil moisture content readings obtained by the theta probe.

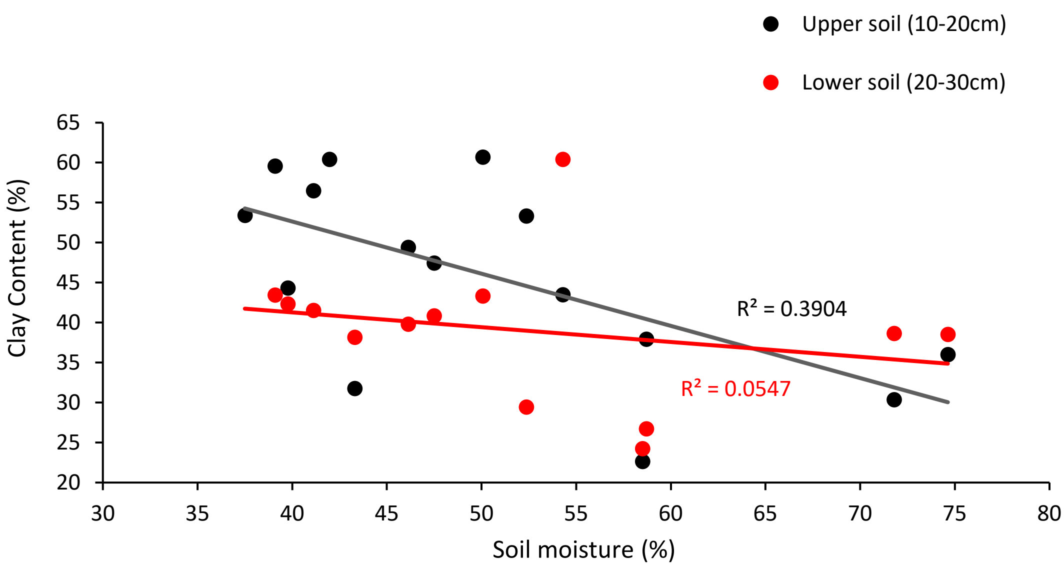

Figure 14. *Scatter plot of soil moisture (%) against clay content (%) for upper and lower soil samples*

Figure 14 shows a negative correlation between clay content and soil moisture in both the upper and lower soil. As the proportion of clay decreases, soil moisture increases, which is the opposite of what you would expect. However, this is a very weak correlation shown in the low R^2 values, which must be considered. Microtopography and slope convergence are factors which also effect soil moisture results so further investigation would be needed to quantitively record their effect.

It is important to note that antecedent conditions prior to our data collection on January 20th would have had an impact on the results. Heavy rain in the weeks before our data collection (Appendix 7) may have largely increased soil moisture content. In any further study, it would be interesting to compare results from data collection after dry weather to see whether it impacts the drainage pattern.

Although it is clear something is controlling the unusual drainage patterns of the site, it cannot be concluded that is from one particular factor, for example the elevation of the site or the effects of the landfill. As stated above, further investigation is needed to establish reasons the drainage patterns.

4.5. pH

Any leachate from the underlying landfill that may be contaminating the soil can be detected by measuring soil pH (Gomes, 2016), which is why pH was an important dataset to collect. The different pH of the soil along the transect (see Figure 9) was used as a standardised indicator to investigate any differences between the grassland and meadow. The average pH for the wildflower meadow was 9.0 and the grassland 8.9, so both are clearly alkaline. However, a t-test was used to measure the extent of the statistical distinction between the meadow and grassland, resulting in a p-value of 0.315, which shows a lack of significant difference.

On the other hand, a p-value of 0.018 was found when a t-test comparing the upper and lower soil across the whole transect was conducted, which proves there is a significant difference between the two soil layers. Average pH for upper soil readings was 8.9 and lower soil readings was 9.1, suggesting that the soil is more alkaline deeper below the surface. The alkalinity of our results was surprising considering the literature, which stated that for a large number of vegetation species a pH between 5.7-8 is the optimum range for growing conditions (Gazey, 2018). Our results also contrasted to results from a previous study, which found an average pH of 6.7 in the topsoil of the grassland and 7.4 in the wildflower meadow (GroupN, 2019).

