Electrical Conductivity Modelling in Calcareous Soils of the Maltese Islands, Developing a Soil:Water Suspension to Saturated Paste Conversion Model

A dissertation submitted in partial fulfilment of the requirements of the degree of Master of Science at the institute of Earth Systems.

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Dedication

I would like to express my heartfelt gratitude to my family and friends for their unwavering assistance, support, and encouragement throughout this journey, particularly during my final year. Additionally, I extend my sincere appreciation to all the remarkable individuals in the agricultural sector in Malta, including dedicated soil researchers and my esteemed colleagues. This thesis is dedicated to every one of them.

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Lastly, I would like to convey my special thanks to my girlfriend, Janice Zerafa. Her continuous care and sacrifices were essential in successfully completing this thesis and played a crucial role in supporting me both practically and morally.

Declaration of Prior Publication

I declare that portions of the research and analysis presented in this thesis have previously been published in a peer-reviewed journal. The published work was written and submitted prior to the completion and submission of this thesis and forms an integral part of the study.

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Abstract

Soil salinity is a critical factor influencing soil health and agricultural productivity, typically measured through the electrical conductivity (EC) of a saturated soil paste extract (EC_e). However, this standard method is time-consuming, and alternative soil: water suspension methods ($EC_{(soil : water)}$) offer quicker results, though conversion models are often soil-specific. This study aimed to develop models to convert $EC_{(1:1, 1:2, and 1:5)}$ to ECe for Malta's calcareous soils, while also assessing the impact soil texture, carbonate, and organic matter content have on model accuracy. Moreover, the effect these variables have on soil salinity in the field was also investigated. A total of 134 soil samples with varying textures, carbonate, and organic matter levels were analysed. The results indicate a considerable variability in salinity levels among the sampled soils with a mean average of 3772 µS/cm. Out of the different soils analysed, 104 can be classified as non-saline, with an electrical conductivity (e) less than 4,000 µS/cm. This study produced generalized models ($EC_e = 10^{(a(logEC(soil))+b))}$ with strong correlation coefficients (r^2 = 0.91-0.93, $p < .001$). Models specific to fine- and medium-textured soils, soils with 35-50 % carbonate content, and those with 2.5-4.2 % organic matter demonstrated even higher accuracy (mean r^2 = 0.96). Validation using 22 independent samples confirmed the reliability of these models (RMSE = 0.93-0.97 dS m^{-1}; NSE = 0.95-0.97), except for coarse-textured soils. These findings suggest that general models can be reliably applied to most of Malta's soils, with exceptions for high sand content soils. This methodology was also applied to analyse metal concentrations, and the resulting general model can estimate the concentrations of key metal ions Na^+, Ca^{2+}, Mg^{2+}, and K^+ in the soil saturation extract (ECe) using measurements derived from soil:water suspensions at 1:1, 1:2, and 1:5 ratios. No significant correlation between ECe and the levels of sand, silt, and clay was observed, nor were significant differences in EC found across contrasting textural classes (p = .465). Weak positive correlations were detected between EC and both carbonate (r_s = 0.216, $p < .05$) and OM content (r_s = 0.269, $p < .05$). These results suggest that salinity in these soils is not primarily governed by physical properties like texture. Organic matter levels, when plotted against sand and clay content, showed no significant correlation, indicating that other factors such as soil management practices and environmental factors seem to have a more pronounced impact on soil salinity.

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1.0 Introduction

Soil salinity, a condition driven by the presence of elevated levels of dissolved ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}), and bicarbonate (HCO_3^-), represents a significant challenge to soil health and agricultural productivity worldwide. The issue is particularly pronounced in arid and semi-arid regions, where limited rainfall and high evaporation rates exacerbate the accumulation of salts. As salinity increases, the osmotic potential of soil water rises, making it more difficult for plants to extract water, a phenomenon often referred to as physiological drought. Furthermore, the imbalance in nutrient availability that accompanies high salinity can lead to both reduced crop yields and long-term damage to soil structure, thus threatening agricultural sustainability (Castillo et al., 2007; Läuchli & Epstein, 1990; Rengasamy & Olsson, 1991).

