Terra Soil: Soil nutrient descriptive statistics

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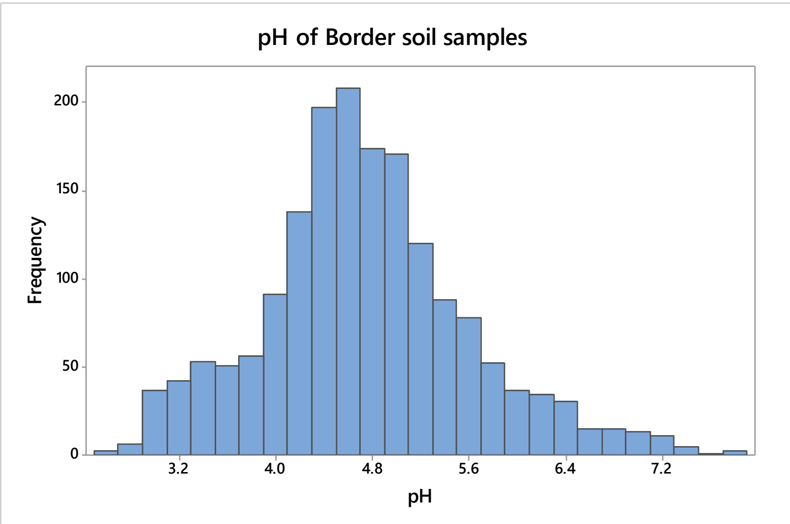
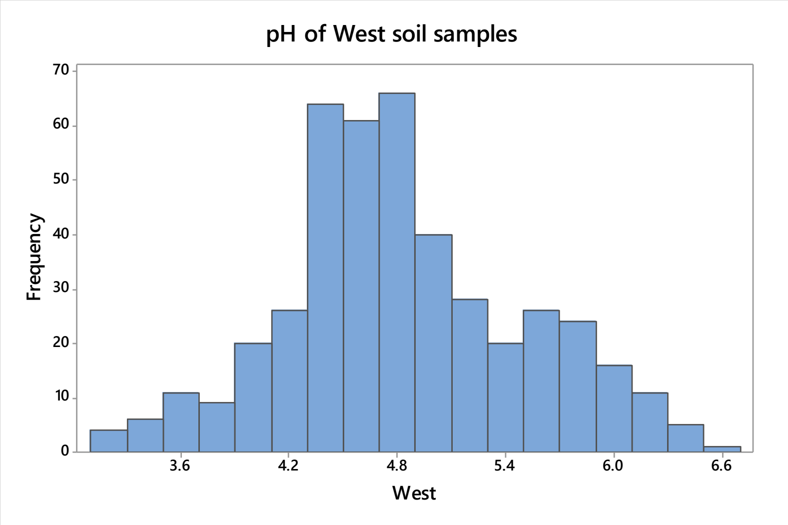
Soil pH

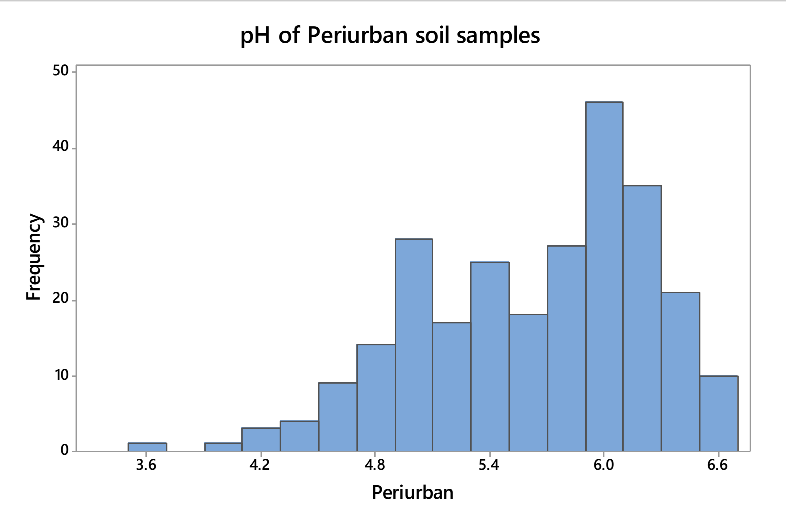
Irish soils are naturally acidic due to acidic bedrock, rainfall intensity and chemical/organic fertiliser applications. Crops differ in sensitivity to soil pH, yet the optimum uptake of fertilisers/essential soil nutrients is obtained with a soil pH of 6.5 (Teagasc[1], 2017). Soils become more acidic, which is a problem for Irish soils, due to; (i) rainwater leaching away basic ions, (ii) carbon dioxide decomposing organic matter and crop root respiration dissolving in soil water to form a weak acid, and (iii) formation of strong organic (nitric) and inorganic acid (sulphuric) from decaying organic matter and oxidation of ammonium/sulphur fertilisers (Fay et al. 2007). Lime is a soil conditioner which corrects soil acidity by neutralising acids so micro-organisms can thrive, to have optimum crop yields soil pH should be regulated by lime addition when needed.

Descriptive statistics of pH:

pH	Borders	West	Periurban	Midlands
Mean	4.5	4.8	5.6	5.0
Min	2.55	3.1	3.5	2.7
Max	7.8	6.7	6.7	7.1
Median	4.5	4.7	5.7	5.0
1st Quartile	3.8	4.4	5.1	4.4
3rd Quartile	5	5.2	6.1	5.7
Interquartile range	1.2	0.8	1	1.3
Skewness	0.55	0.23	-0.54	-0.37
Missing values	0	0	0	0