Leachate itself is more alkaline so could be a possible influence on the nature of our findings, as we were investigating deeper into the soil compared to last year's project (Gomes, 2016). Wet weather conditions (Appendix 7) may have also had an impact on our pH findings. However, clay soils are more resistant to change than other soil types, so it is surprising to see such a difference in results, due to the similarity in transect location. Conversely, with the flourishing of species noted in the summer months, the pH condition of the meadow and grassland must be sufficient for optimal growth, even with the high values we collected. Important to note, variation in pH is to be expected across different wildflower meadows (Gough, 1990).

The alkaline pH of the soil gives a possible indication of landfill effects on the soil profile of the site. As stated previously leachate from landfill can cause pH to turn alkaline. However, due to previous studies not discovering the same results, more investigation is needed to fully determine whether the landfill is having a significant affect or not.

4.6. Heavy Metals

In our results, zinc and lead were found in the highest quantities in both the upper and lower soils, shown in Figure 10, which was expected as these metals naturally occur in high quantities in soils (Wuana & Okieimen, 2011). The highest quantity of both metals was found in the lower soil at 170m with quantities of 1467.58ppb zinc and 449.83ppb lead. These peaks could possibly be due to leachate from the landfill, which commonly contains high quantities of heavy metals (Wuana & Okieimen, 2011). In our results, zinc and lead were found in the highest quantities in both the upper and lower soils, see Figure 10, which was expected as these metals naturally occur in high quantities in soils (Wuana & Okieimen, 2011). The highest quantity of both metals was found in the lower soil at 170m with quantities of 1467.58ppb zinc and 449.83ppb lead (see Figure 15B). These peaks could possibly be due to leachate from the landfill, which commonly contains high quantities of heavy metals (Wuana & Okieimen, 2011). However, even the highest values we recorded were significantly lower than the UK averages for heavy metals in soils (see Appendix 4). For instance, average zinc quantity is 82,000ppb, lead is 40,000ppb and a similar theme occurs with chromium, copper, nickel and cadmium. This would suggest that the heavy metals in the soil were not having any significant negative effect. However, all the metals analysed were over the detection limit so there is significance to these findings, despite them being so much smaller than the UK averages seen in Appendix 4.

From initial viewing of Figure 15, zinc and lead show relatively stable quantities along the transect until 102m, where a sharp increase occurs which could be linked to soil properties. Consequently, a t-test was conducted to assess whether zinc and lead had a significant difference between the meadow and grassland, but p-values of 0.348 and 0.294 respectively suggested a lack of relationship between the two variables.

Since heavy metals are known to bind to positively charged clay (Gustafsson, Pechová, & Berggren, 2003), we expected the greatest quantity of metals to be found in our upper soil, which had greater clay percentages. However, the lower samples generally had a higher quantity of heavy metals (see Figure 10) which contradicts this claim. This may be due to the possible influence of other factors such as pH and soil moisture which can affect the metal binding in soils (Wuana & Okieimen, 2011). The overall low heavy metal values would suggest that there is no metal pollution from the underlying landfill deeper below the surface. Linking back to our research question, the fact that heavy metal quantities were so low suggests that there is little impact on the wildflower meadow from possible arisings deeper below the surface.