Globally, saline soils make up over 3 % of the Earth's topsoil and 6 % of subsoils, according to recent estimates (FAO, 2021). The Mediterranean region, which includes the Maltese Islands, is particularly susceptible to salinity due to its climatic conditions. In this region, the combination of low rainfall, high evaporation, and widespread irrigation practices often leads to a gradual build-up of salts in the soil. Agricultural irrigation, especially when conducted with water containing high levels of dissolved salts, further exacerbates soil salinity. Additionally, the extensive use of fertilizers and the impact of sea spray in coastal regions contribute to rising salinity levels in soils. These factors collectively present significant challenges for local agriculture, soil stability, and water management.

Although the soils of Malta are generally considered non-saline, there is growing concern about the impact of human activities and environmental factors on salinity levels. According to the Rural Development Department (2013), the mean electrical conductivity ($EC_{1:5}$) of non-irrigated soils in Malta is 347 µS/cm, while that of irrigated soils is 695 µS/cm, indicating a notable increase in salinity where irrigation is practiced. The rising salinity levels in irrigation water, a consequence of unsustainable water extraction from

the main sea-level aquifer, further contribute to this trend. Additional sources of soil salinity in Malta include the excessive use of artificial fertilizers and the potential impact of sea spray in coastal areas, although research into the latter remains limited (Cassar, 2016).

Despite these emerging concerns, the soils of Malta remain classified as non-saline overall, and the risk of sodicity is a condition where sodium ions (Na^+) dominate the soil's cation exchange capacity, leading to soil structure degradation is considered low. This is due to the high levels of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in soils of Malta, which tend to counteract the effects of Na^+ accumulation. However, limited research has been conducted on the long-term impacts of these conditions on local soil health, and more studies are needed to assess the full scope of the issue.

Understanding the dynamics of soil salinity is critical because of its direct impact on plant growth and crop productivity. Inorganic salts play an essential role in plant metabolism and growth, providing key nutrients that are absorbed through the roots from the surrounding soil solution. These salts are integral to various physiological processes, including the formation of metabolites, structures, and enzymes within plant cells (Kramer & Boyer, 1995). However, when the concentration of dissolved salts in the soil solution rises to harmful levels, as in saline soils, the osmotic pressure increases, making it difficult for plants and microorganisms to maintain the balance of water and nutrients required for survival (Bernstein, 1975; Parida & Das, 2005). As a result, plant water uptake is compromised, leading to reduced growth rates, nutrient imbalances, and, ultimately, lower crop yields.

In addition to its impact on plant health, salinity also affects soil microbial communities. Microorganisms play a crucial role in soil nutrient cycling and organic matter decomposition, and their activity is highly sensitive to changes in salinity levels. Elevated salinity can disrupt microbial community structure and function, further affecting nutrient availability and soil health (Rath et al., 2019; Wichern, Wichern, & Joergensen, 2006).

One of the most complex challenges associated with soil salinity is the phenomenon of sodicity, which can occur in tandem with salinity issues. Sodium has a unique effect on

soil structure; it causes clay particles to disperse, which can lead to poor soil aggregation and reduced permeability. This in turn affects water infiltration, drainage, and aeration, ultimately impairing plant root development and crop productivity (Oren, Yechieli, Bohlke, & Dody, 2004). In non-saline soils, such as those generally found in Malta, this problem is less prevalent due to the abundance of calcium and magnesium, but the potential for sodicity issues to arise with increasing salinity and sodium levels remains a concern especially when soils are non-saline but still sodic.