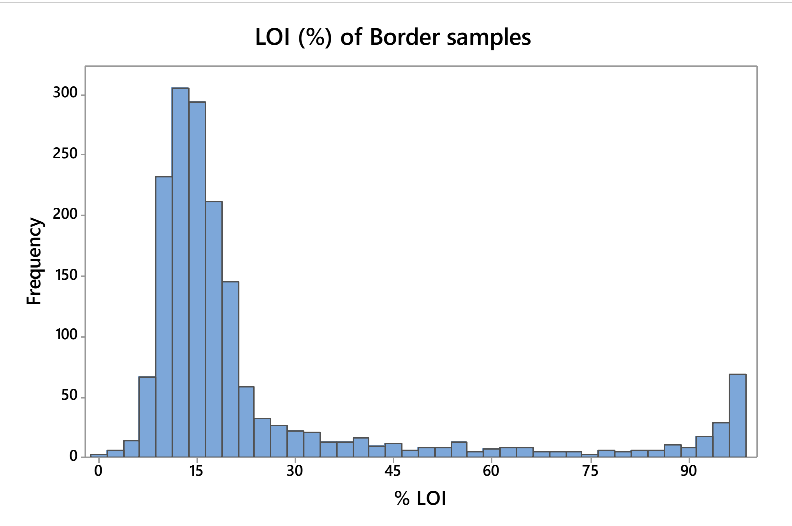
Loss on ignition, LOI

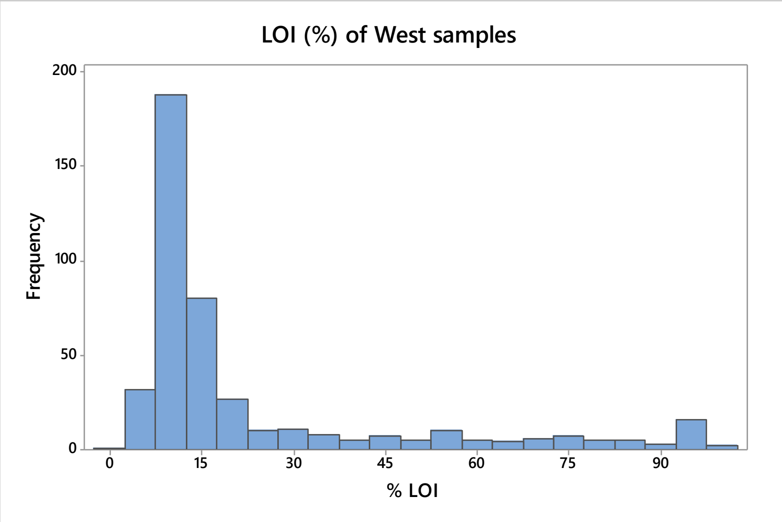
Soil organic matter is the foundation for healthy and productive agricultural soils, and is central to a range of soil functions and ecosystem services. Soils low in organic matter may have reduced functionality, and may not be as resilient to damage. Soil organic matter is important for a soils physical, chemical, and biological health. It contributes to soil structure as it acts as the glue holding soil mineral matter together. Soil organic matter is the largest terrestrial store of carbon on earth and helps to regulate our climate (O'Sullivan & Creamer, 2018). Increasing soil organic matter improves soil water storage and supply capacity. It also contributes to the storage and recycling of important plant nutrients. Soils with adequate levels of organic matter provide a good habitat for microbes and other living organisms, which enhances soil biodiversity.

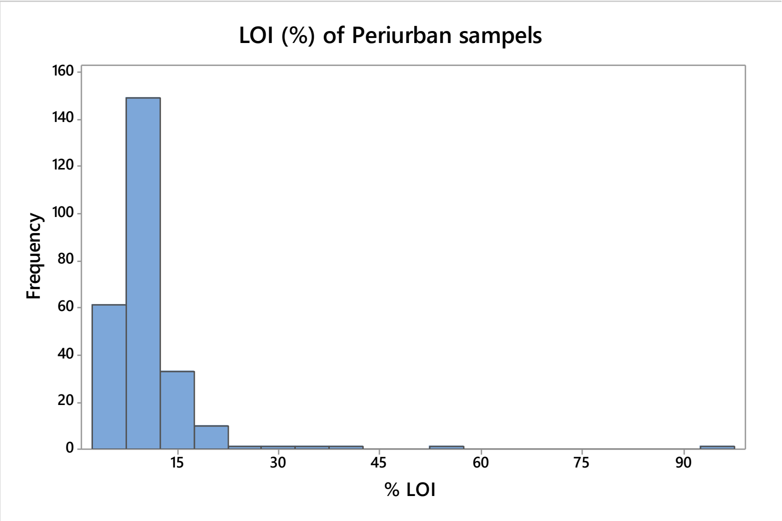
Soil organic matter is calculated by loss on ignition (LOI) where soil is burned in muffled oven and the organic matter is determined from the weight loss and recorded as % LOI. LOI is an important agronomic indicator in soil management as it can determine if a soil is mineral (<30%) or peat (>30%) (Wall, D., & Plunkett, 2021). This determination is important as some organic soils contain stable organic components which is difficult to break down and can retain phosphorus (Peats), yet mineral soils with <20% LOI mainly contain labile forms of organic material which are available for soil microbes to consume, and plants to assimilate. Furthermore, organic matter can be a key component in holding some nutrients such as K and Mg. Therefore, land management decisions and soil index systems will be different based on LOI.

Descriptive statistics of LOI (%):

LOI (%)	Borders	West	Periurban	Midlands
Mean	35	23	11	28
Min	0.63	2	3	2
Max	99	98	94	100
Median	18	12	9	11.4
1st Quartile	13	10	8	8.33
3rd Quartile	55	23	12	32
Interquartile range	43	13	4	24
Skewness	1.07	1.87	7.09	1.40
Missing values	0	1	0	0







Cation exchange capacity (CEC)

Cation exchange capacity (CEC) provides an understanding into the fertility and nutrient retention capacity of soil. Certain soil minerals, such as clay, particularly in combination with organic matter, possess a number of electrically charged sites, which can attract and hold oppositely charged ions. CEC of a soil is a measure of the negatively charged sites on the soil surfaces that can hold cations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), by electrostatic forces. Cations retained are easily exchangeable with cations in the soil solution so a soil with a higher CEC has a greater capacity to maintain adequate quantities of Ca^{2+}, Mg^{2+} and K^+ than a soil with a low CEC. Soils with a high CEC may not always be more fertile as the negative charged sites may be occupied by Al^{3+} or H^+. However, when combined with other soil indicators (such as base saturation, pH, LOI etc.) CEC can be a good indicator of soil quality and productivity.