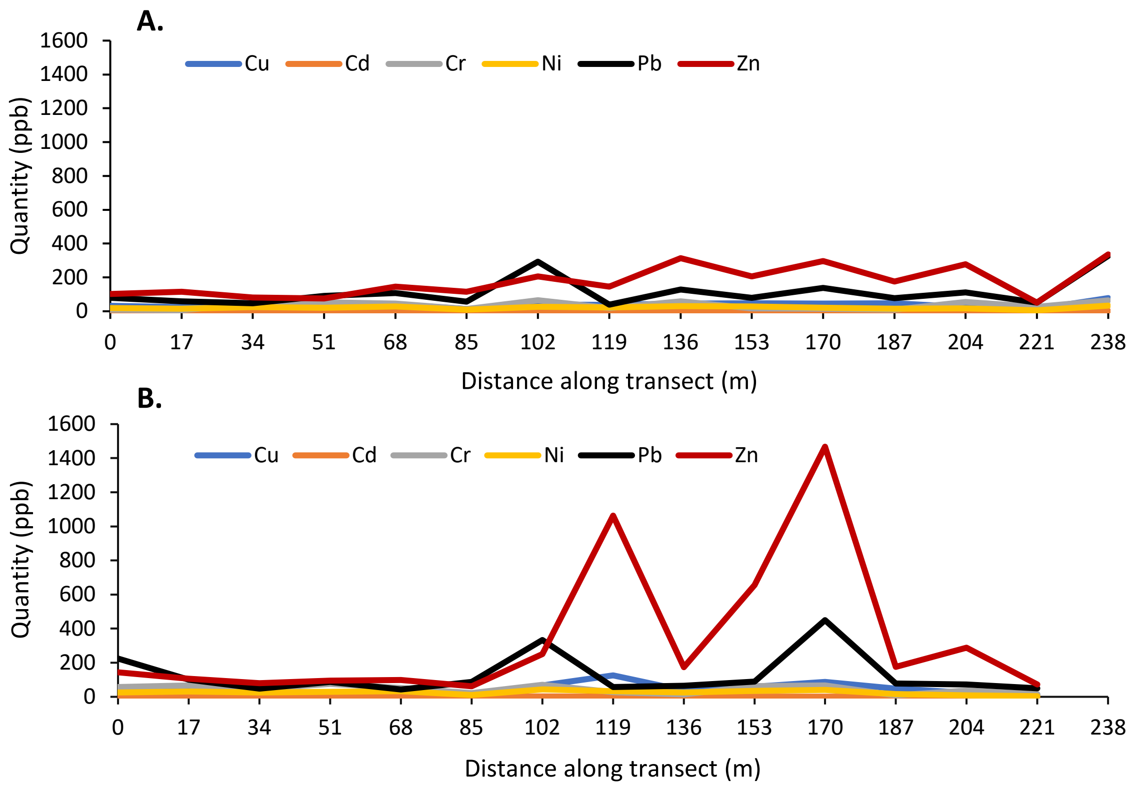

Figure 15. *Heavy metal quantities (ppb), including Copper (Cu), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Lead (Pb) and Zinc (Zn), found in the upper (Graph* ***A****) and lower (Graph* ***B****) layers of soil along our transect.*

5. Limitations

1. **One transect** – Following on from a previous study, we limited the investigation to just one transect, however this meant our results were not an accurate representation of the meadow as a whole. As a result, our conclusions and suggested future work should be handled with caution, as other parts of the meadow would likely show different results.
2. **One set of antecedent conditions** – Due to time pressures, we were only able to collect data in a 1-week period in January and found the ground to be almost frozen. This meant it was very difficult to core to the lower depth at site 15, with samples unable to be collected here. Sampling in summer months, or in a different set of antecedent conditions would be fundamental to creating a more complete data set, that could highlight more trends.
3. **Low number of repeats in the field** - For our research we were restricted to 30 samples and this proved problematic. We felt it was more important to cover

the length of the meadow and the amenity grassland rather than focus on one smaller transect length covering just one of these areas. However, a consequence of this decision meant there was a maximum number of 2 samples per site. We also felt it was important to assess the change in soil property by depth, and thus chose two depths at each site with an upper soil layer at 10-20cm and a lower soil layer at 20-30cm. This restricted repetition of soil samples to just one at each soil depth, so analysis is based from one set of results. This means that our data is not as reliable or rigorous as we had hoped. Moreover, the cleaning of the soil corer between sample collections would not have prevented cross-contamination, due to the basic method of just wiping it with a paper towel. This meant that particles of soil remained on the corer between upper and lower sample collection, so mixing of samples will have occurred that could impact our results. However, elimination of this as a factor could be laborious due to the difficulty of removing every soil particle, and the remaining soil for contamination is minimal.