Given the growing salinity concerns in Malta, there is a clear need for more comprehensive research to better understand the factors driving these changes and their long-term implications for soil health and agriculture. To date, little research has been conducted on the specific impact of sea spray on soil salinity in Malta, despite the country's coastal geography making it a plausible contributor. Establishing a clearer understanding of the sources and effects of salinity on soils of Malta is essential for developing effective management strategies to safeguard agricultural productivity and soil quality in the face of increasing environmental pressures. The standard method of measuring soil salinity is expressed by measuring the electrical conductivity of a soil water saturated paste however as this procedure is labor-intensive, time-consuming, and requires specialized skills, particularly when working with clay-rich soils. As a result, electrical conductivity is often measured using soil-to-water suspensions at ratios of 1:1, 1:2, or 1:5 as an alternative. This study was carried out to assess the possibility of measuring the electrical conductivity of various soil/water extracts (1:1, 1:2 or 1:5) and compare it with the electrical conductivity of the soil paste extract for various soils from Malta and produce a model to convert from one method to the other.

The aim of this dissertation is to address these knowledge gaps by investigating salinity and sodicity patterns in various soils across Malta. A key focus will be on comparing different methods of measuring electrical conductivity (EC), which is used as an indicator of soil salinity, and establishing a conversion factor to transform readings from EC (1:5), a commonly used method, to the standard EC (e) measurement. By doing so, this study seeks to provide a more accurate assessment of salinity levels in soils of Malta and to inform better management practices for mitigating the risks posed by salinity and sodicity.

In summary, soil salinity is a growing concern both globally and in Malta, with far-reaching implications for agriculture, water management, and ecosystem health. Understanding the causes, effects, and management of salinity is critical to ensuring the long-term sustainability of soil resources. This dissertation aims to contribute to that understanding by examining the specific conditions in soils of Malta, exploring the relationship between salinity and sodicity, and exploring conversion models.

Literature Review

2.0 Literature review

Soil salinity, the accumulation of soluble salts in soil, is influenced by a multitude of factors encompassing both natural processes and human activities. Understanding these causes is crucial for effective soil management and mitigation strategies:

- ❖ Geographical Location:
    - Proximity to coastal regions and arid/semi-arid climates predisposes soils to salinity due to high evaporation rates and limited rainfall, which concentrate salts in the soil through water loss.
- ❖ Climate and Weather Patterns:
    - Arid and semi-arid climates with low precipitation rates lead to minimal leaching of salts from the soil profile, allowing salt accumulation to occur.
    - High temperatures exacerbate evaporation, further concentrating salts at the soil surface.
- ❖ Poor Drainage:
    - Inadequate drainage systems impede the removal of excess water from the soil, leading to waterlogging and subsequent salinization as dissolved salts become more concentrated.
- ❖ Irrigation Practices:
    - Improper irrigation methods, such as excessive or inefficient watering, can result in waterlogging and subsequent salt accumulation.
    - The use of low-quality irrigation water containing dissolved salts contributes to soil salinity over time.
- ❖ Natural Processes:
    - Weathering of rocks and minerals naturally releases salts into the soil, particularly in regions with high salt content in parent materials.

- Organic matter decomposition can also release salts into the soil solution.
- Rising sea levels due to climate change can exacerbate soil salinity in coastal areas through saltwater intrusion into freshwater aquifers and soil profiles.

❖ Soil Texture:

- Fine-textured soils, such as clayey soils, have a higher surface area and cation exchange capacity, allowing them to retain more salts compared to coarse-textured soils.
- Soil texture influences water movement and drainage, with finer soils often exhibiting poorer drainage, which can lead to salt accumulation.

❖ Anthropogenic Activities:

- Deforestation and land clearing can disrupt natural hydrological cycles, leading to altered soil moisture regimes and increased soil salinity.
- Overuse of fertilizers containing soluble salts can contribute to soil salinity if not properly managed.
- Industrial activities and improper waste disposal practices can introduce salts and other contaminants into the soil, exacerbating salinization.