There are many differing methods to estimate CEC so it is important to know the intended use of the data. For soil classification/regulatory purposes, a soil's CEC is often measured at a standard pH value. In this project the barium chloride-triethanolamine method of Mehlich (1938) has been used, which is buffered at pH 8.2. When a soils pH is ≤7.5 and has not been recently limed, it is reasonable to use a sum of Mehlich Ca^{2+}, Mg^{2+} and K^+ (CEC_{sum}) to calculate the effective CEC (Ross, 2009). However, soil samples with pH >7.5 free salts may be dissolved into the Mehlich extracting solution and overestimating the CEC.

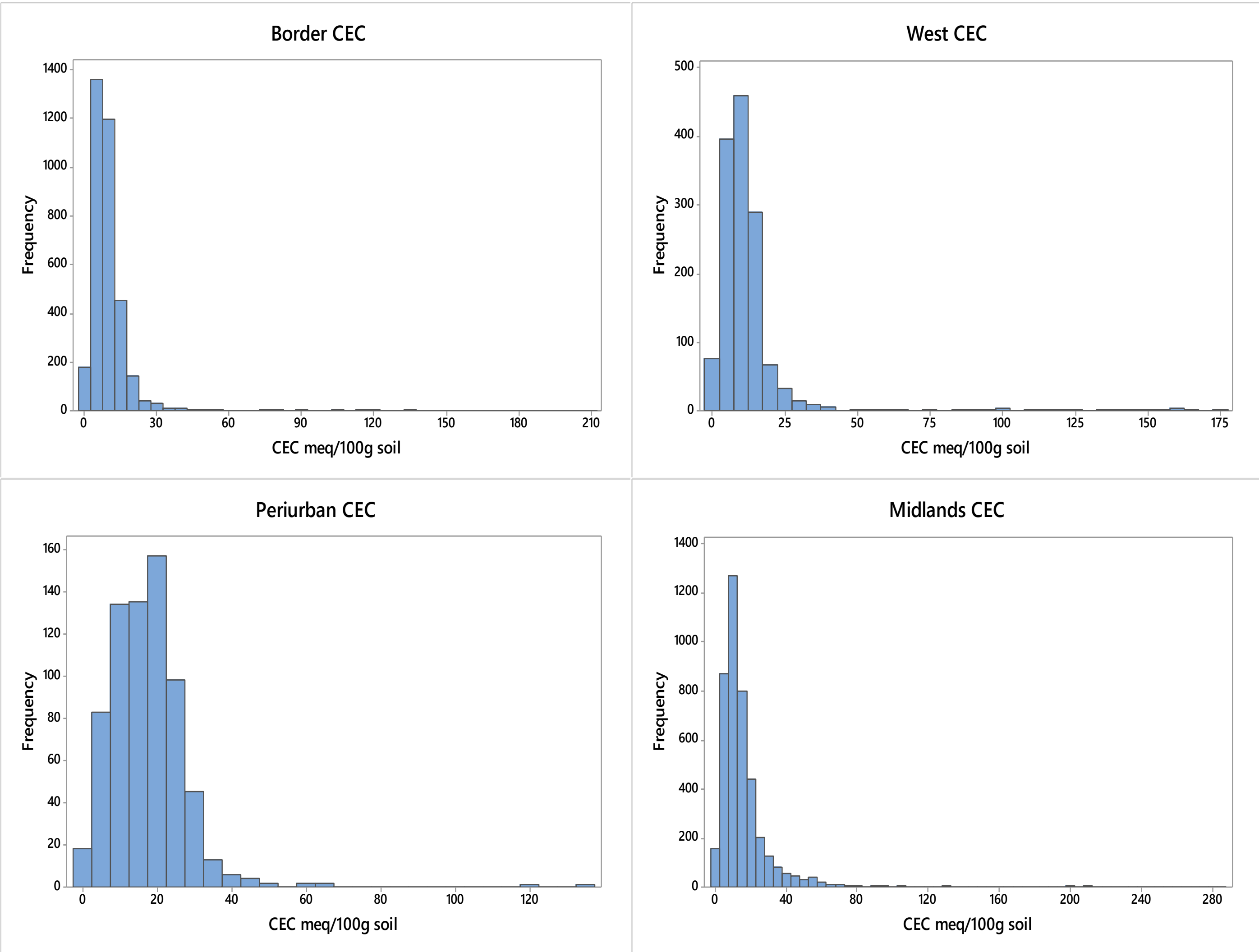
The units used to measure CEC is milliequivalents per 100 grams of oven-dry soil (meq/100g). A high CEC value (>25) is a good indicator that a soil has a high clay and/or organic matter content and can hold a lot of cations. A soil with a low CEC value (<5) is a good indication that a soil is sandy with little or no organic matter that cannot hold many cations.

CEC Calculation:

To calculate the gram equivalent of each cation each base cations atomic number needs to be divided by the charge (e.g. Ca^{2+} = 40/2). This is then multiplied by 100 to make meq/100g soil. All cations are then added together to make the CEC.

Descriptive statistics of CEC (meq/100g):

CEC (meq/100g)	Borders	West	Periurban	Midlands
Mean	11	13	17	16
Min	0	0	0	0
Max	209	175	134	285
Median	8.17	10	17	12
1^{st} Quartile	5.24	5.85	9.97	7.58
3^{rd} Quartile	12	14	23	18
Interquartile range	6.5	7.84	13	11
Skewness	7.81	5.95	3.56	6.40
Missing values	0	65	2	65


Border CEC
Frequency
CEC meq/100g soil
West CEC
Frequency
CEC meq/100g soil
Periurban CEC
Frequency
CEC meq/100g soil
Midlands CEC
Frequency
CEC meq/100g soil

Soil index systems (Teagasc.ie guidance)

Advice on nutrient and trace element application rates depend on the quantity of the element in the soil that is available to the crop. Apart from N and S, this is determined by soil analysis. For most elements, the soil is extracted with a suitable reagent and the amount extracted is deemed to be or related to the amount available to the plant. For elements that are extracted by the Morgan's reagent (i.e. K and P), the analysis unit is milligrams per litre of soil (mg/l). For elements that are digested in EDTA, the analysis units are mg/kg.