4. **Low number of repeats in the lab** - Due to laboratory logistical issues, no laboratory analysis was able to be repeated. For our grainsize data, 3 samples were repeated and the Mastersizer produced very different results each time. This variation in results is caused by the Mastersizer only requiring 0.2g of each soil sample. Our samples would not have been fully homogenised which lead to the difference in the results. Without lab constraints, repetition of all of the Mastersizer data would be useful for more representative values of grain size for each sample and consequently more reliable data.
5. **Limited set of secondary data** – due to the niche nature of our investigation, there was a limited set of secondary data relating to landfill's effect on recreational land, meaning it was difficult to compare our results to others in the field. Therefore, our results should be treated with caution, and repeated by others for a more reliable data set, in order to derive accurate conclusions.

6. Future Research

There are many areas in which we felt that there were unexplored possibilities within the wildflower meadow. Due to lab constraints, we could only collect 30 samples, so a future group could replicate our experiment over a larger pool of sample sites. This would help to possibly give a wider representation of the properties of the soil across the meadow. Additionally, sampling over a longer time period could establish the role of wider external factors such as the influence of weather and seasonality on the soil, rather than just sampling in January which was a struggle due to frozen ground. Analysing the wildflower meadow in the summer months would undoubtedly provide vastly contrasting results. Deeper soil cores could also be investigated to assess the depth of a possible clay cap, which at a depth of 30cm was not discovered. This would help to assess the extent of the landfill that has been documented in our historical research.

Multiple transects covering the entire wildflower meadow could also be investigated to further develop data from our soil moisture content analysis that showed a trend of ground being wetter at the top of the slope, contrary to usual understanding of hillslope processes. The possible causes for this pattern of soil moisture content would need to be understood and researched in more depth, such as the compaction of the soil, texture of the soil and presence of macropores. Again, this could be investigated in relation to seasonality and weather to notice changes on the wildflower meadow across the course of the year.

Areas of bog were also identified during our project, which could provide an interesting future research basis to assess why these occur sporadically across the meadow in no clear pattern. Deeper investigation into the relationship between type of vegetation and soil moisture could be conducted as a possible cause of a differing pattern between the meadow and amenity grassland. Furthermore, the fact that our heavy metal content analysis in the soil provided such low quantities compared to UK average values could be a key area of future research, as there could be an undetermined factor contributing to this that could be useful for conservation of the wildflower meadow. Finally, literature has pointed to rivers as a key channel of landfill investigation (Jaber, 2012), so the nearby Malago River to the wildflower meadow could be assessed for leachate concentrations to analyse a possible presence of landfill.

7. Conclusions

Understanding the effects of landfill on the overlying recreational land is vital due to the potential threat it causes to millions of people that use these areas every year. Our research revealed that the underlying landfill at this site had no obvious effect on the soil profile or drainage patterns in the Manor Woods Valley Wildflower Meadow. Although unusual drainage patterns were found, we established that there was no correlation between the landfill and elevation with these patterns, and concluded it was potentially due to the varying levels of compaction at the surface from heavy metal machinery during the construction of the Bristol Storm Drain. Quantities of different heavy metals in the soils were also found to all be low, especially when compared to the UK average, suggesting there was no leachate from the landfill contaminating the soil and therefore having no effect on the soil profile. Overall, we found the recreational land of Manor Woods was not affected by the landfill however without further research into the site and other recreational sites, this is not representative and conclusive for the effects on landfill on all overlying recreational land. Therefore, our investigation further exemplifies the need for wider research in the effects of landfill lying beneath recreational grounds.