Soil salinity arises from a complex interplay of natural and human-induced factors, with geographical, climatic, hydrological, and anthropogenic influences all contributing to salt accumulation in soils. Effective management strategies must address these diverse causes to mitigate soil salinity and sustainably manage soil resources for agricultural productivity and environmental health especially for regions prone to one or more factors that enhance salt build up.

2.1 Distribution of salinity in the world.

Salt-affected soils (SAS) encompass various categories such as saline, sodic, and saline-sodic soils, each distinguished by the predominance of specific salt types. Saline soils exhibit an abundance of soluble salts, impairing the water uptake capability of plants. Only halophytes and salt-tolerant crops thrive in such environments. Sodic soils, on the other hand, are characterized by elevated levels of adsorbed sodium ions, leading to soil structure deterioration and restricted aeration and water movement. The agricultural productivity of both saline and sodic soils is significantly diminished. Natural salt accumulation predominantly occurs in coastal and arid/semi-arid regions with inadequate drainage. However, human activities like unsustainable irrigation practices, poor drainage systems, and alterations in soil and water management exacerbate salt accumulation, potentially transforming non-saline soils into salt-affected ones. Climate change further intensifies soil salinization through factors such as dryland expansion, water scarcity, and saltwater intrusion due to rising sea levels. These salt-related challenges are widespread globally.

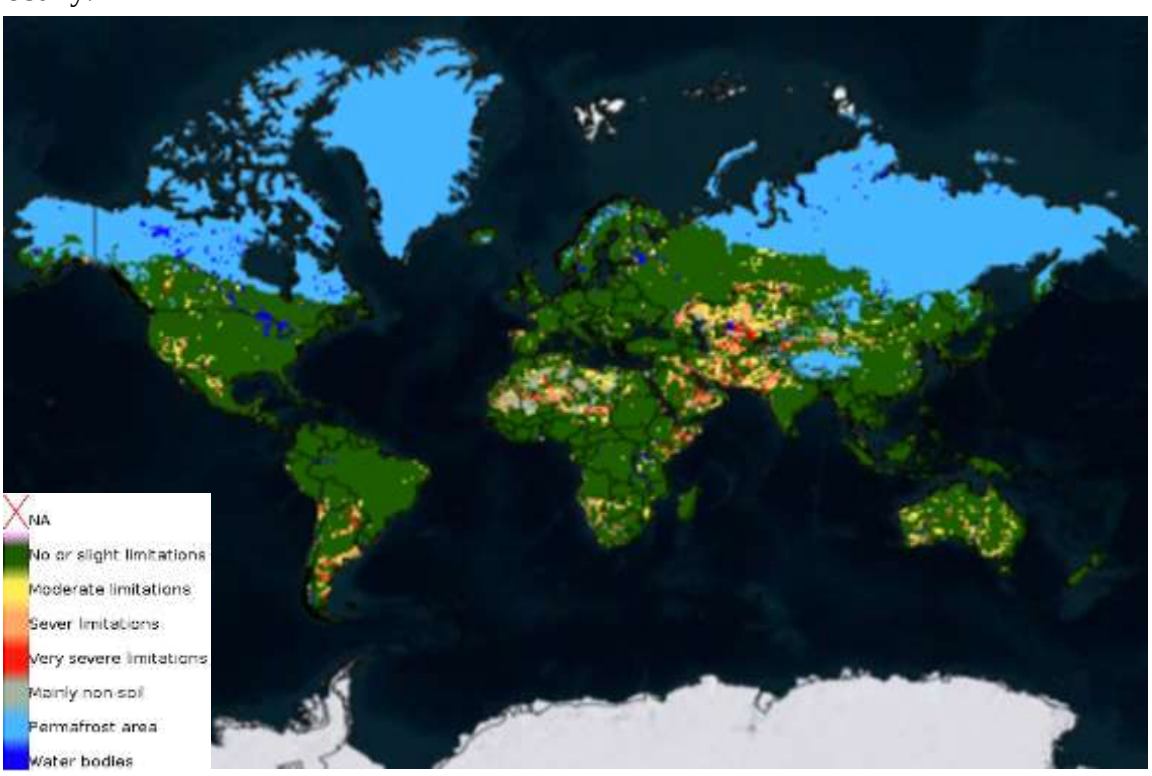


FIGURE 1: THE GLOBAL MAP OF SALT-AFFECTED SOILS, AS DETAILED BY FAO.