In order to simplify advice tables, it is normal to classify soil available levels of nutrients and trace elements into classes. The class is referred to as the Soil Index. At Johnstown Castle, soil analysis levels are classified into Index 1 – 4. The exact interpretation of the Soil Index varies somewhat with the element and the crop but the definitions in Table 1 apply in most circumstances.

Table 1: The Soil Index System		
Soil Index	Index Description	Response to Fertilisers
1	Very Low	Definite
2	Low	Likely
3	Medium	Unlikely/Tenuous
4	Sufficient/Excess	None

Phosphorus

Phosphorus (P) is an essential requirement for plant growth which cannot be substituted and is needed in sufficient concentrations. In agriculture P is constantly removed from the soil by crops therefore replenishment of soil P reserves are needed to ensure that soils are not extensively depleted of P in order to maintain productivity. However, mobilization of P into water courses causes toxic algal blooms and eutrophication. Therefore, understanding the changes in P forms and chemistry in the soil is essential for agronomic and environmental sustainability. P cycling in the soil system and its losses to water is influenced by factors such as P form, soil type, soil organic matter content and rainfall.

Total P in soil can generally be defined in three pools (i) bioavailable to the plant (available P), (ii) P held by the soil and likely to undergo a change of state to become available (labile P) or (iii) insoluble forms of P (non-labile P). To measure these pools different soil tests can be used. In the Terra soil project Total P is measured by inductively coupled plasma mass spectroscopy following extraction by aqua regia (ICPar) or

X-ray florescence (XRF). Whereas available P is measured by Morgan P and potentially labile P is measured by Mehlich-3 P. The organic fraction of P is not measured in this project but can be calculated by *Total P – available P*. For full analysis see (R. Hall et al., 2023; R. L. Hall et al., 2023)

Total P

ICP mg/kg	Borders	West	Periurban	Midlands
Mean	883	800	990	840
Min	90	163	588	60
Max	2480	2514	2944	3630
Median	850	753	905	820
1st Quartile	600	588	767	620
3rd Quartile	1110	956	1132	1030
Interquartile range	510	367	364	410
Skewness	0.81	1.19	1.93	0.84
Missing values	0	0	0	0

XRF %	Borders	West	Periurban	Midlands
Mean	0.28	0.23	0.29	
Min	0.03	0.03	0.12	
Max	0.68	0.69	0.77	
Median	0.28	0.22	0.27	
1st Quartile	0.19	0.16	0.23	
3rd Quartile	0.36	0.28	0.32	
Interquartile range	0.17	0.12	0.09	
Skewness	0.28	0.79	1.79	
Missing values	0	0	0	

Available P

Analysis Methods:

Method	P fraction	Application	Method limitations
Morgan P	Orthophosphate/plant available	Agricultural monitoring	Inaccuracy above 20% LOI
Mehlich P	Orthophosphate/plant available	Research/Technical	

Morgan P (mg/L)	Borders	West	Periurban	Midlands
Mean	8.26	9.32	8.83	6.21
Min	0.43	2.74	0.6	0.20
Max	179	129	121	209
Median	5.15	6.44	5.07	4.3
1st Quartile	3.06	3.37	3.16	2.69
3rd Quartile	9.75	11	9.59	7.62
Interquartile range	6.69	7.63	6.43	4.93
Skewness	4.88	4.63	5.04	9.83
Missing values	59	37	0	0

Mehlich P (mg/kg)	Borders	West	Periurban	Midlands
Mean	61	39	43	40
Min	0.12	0.06	0.54	0.11
Max	449	241	623	448
Median	50	30	34	32
1st Quartile	31	19	21	20
3rd Quartile	78	52	55	50
Interquartile range	47	33	34	31
Skewness	2.08	1.71	2.09	2.90
Missing values	6	10	8	0

Soil P Index

P index (% of samples)			
	Mineral	> 20% LOI	Peat
1	23	29	0
2	27	29	0
3	20	21	100
4	30	21	0

Potassium, K

Potassium is a requirement for most living organisms, and is found in an abundance of approximately 2.5% (2500 mg/l) in the Earth's crust (Fay et al, 2007). K differs from other macronutrients in that it is not incorporated into structural tissue—it regulates the charge balance across plant membranes. Regular monitoring (every 5 years) is necessary for K as rapid drops in concentration can occur in some soil types and reduce yields or stunt growth of livestock.

Forms of potassium that are accessible to plants from soil are exchangeable potassium and soil solution potassium. Soil K can appear in different forms; immediately available (water soluble), readily available (exchangeable), slowly available (non-exchangeable) and relatively unavailable (mineral-K) (Wang et al., 2010). The form of K in the soil depends on the potential supply to plants, in the Terra soil project water soluble K is measured by Morgan's K and Total K is measured by ICPar/XRF.