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Appendix

Raw data:

Appendix 1 - Results table for nutrients, LOI, CaCO3, soil moisture and pH along the transect

Sample	Location	Distance along transect (m)	Phosphate (µg/l)	Nitrogen (µg/l)	LOI (%)	Soil Moisture (%)	Average soil moisture (%)	pH
1a 1b	527159E 5697185N	0	47.50434 56.19559	0.28981 0.50565	11.13761 9.548456	8.952 72.2 73.7	71.8	9.125 9.300
2a 2b	527177E 5697150N	17	175.5914 54.61683	6.35469 0.78365	12.06026 10.18735	56.6 60 58.9	58.5	8.415 9.267
3a 3b	527193E 5697175N	34	103.1268 48.21874	13.90142 2.2686	13.84158 6.960548	58.9 54.2 63	58.7	8.993 9.309
4a 4b	521210E 5697174N	51	30.96542 50.73281	0.57566 3.95323	11.17456 7.756082	42.1 59.7 55.3	52.37	9.178 9.208
5a 5b	527227E 5697172N	68	41.4691 53.56985	0.95034 10.51383	8.869948 11.60821	75.5 73.9 74.5	74.63	9.263 9.298
6a 6b	527243E 5697171N	85	91.33263 49.38186	10.78218 1.09114	9.381746 9.390581	41.4 44.7 43.8	43.3	9.068 9.278
7a 7b	527260E 5697169N	102	256.8027 281.5066	26.26706 46.42717	12.15256 13.2116	38.5 40.5 38.3	39.1	8.216 8.749
8a 8b	527278E 5697167N	119	40.6874 74.56808	1.53148 0.68228	10.70824 14.9622	43.6 40.6 35.1	39.77	9.042 8.763
9a 9b	527294E 5697165N	136	105.2788 47.33452	5.2791 1.00365	17.9893 13.35464	40.9 38.8 45.9	41.13	8.911 9.109
10a 10b	527310E 5607164N	153	56.37954 74.44318	1.70277 14.65245	16.08786 14.90212	45.5 50.6 54.1	50.07	8.901 9.83
11a 11b	527327E 5697161N	170	42.16806 260.6347	0.5139 42.00924	13.93151 15.6648	48.7 45.7 44	46.13	8.822 8.884

12a 12b	527345E 5697158N	187	48.47189 48.47189	0.41626 0.41626	17.84684 17.84684	48 46.5 48	47.5	8.923 8.923
13a 13b	527360E 5697154N	204	50.5985 11.07887	0.72765 0.54765	7.005165 7.303458	53.5 49.4 60	54.3	8.093 8.013
14a 14b	527316E 5697150N	221	40.98077 48.97786	0.56035 22.75224	8.868984 8.436328	38.1 41.9 45.9	41.97	9.149 9.304
15a 15b	527392E 5697146N	238			14.417	39.7 35.5 37.3	37.5	8.952

Appendix 2 – Table of results of heavy metal analysis

Sample	Cadmium (ppb)	Chromium (ppb)	Copper (ppb)	Lead (ppb)	Nickel (ppb)	Zinc (ppb)
1a 1b	0.35 0.65	8.78 58.04	32.31 51.48	80.42 224.38	18.31 24.64	101.69 142.88
2a 2b	0.32 1.06	5.91 66.19	24.23 36.96	58.58 101.38	14.95 31.29	115.26 105.34
3a 3b	0.33 0.33	44.64 44.64	17.47 17.45	48.16 47.75	24.61 24.59	80.57 80.48
4a 4b	0.36 0.28	52.70 75.81	14.54 19.22	90.74 88.37	21.14 28.64	76.09 94.45
5a 5b	0.16 0.97	44.56 52.03	42.36 30.72	107.08 42.99	29.37 32.52	145.80 97.84
6a 6b	0.64 0.13	12.62 21.13	14.22 14.69	57.60 87.79	10.35 11.06	114.48 61.91
7a 7b	2.19 2.38	65.32 70.53	40.02 66.76	293.34 332.84	26.08 43.42	206.19 249.77
8a 8b	0.49 0.55	18.45 27.43	37.08 125.76	29.14 59.63	21.87 33.77	145.14 1064.07
9a 9b	0.73 0.38	58.91 14.70	45.49 36.37	129.08 65.03	30.97 24.81	314.43 173.36
10a 10b	0.73 1.38	17.62 63.20	46.60 58.44	80.16 89.12	29.36 35.07	205.92 659.04
11a 11b	0.56 2.77	15.25 65.86	46.07 87.87	137.94 449.83	20.91 40.30	296.27 1467.58
12a 12b	0.32 -	8.61 -	48.15 -	77.72 -	16.04 -	176.44 -
13a 13b	1.95 2.31	54.37 36.11	23.98 23.97	111.53 72.71	16.55 9.47	278.80 288.18
14a 14b	0.34 0.17	26.87 15.46	13.46 11.59	50.42 49.89	5.76 3.68	51.01 72.19
15a 15b	2.32 -	63.46 -	77.99 -	327.64 -	33.36 -	336.10 -