The Global Map of Salt-Affected Soils (GSAS map), as detailed by the Food and Agriculture Organization (FAO) presented above as figure 1, provides insights into the spatial distribution of salt-affected soils, characterized by specific thresholds of electrical conductivity (EC), exchangeable sodium percentage (ESP), and pH at various depths. According to the GSAS map, over 4.24 x 10^8 hectares of topsoil (0-30 cm) and 833 million hectares of subsoil (30-100 cm) are affected by salinity. Saline soils dominate, comprising 85 % of affected topsoil and 62 % of subsoil, followed by sodic and saline-sodic soils. These estimates, derived from data covering 118 countries, indicate that salt-affected soils occupy more than 4.4 % of the global land area.

A significant proportion of salt-affected soils, over two-thirds, are concentrated in arid and semi-arid climatic zones, with 37 % located in arid deserts and 27 % in arid grasslands. The prevalence of SAS underscores the urgency of implementing effective soil management strategies to mitigate the adverse impacts on agricultural productivity and environmental sustainability.

2.1.1 European Context

Salinization impacts approximately 3.8 million hectares across Europe as shown in figure 2, with irrigated zones being particularly susceptible. In the Mediterranean region alone, it's estimated that 25 % of irrigated farmland experiences moderate to severe salinization, leading to significant soil degradation. Predicted rises in temperature and alterations in precipitation patterns in the Mediterranean are anticipated to exacerbate salinization issues further. Saline soils (with electrical conductivity, EC, exceeding 4 dScm-1 within 100 cm soil depth) and sodic soils (with sodium adsorption ratio, Na/T, surpassing 6 % within the same depth) pose primary and secondary constraints on agricultural activities, alongside areas impacted by seawater intrusion within the European Union.