Total K

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	0.14	0.12	0.17	0.13
Min	0.01	0.01	0.06	0.01
Max	0.42	0.45	0.3	0.06
Median	0.13	0.11	0.17	0.12
1st Quartile	0.08	0.08	0.14	0.06
3rd Quartile	0.18	0.14	0.19	0.18
Interquartile range	0.1	0.07	0.05	0.12
Skewness	0.71	1.52	0.53	0.47
Missing values	0	0	0	

XRF %	Border	West	Periurban	Midlands
Mean	1.55	1.32	1.35	
Min	0.06	0.06	0.59	
Max	3.65	4.07	4.25	
Median	1.65	1.24	1.24	
1st Quartile	0.87	0.83	1.07	
3rd Quartile	2.13	1.79	1.53	
Interquartile range	1.27	0.96	0.56	
Skewness	-0.13	0.44	2.18	
Missing values	0	0	0	

Normally Distributer: Data not normally distributed**.**

Available K

Descriptive statistics:

Morgan K mg/L	Borders	West	Periurban	Midlands
Mean	88	82	86	82
Min	11	1.19	2.65	0
Max	1060	480	344	832
Median	66	79	66	66
1st Quartile	44	46	40	42
3rd Quartile	103	106	119	103
Interquartile range	58	60	80	61
Skewness	6.02	2.36	1.34	2.61
Missing values	0	0	0	

Mehlich K mg/kg	Borders	West	Periurban	Midlands
Mean	143	140	146	129
Min	9.17	1.19	31	0.84
Max	1556	509	544	769
Median	106	122	116	105
1st Quartile	77	77	77	71
3rd Quartile	179	177	186	165
Interquartile range	102	100	109	94
Skewness	5.32	1.49	1.6	1.99
Missing values	0	0	0	

Normally Distributer: Data not normally distributed**.**

K index based on Morgan's K analysis

K index	Mineral (<20% LOI)	> 20% LOI	Peat (>30% LOI)
1	28	73	87
2	40	17	9
3	20	4	2
4	12	3	2

Calcium

Calcium is an essential nutrient for plants and animals. Calcium plays a major role of soil structure, and acts as a filler to maintain balance among cation nutrients and to limit the influence of acid cations (Omenda et al., 2021). Retention of calcium in the soil and its function as a balancing agent depends upon the cation exchange properties of the soil. Ca deficiency causes plants to wither and die and also helps to neutralize toxic materials in a plant.

Total Ca

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	0.45	0.93	0.8	1.07
Min	0.02	0.04	0.03	0.02
Max	7.63	25	9.03	25
Median	0.26	0.29	0.42	0.36
1st Quartile	0.15	0.17	0.25	0.82
3rd Quartile	0.42	0.63	0.75	0.82
Interquartile range	0.27	0.46	0.5	0.59
Skewness	6.2	7.05	3.89	5.74
Missing values	0	0	0	0

XRF %	Border	West	Periurban	Midlands
Mean	0.86	1.53	1.24	
Min	0.06	0.1	0.21	
Max	10	43	13	
Median	0.52	0.59	0.68	
1st Quartile	0.34	0.38	0.46	
3rd Quartile	0.82	1.16	1.16	
Interquartile range	0.48	0.78	0.71	
Skewness	4.9	7.44	3.92	
Missing values	0	0	0	

Available Ca

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	1766	2006	2625	2797
Min	88	85	93	0.1
Max	20288	33859	9609	56970
Median	1366	1101	2490	1867
1st Quartile	714	631	1430	1122
3rd Quartile	2057	2299	3541	3213
Interquartile range	1343	1668	2111	2091
Skewness	5.45	6.35	0.89	6.59
Missing values	0	19	2	

Cobalt, Co

Cobalt is an essential element in animal and human health and background concentrations in Ireland range from 5 – 30 mg/kg [1] (Fay et al., 2007). Cobalt is a central component of vitamin B_{12} which is essential for metabolism and the production of red blood cells in ruminant animals. Co is extracted from plant tissue so it is essential to have sufficient Co in agricultural soils, where soil is low in Co grazing animals will become B_{12} deficient and more susceptible to disease (Lark et al., 2014).

Total Co

Descriptive statistics:

ICP mg/kg	Border	West	Periurban	Midlands
Mean	8.66	3.51	9.45	6.43
Min	0.2	0.1	0.32	0.04
Max	185	17	43	40
Median	7.65	2.71	9.71	6.53
1st Quartile	3	1.34	7.37	2.73
3rd Quartile	12	4.89	11	9.46
Interquartile range	10	3.55	3.95	6.74
Skewness	12	1.76	2.75	0.55
Missing values	0	0	0	

XRF mg/kg	Border	West	Periurban	Midlands
Mean	9.9	4.79	11.03	
Min	0.1	0.1	1.08	
Max	156	24	49	
Median	9.18	3.99	11	
1st Quartile	4.32	2.16	8.97	
3rd Quartile	13	6.26	13	
Interquartile range	9.26	4.1	3.92	
Skewness	9.27	1.76	3.25	
Missing values	0	0	0	

Available Co

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	0.35	0.2	0.4	2798
Min	0	0	0	0.1
Max	7.33	1.92	1.39	56970
Median	0.29	0.14	0.38	1867
1st Quartile	0.14	0.09	0.26	1122
3rd Quartile	0.43	0.26	0.51	3213
Interquartile range	0.29	0.17	0.25	2091
Skewness	10.63	4.54	1.25	6.59
Missing values	0	19	3	

Normally Distributed: Data not normally distributed**.**

Copper, Cu

Copper (Cu) has an important role in the plant as an enzyme activator and as part of some of the enzymes involved in respiration. It also has an indirect role in chlorophyll production. It is very important in the plants reproductive stage of growth, and in cereals is important for floral fertility and grain development. Cu is fairly immobile in the plant, tending to remain in the older leaves (Teagasc[2] 2017). This leads to deficiency symptoms most commonly occurring in the younger growth. Cu increases plant sugar content, intensifies plant colour and improves flavour in fruit and vegetables.

The risk of Cu deficiency is high when the levels in heavy and light textured mineral soils are less than 1mg/kg and 2 mg/kg of EDTA extractible Cu respectively (Wall, D., & Plunkett, 2021). Soils high in organic matter maintain a tight hold on Cu and the availability is decreased. Soils high in organic matter are, therefore, more likely to respond to addition of Cu. Very high levels of phosphorus & Molybdenum may reduce Cu availability. High levels of N application may cause more Cu uptake by the plant. The uptake of Cu can be either increased or decreased, depending on the relationship with other micronutrients as Al, zinc, iron and manganese.