Appendix 3 - Table of detection limit table for heavy metals

	Cadmium (ppb)	Chromium (ppb)	Copper (ppb)	Lead (ppb)	Nickel (ppb)	Zinc (ppb)

Detection Limit	0.23	1.00	0.25	100.00	0.71	0.05

Appendix 4 – Table of UK average of heavy metal quantities in soils

Heavy Metal	UK Average (ppb)
Cadmium (Cd)	18,0000
Chromium (Cr)	23,000
Copper (Cu)	39,000
Lead (Pb)	40,000
Nickel (Ni)	700
Zinc (Zn)	82,000

Source: McGrath, S. and Zhao, F. (2006) Ambient Background Metal concentrations for Soils in England and Wales. [online] Assets.publishing.service.gov.uk. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attac hment_data/file/290474/scho1106blpv-e-e.pdf (Accessed 28 February 2019

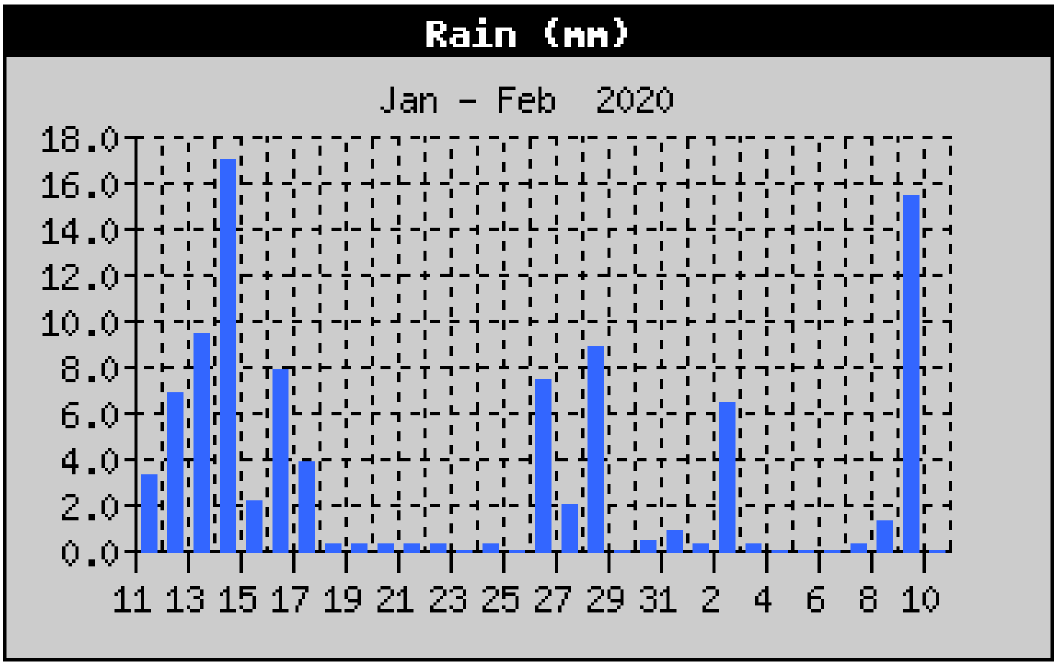
Appendix 5 - Table of grainsize results

Sample	% Sand	% Silt	% Clay
1a 1b	7.46 6.92	62.186 54.4	30.35 38.67
2a 2b	9.128 11.466	68.256 64.286	22.638 24.24
3a 3b	6.28 11.18	55.796 62.106	37.922 26.712
4a 4b	3.76 12.094	42.88 58.468	53.35 29.434
5a 5b	7.244 6.564	53.292 54.876	36.028 38.55
6a 6b	9.312 7.322	58.902 54.496	31.788 38.176
7a 7b	2.424 5.83	37.972 50.562	59.592 43.468
8a 8b	5.316 5.262	50.296 52.396	44.316 42.338
9a 9b	3.52 6.142	39.994 52.32	56.498 41.544
10a 10b	3.14 5.822	36.166 50.836	60.69 43.328
11a 11b	4.514 5.068	46.104 55.112	49.396 39.802
12a 12b	4.424	48.104	47.45
13a 13b	3.876 4.09	52.62 55.064	43.496 40.842
14a 14b	1.83 1.83	37.79 37.79	60.4 60.4
15a 15b	2.476	44.106	53.406

Appendix 6 – Table of results for Loss on Ignition in topsoil (GroupN, 2019)

Sample	Location	LOI (%)
1	51°25’30.4”N 02°36’34.4”W	17
2	51°25’30.3”N 02°36’33.3”W	18.8
3	51°25’30.1”N 02°36’32.3”W	17.4