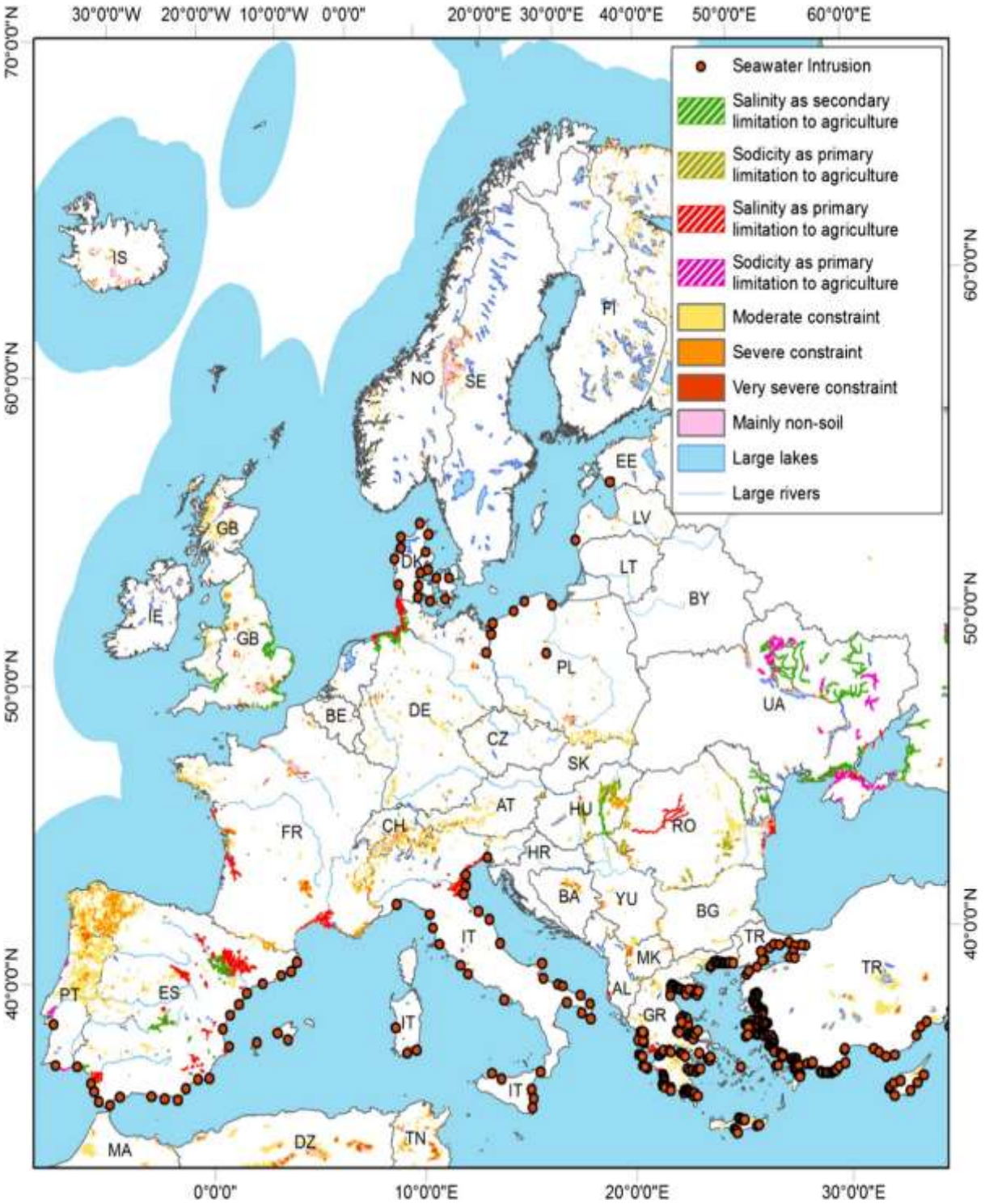


FIGURE 2: SALINE AND SODIC SOILS AS AGRICULTURAL CONSTRAINT IN EUROPE, DALIAKOPOULOS ET AL. (2016)

2.1.2 Understanding the Maltese perspective

A group of islands with a total area of 316 km^2 make up the Islands of Malta. The three main islands are Malta, Gozo, and Comino. Malta, the biggest island, is around 14 km broad and 27 km long. This demonstrates the strong coastline effect the Maltese islands have on all the islands which impacts directly soil and water quality. The Maltese Islands are likewise lay low, with Dingli having the highest point at 253 metres (Schembri, 1993). The climate of the Maltese Islands is Mediterranean, with warm, dry summers and chilly, rainy winters. The average annual temperature is 18.6 °C, according on the climatic trend seen between 1961 and 1990. (Galdies, 2011). The overall average temperature change during these thirty years is 1.8 °C each year. The observation of the average winter temperature, which is 12.4 °C, and the average summer temperature, which is 26.3 °C, reveals the distinctive feature of a bi-seasonal climate. Similar patterns may be seen when it comes to precipitation because there are clear variances between winter and summer numbers. 553 mm of precipitation falls annually on average (Galdies, 2011). However, the yearly precipitation decreases by 50 % from October to December. Just 2 % of the total precipitation that falls between June and August falls during this time. The average precipitation reported for the years 1961 to 1990 ranges from 274 mm to 874 mm, on average (Galdies, 2011). As a result, the percolation rate decreases as the likelihood of surface runoff rises. The severe seasonal fluctuation affects soils and crops because they must resist prolonged periods of drought and prolonged periods of high rate of evaporation, while prolonged periods of heavy rain can cause soil erosion (Graiss & Krautzer, 2011). All of these factors contribute to the salinisation of soil and water on the islands with different impacts on the environment and agricultural sector.