Terra Soil has analysed the plant available Cu fraction via Mehlich-3, however, EDTA is used in the Irish soil index. Mehlich-3 can be converted to EDTA in Irish soils by the following equation (Brennan, 2002);

$$y = 0.724x + 0.273$$

Total Cu

Descriptive statistics:

ICP mg/kg	Border	West	Periurban	Midlands
Mean	28	19	28	18
Min	0.25	1.04	3.43	0.08
Max	168	179	193	315
Median	23	14	27	16
1st Quartile	12	8.23	19	10
3rd Quartile	35	25	34	24
Interquartile range	23	17	15	14
Skewness	2.42	3.48	5.76	5.38
Missing values	0	0	0	0

XRF mg/kg	Border	West	Periurban	Midlands
Mean	28	20	29	
Min	2.9	0.88	6.73	
Max	167	166	192	
Median	24	15	28	
1st Quartile	14	10	21	
3rd Quartile	25	25	34	
Interquartile range	21	15	13	
Skewness	2.68	3.44	6.18	
Missing values	0	0	0	

Available Cu

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	5.13	2.98	5.57	3.43
Min	0.02	0.01	0.11	0
Max	28	19.00	22	130
Median	4.32	1.68	5.22	2.95
1st Quartile	1.69	0.51	3.3	1.33
3rd Quartile	7.35	4.18	7.51	4.7
Interquartile range	5.66	3.67	4.21	3.37
Skewness	1.41	1.87	1.22	12.25
Missing values	0	19	2	

Magnesium, Mg

Magnesium (Mg) is an essential element for plant growth and development. The availability of Mg to plants depends on various factors: the underlying geochemistry, climate, and land management practices. Crops uptake Mg in large quantities and if the Mg levels are not replenished there will be a reduction in yield and visible chlorosis, i.e. degradation of chlorophyll (Gransee & Führs, 2013). Terra Soil has analysed the plant available Mg fraction via Mehlich-3, however, EDTA is used in the Irish soil index. The relationship of Mehlich-3 to EDTA has been described as 1:1 (Ketterings et al., 2001).

Total Mg

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	0.36	0.16	0.22	0.19
Min	0.02	0.03	0.03	0.02
Max	1.48	1.5	0.85	3.68
Median	0.28	0.16	0.19	0.15
1st Quartile	0.12	0.08	0.14	0.10
3rd Quartile	0.55	0.17	0.26	0.22
Interquartile range	0.43	0.09	0.11	0.12
Skewness	1.11	4.74	2.02	6.51
Missing values	0	0	0	0

XRF %	Border	West	Periurban	Midlands
Mean	1.28	0.6	0.85	
Min	0.1	0.1	0.1	
Max	11	4	2.4	
Median	1.1	0.5	0.8	
1st Quartile	0.4	0.3	0.6	
3rd Quartile	1.8	0.7	1	
Interquartile range	0.14	0.4	0.4	
Skewness	3.17	3.46	1.49	
Missing values	0	0	0	

Plant Available Mg

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	185	326	145	240
Min	26	30	41	0.6
Max	1406	1635	664	2300
Median	128	144	125	127
1st Quartile	84	98	89	90
3rd Quartile	188	409	172	219
Interquartile range	103	312	83	129
Skewness	3.37	1.73	2.23	2.81
Missing values	0	19	2	

Manganese, Mn

Manganese (Mn) is essential for both plants and animals (Teagasc[3] 2017). Deficiencies of Mn can occur in cereal and root crops on soils of high pH and high organic matter. Mn has many important functions in plants, particularly as an activator of various enzyme systems involved in plant metabolism including chlorophyll synthesis (Fay et al., 2007). Cereals are susceptible to manganese deficiency and yield losses of up to 30 – 60% can occur if severe manganese deficiency is left untreated (Wall, D., & Plunkett, 2021). Similar to P and K, Mn deficiency is usually due to the low content of available Mn, rather than an absolute shortage of Mn in soil S.

Total Mn

Descriptive statistics:

ICP mg/kg	Border	West	Periurban	Midlands
Mean	628	301	1175	625
Min	2	4.1	21	0.1
Max	10000	6379	20558	15300
Median	379	144	985	495
1st Quartile	143	67	674	154
3rd Quartile	676	358	1428	901
Interquartile range	533	291	754	748
Skewness	6.16	7.45	11	8.58
Missing values	0	0	0	0

XRF %	Border	West	Periurban	Midlands
Mean	0.09	0.05	0.17	
Min	0.001	0.001	0.01	
Max	2.33	0.91	2.93	
Median	0.06	0.03	0.2	
1st Quartile	0.03	0.01	0.1	
3rd Quartile	0.1	0.05	0.2	
Interquartile range	0.07	0.04	0.11	
Skewness	7.98	7.4	12	
Missing values	0	0	0	

Plant Available Mn

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	70	34	132	69
Min	0.53	0.91	1.99	0.06
Max	735	415	630	1656
Median	46	17	115	53
1st Quartile	18	6.27	77	18
3rd Quartile	85	47	170	104
Interquartile range	67	42	93	87
Skewness	3.56	3.55	2.18	5.90
Missing values	0	19	2	

Sulphur, S

Sulphur (S) is a non-metal which occurs as a pure element as either sulphate or sulphide minerals in the earth's core (Teagasc[4], 2017). S is essential for the formation on amino acids, the building blocks for proteins which are needed for growth and development in plants and animals. S is required to convert Nitrogen to plant dry matter, yet is often a forgotten mineral in agricultural management (Teagasc[4], 20217). Sulphur deficiency is often hard to distinguish from nitrogen deficiency, to which it may be linked. Symptoms include a yellowing of the younger leaves, as a result of low chlorophyll production. Growth is generally reduced. In cereals, tilling is reduced. In oilseed rape, flowers are pale and leafs are distorted. In most cases, symptoms appear too late for effective treatment. Hidden deficiency is by far more frequent than acute deficiency.