4	51°25’30.0”N 02°36’31.1”W	13.7
5	51°25’29.9”N 02°36’30.1”W	16.3
6	51°25’29.8”N 02°36’29.0”W	16
7	51°25’29.7”N 02°36’27.8”W	11.8
8	51°25’29.6”N 02°36’27.2”W	14
9	51°25’29.5”N 02°36’26.5”W	20
10	51°25’29.4”N 02°36’25.4”W	18.4
11	51°25’29.2”N 02°36’23.6”W	14
12	51°25’29.1”N 02°36’23.0”W	13.7
13	51°25’29.0”N 02°36’21.8”W	12.4
14	51°25’28.9”N 02°36’21.0”W	24

Appendix 7 – Graph of rainfall measurements for month of fieldwork (Bristol Weather, 2020)



Appendix 8 – Loss on Ignition crucible calculations

(a) Weight of crucible + weight of soil
(b) Weight of crucible
(c) Weight of Soil (a-b)
(d) Weight of Crucible + weight of ash
(e) Weight of crucible
(f) Weight of ash (d-e)
    (f/c x 100) = % of ash
(g) Loss on ignition-f)
    % loss on ignition (g/c x 100)

Source: G:\Teaching\RMES\2008-9\critical data analysis\handouts\organic analysis method.doc

Appendix 9 – Nitrogen phosphorous digest

Step 1: add 0.42g selenium powder and 14g lithium sulphate to 350mL 30% hydrogen peroxide. Once added, mix well
Step 2: Slowly add 420mL concentrated sulphuric acid whilst cooling

Source: Cobb, S., 2019. *Teaching Laboratories Manual of Field and Laboratory Methods.* Bristol: s.n, pp. 24-25

Appendix 10 – Rstudio t-test output

```
```{r setup,message=FALSE}
knitr::opts_chunk$set(echo = TRUE)
```

```{r}
library(mosaic)
library(tidyverse)
```

```{r}
cor_test (Phosphate ~ Nitrate, data = Nutrients)
```
```

```
        Pearson's product-moment correlation

data:  Phosphate and Nitrate
t = 7.893, df = 27, p-value = 1.742e-08
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.6755477 0.9200940
sample estimates:
```