Agriculture in Malta makes up for only 1.4 % of the total Gross Value Added generated by the island's economy; however, it is the major contributor to the primary sector (NSO,2020). Nevertheless, it is negligible direct input to economic growth, agriculture has a major influence in structuring the rural landscape and the environmental nature of the country. Today's agriculture plays a significant role in maintaining the quality of the

landscape whilst being a vital element for the cultural heritage and essential setting for tourism.

2.1.2.1 Characteristics of Maltese Agriculture

Maltese agriculture is characterised by small holdings normally bounded by rubble walls. Due to land fragmentation which took place over the last hundred years, the average size of the holding had decreased by half from two hectares to one hectare, between 1981 and 2001. When looking at the latest two Agricultural census, that of 2010 and 2020 the total holdings that had an area of less than 1 hectare in 2010 were 71 % whilst in 2020 it remained almost the same as it was calculated to be 69.7 % (NSO, 2010; NSO, 2020).

Agriculture productivity has always been hindered by lack of sufficient water (Hartfiel et al., 2020) The economic effects of drought are further aggravated with the seasonal and temporal fluctuations of rainfall. The climatic uncertainties prompt farmers to use agronomic practices that deplete soil and obtain low yield. Additionally, the size of the island is also negatively impacting the agricultural sector due to lack of land whilst being an island also makes coastal agricultural parcels prone to excessive saline conditions that can impact both productivity and soil fertility, whilst in some cases causing soil erosion.

All in all the agricultural sector in Malta is under the effect of natural mishaps such as low soil productivity and poor climate conditions (MRRA, 2008), Camilleri (2005) identified that land fragmentation, lack of farm access, topological position and lack of water are also affecting the agricultural sector in Malta whilst adding soil characteristics that hinder cultivation such as shallow soils, abundance of stones, exposed bed rock and poor tilt.

2.1.2.2 Land Use

Agricultural land occupies 49 % of the Maltese territory, making it the most predominant use of land. On the other hand, urban areas, natural habitats, and forests cover 23 % (EEA, 2004). As per the 2020 Agricultural Census the total amount of utilised agricultural land has decreased by 6.2 % (10,730 hectares) from the previous 11,445 hectares in 2010. The census categorizes utilised agricultural areas into three land uses:

1. Arable Land; Land cultivated under a system of crop rotation
2. Kitchen Gardens: Small plots of land intended for self-consumption.
3. Land under permanent crop; Area of land not worked under a system of crop rotation but occupying the same field for a period of 5 years or more.

Arable land occupies 7,782 hectares or 72.5 % of the utilised agricultural area, whilst kitchen gardens and permanent crops accounted for 18.6 % or 1,995 hectares and 8.9 % or 953 hectares, respectively. Forage was mostly cultivated on arable land covering 5,251 hectares, followed by vegetables with an area of 1090 hectares and potatoes with 570 hectares. Fallow land amounted to 725 hectares. Permanent crops included 228 hectares of fruit and berry plantations, 107 hectares of citrus orchards, 154 hectares olive groves, 456 hectares vineyards and eight hectares nurseries. According to the farm structure survey of 2005 (NSO, 2005), there were seventy hectares of land under green houses, on the other hand within the most recent 2020 survey a total of eighty-five hectares were under protected cropping. A total 3498.4 hectares or 30.5 % of the total utilised agricultural area was recorded as irrigated in 2010. This shows a significant increase of more than 500 % in the irrigated area over the last 30 years from 580 hectares in 1983 to 3498.4 hectares in 2010. The use of water for agricultural purposes accounts for approximately eighteen million meters cubed or 37 % of the total estimated water consumption in Malta (FAO, 2006). The northern and western districts are the largest consumers of irrigation water with a total of 960 hectares, representing 63.4 % of the irrigated land in Malta. Vegetables and potatoes are the major consumers of irrigation water accounting for 57 % of the total irrigated area.