Soil sampling and analysis can be conducted to quantify of actual amount of available sulphur in the soil. However, results can be variable and change rapidly due to plant uptake, soil mineralisation, capillary rise and leaching. Soil sampling is therefore very rarely used.

S

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	0.12	0.13	0.06	0.14
Min	0.02	0.02	0.02	0.01
Max	0.55	0.63	0.25	1.09
Median	0.07	0.07	0.06	0.07
1st Quartile	0.06	0.06	0.05	0.05
3rd Quartile	0.13	0.16	0.07	0.19
Interquartile range	0.07	0.1	0.02	0.14
Skewness	1.96	1.84	2.32	1.90
Missing values	0	0	0	0

XRF mg/kg	Border	West	Periurban	Midlands
Mean	624	1023	446	
Min	2	82	132	
Max	3447	5182	1886	
Median	461	543	386	
1st Quartile	140	350	315	
3rd Quartile	596	1310	513	
Interquartile range	457	961	199	
Skewness	1.92	1.71	2.24	
Missing values	0	0	0	

Mehlich S

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	41	48	23	33
Min	10	12	10	5.93
Max	536	712	580	1322
Median	32	30	20	23
1st Quartile	26	24	17	19
3rd Quartile	42	59	24	33
Interquartile range	199	15	35	14
Skewness	2.24	8.37	7.25	12.81
Missing values	0	0	19	

Zinc, Zn

Zinc (Zn) acts as a catalyst in the processes of oxidation in plant cells, and is vital for the transformation of carbohydrates (Teagasc[5], 2017). It regulates the consumption of sugars, which provide energy for the production of chlorophyll. It plays a part in the formation of growth promoting compounds within the plant, and it aids in the absorption of adequate moisture. Zinc is a major component in seed, grain formation, in plant height, protein synthesis and crop maturation date.

Zn

Descriptive statistics:

ICP mg/kg	Border	West	Periurban	Midlands
Mean	61	35	110	70
Min	4	3.24	16	1.2
Max	978	454	283	9120
Median	55	27	113	65
1st Quartile	28	18	85	34
3rd Quartile	81	44	133	95
Interquartile range	53	26	48	61
Skewness	10	7.26	0.37	56.6
Missing values	0	0	0	0

XRF mg/kg	Border	West	Periurban	Midlands
Mean	68	39	118	
Min	3.6	3	26	
Max	1160	494	287	
Median	61	31	121	
1st Quartile	35	21	96	
3rd Quartile	87	49	139	
Interquartile range	52	28	43	
Skewness	11	7.45	0.37	
Missing values	0	0	0	

Mehlich Zn

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	4.12	4.41	5.8	5.43
Min	0.42	0.19	0.63	0.03
Max	61	80	44	844
Median	2.69	2.96	4.64	3.64
1st Quartile	1.53	1.76	3.2	2.26
3rd Quartile	4.73	5	7.42	6.25
Interquartile range	3.21	3.24	4.22	3.985
Skewness	6.06	7.39	3.88	49.8
Missing values	0	19	2	

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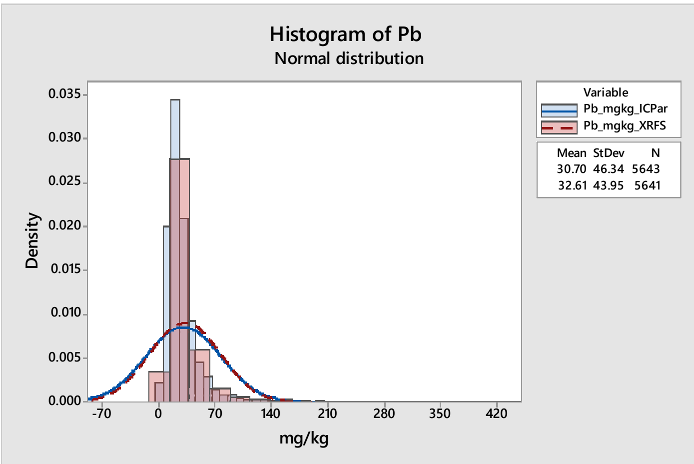

Aluminium

Aluminium (Al) is the world's third most abundant metal and is found in the earth's crust at around 80,000 mg/kg (Fay et al., 20). Al can be found in Irish soils mainly above 40,000 mg/kg depending on soil type. Al has an impact on P retention in soils and can be used to develop soil P sorption characteristics in Irish soils.

Al

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	1.25	0.7	1.33	1.01
Min	0.05	0.02	0.38	0.01
Max	3.34	2.78	2.66	9.27
Median	1.27	0.75	1.28	1.03
1st Quartile	0.74	0.46	1.14	0.54
3rd Quartile	1.74	1.04	1.43	1.43
Interquartile range	0.99	0.58	0.28	0.89
Skewness	0.16	1.04	1.24	0.71
Missing values	0	0	0	0

XRF %	Border	West	Periurban	Midlands
Mean	8.87	5.57	8.71	
Min	0.1	0.1	5.2	
Max	20	11	13	
Median	9.9	5.5	8.6	
1st Quartile	6.02	4	7.67	
3rd Quartile	12	7.55	10	
Interquartile range	6.05	3.55	1.92	
Skewness	-0.58	-0.1	0.58	
Missing values	0	0	0	

Mehlich Al

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	866	592	622	589
Min	1.6	3.2	0.3	0.02
Max	1933	1757	1359	2670
Median	907	656	654	622
1st Quartile	695	216	408	272
3rd Quartile	1102	906	813	787
Interquartile range	406	690	404	515
Skewness	-0.35	0.17	-0.28	0.24
Missing values	0	19	2	

Iron, Fe

Iron (Fe) is the second most abundant metal and fourth most abundant metal in the earth's crust, which it makes up more than 5% (Fay et al., 2008). Although required by plants in small amounts, Fe is involved in many important compounds and physiological processes in plants. Fe is involved in the development process of chlorophyll, and it is required for certain enzyme functions. Fe's involvement in chlorophyll synthesis is the reason for the chlorosis (yellowing) associated with Fe deficiency. Fe uptake by the plant is not as simple as with other essential elements and is taken up by plant roots in greatest amounts in the zone of the root between cell elongation and maturation, about 1 to 4 cm behind the root tip.

Fe

Descriptive statistics:

ICP %	Border	West	Periurban	Midlands
Mean	2.67	1.31	2.12	1.56
Min	0.05	0.05	0.21	0.01
Max	15	6.06	5.82	17
Median	2.26	1.64	2.14	1.56
1st Quartile	1.25	0.68	1.84	0.89
3rd Quartile	3.06	1.66	2.42	2.14
Interquartile range	1.82	0.97	0.58	1.25
Skewness	2.74	1.81	0.76	2.90
Missing values	0	0	0	0

XRF %	Border	West	Periurban	Midlands
Mean	3.71	2.2	3.32	
Min	0.14	0.01	0.58	
Max	36	9.01	8.63	
Median	3.81	1.96	3.41	
1st Quartile	2.24	1.25	2.86	
3rd Quartile	4.91	2.58	3.79	
Interquartile range	2.67	1.59	0.94	
Skewness	6.03	1.5	0.8	
Missing values	0	0	0	

Mehlich Fe

Descriptive statistics:

Mehlich mg/kg	Border	West	Periurban	Midlands
Mean	338	355	249	315
Min	20	8.77	89	0.08
Max	918	909	558	1446
Median	328	351	238	304
1st Quartile	258	245	193	222
3rd Quartile	413	459	292	393
Interquartile range	155	214	98	171
Skewness	0.62	0.29	0.87	1.01
Missing values	0	19	2	

References

Brennan, D. (2002) Evaluation of Mehlich-3 as a Micronutrient Extractant on Irish Grassland Soils. Available at: https://t-stor.teagasc.ie/bitstream/handle/11019/399/Denis%20Brennan%20Thesis%20Total%20Fin.pdf?sequence=1&isAllowed=y [Accessed 31/01/2024]

Donald S Ross, Q. K. (2009). Recommended Methods for Determining Soil Cation Exchange Capacity. In Q. K. Donald S Ross (Ed.), *Recommended soil testing procedures for the northeastern United States* (1st ed., pp. 75–86). Northeastern Regional Publication. https://doi.org/10.2137/1239099041838058

Gransee, A., & Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant and Soil*, *368*(1–2), 5–21. https://doi.org/10.1007/s11104-012-1567-y

Hall, R., Felipe Bachion, de S., Gallagher, Vincent Margaret, B., Grunskyb, E. C., Loweb, V., & Dalya, K. (2023). Geospatial Modelling of Soil Phosphorus Fractions and Sorption Indicators from Heterogeneous Landscapes. *Available at SSRN 4425542*, *35*(October), e00729. https://doi.org/10.1016/j.geodrs.2023.e00729

Hall, R. L., de Santana, F. B., Grunsky, E. C., Browne, M. A., Lowe, V., Fitzsimons, M., Higgins, S., Gallagher, V., & Daly, K. (2023). A machine learning approach to predicting plant available phosphorus that accounts for soil heterogeneity and regional variability. *Journal of Soils and Sediments*, *0123456789*. https://doi.org/10.1007/s11368-023-03648-y

Ketterings, Q. M., Bellows, B., Czymmek, K., & Reid, W. (2001). *Do Modified Morgan and Mehlich-III P Have a Morgan P Equivalent? Whole-farm nutrient mass balances for New York dairy farms View project On-farm Research: strip trial analysis, Precision Agriculture method View project*. https://www.researchgate.net/publication/241752390

Lark, R. M., Ander, E. L., Cave, M. R., Knights, K. V., Glennon, M. M., & Scanlon, R. P. (2014). Mapping trace element deficiency by cokriging from regional geochemical soil data: A case study on cobalt for grazing sheep in Ireland. *Geoderma*, *226–227*(1), 64–78. https://doi.org/10.1016/j.geoderma.2014.03.002

O'Sullivan, L., & Creamer, R. (2018). *The Soils of Ireland* (L. O. Rachel Creamer (ed.)). Springer Nature. https://doi.org/10.1007/978-3-319-71189-8_13

Omenda, J. A., Ngetich, K. F., Kiboi, M. N., Mucheru-Muna, M. W., & Mugendi, D. N. (2021). Phosphorus availability and exchangeable aluminum response to phosphate rock and organic inputs in the Central Highlands of Kenya. *Heliyon*, *7*(3), e06371. https://doi.org/10.1016/j.heliyon.2021.e06371

Teagasc1 (2017). Soil pH. Available at: https://www.teagasc.ie/crops/soil--soil-fertility/soil-ph--liming/grassland/ [Accessed 31/01/2024]

Teagasc1 (2017) Soil Cu. Available at: https://www.teagasc.ie/crops/soil--soil-fertility/trace-elements/grassland/copper/ [Accessed 31/01/2024]

Teagasc3 (2017) Soil Mn. Available at: https://www.teagasc.ie/crops/soil--soil-fertility/trace-elements/grassland/manganese/ [Accessed 31/01/2024]

Teagasc4 (2017) Soil S. Available at: https://www.teagasc.ie/crops/soil--soil-fertility/trace-elements/grassland/Sulphur/ [Accessed 31/01/2024]

Teagasc4 (2017) Soil Zn. Available at: https://www.teagasc.ie/crops/soil--soil-fertility/trace-elements/grassland/Zinc/ [Accessed 31/01/2024]

Wall, D., & Plunkett, M. (2021). *Major and micro nutrient advice for productive agricultural crops*. *5*, 51–53.

http://hdl.handle.net/11019/2475

Wang, H. Y., ZHOU, J. M., DU, C. W., & CHEN, X. Q. (2010). Potassium Fractions in Soils as Affected by Monocalcium Phosphate, Ammonium Sulfate, and Potassium Chloride Application. *Pedosphere*, *20*(3), 368–377. https://doi.org/10.1016/S1002-0160(10)60026-4