The lack of water led farmers to use irrigation systems that make efficient use of water such as drip irrigation. According to NSO (2010) drip irrigation is the most technique used, this practice can also lead to surface crust salinisation. Water application is based on judgement rather than measured scheduling to meet the crops' requirements and soil moisture conditions, this also might negatively affect water usage due to excessive watering since no instruments of water moisture are generally used. Ground water pumped from boreholes is the main source of irrigation water and in recent years the quality of this water dropped significantly. This is because it is estimated that 80 % of water demanded by the agricultural sector is collected from ground water, hence issues related to soil salinity and sodicity are on the rise.

2.1.2.3 Agronomic Practices

Climatic factors influence the cropping practices which follow three patterns. In rainfed farming crops are sown before or during the rainy period, whilst crops which rely on the conservation of soil moisture are planted at the end of the rainy season. Where irrigation water can be used to supplement rainfall and sustain soil moisture, three crops a year can be produced.

Current cropping is dominated by potatoes, especially destined for export and vegetables with wheat, barley and sulla grown as livestock feeds. In addition to animal manure mineral fertilisers are also applied to crops. The application of manure to land is mostly done in late Summer prior to the Autumn cultivation. The most used farm manure is cow manure. Farmers are obliged to formulate a fertiliser plan so that Nitrate insurance levels are applied without any excess to the field. Apart from nitrates manuring excessively can also be a factor impacting soil salinisation over a period of time.

Soils of Malta lack horizons because they are frequently shallow and young. The soils of Malta and the parent material from which they were formed share a lot in common. (Lang, 1960). Additionally, almost all of Malta's soil has been impacted by human activities in some way. All the soils in the Maltese Islands have undergone some sort of anthropogenic modification. The pH of the soils, which ranges between 7.3 and 8.5, tends to be slightly

alkaline as well (MALSIS, 2004). Since 77 % of all soils of Malta have a clay concentration of 48 % or above, the quantity of clay in such soils is likewise relatively high. Due to the immaturity of the soil in the Maltese Islands, when it comes to soil salinity the contribution of salts from the parent material to the soil's salinity is minimal (MEPA, 2006).

The soils on the Maltese islands are mostly non-saline. The total salinity of irrigated soils is typically 695 S/cm, while the salinity of non-irrigated soils is 347 S/cm (MALSIS 2004). This clearly demonstrates that irrigation has a significant impact on the rise in soil salinity (Muscat, 1997). However, it is crucial to remember that there are certain soils with salt levels that are higher than the averages given, thus these average numbers may not necessarily convey the whole picture. FAO 1971 investigation revealed that the soils of the Tas-Sigra (Calcisols) and Alcol (Cambisols) Series in the Pwales valley, as well as the soils of the Tas-Sigra Series surrounding Ghadira, had the greatest salt levels (Sivarajasingham, 1971).

The main contributors to a rise in soil salinity were irrigation with ground water and treated sewage effluent (Muscat, 1997). The electrical conductivity of the irrigation water varied from 790 S/cm to 4920 S/cm overall. Boreholes connected to the Perched Aquifer and Mean Sea Level Aquifer provide irrigation waters (Vella & Camilleri, 2003). Since the aquifer is typically highly salty, further increases in water salinity are anticipated (Agius, C., von Tucher, S., & Rozhon, W, 2022)

This rise is due to needless groundwater extraction that leads to seawater intrusion (Vella & Camilleri, 2003). The mean sea level aquifer's average salinity was measured at 3365 S/cm, but the perched aquifer's is 1006 S/cm. Since treated sewage effluent had an average electrical conductivity of 6590 S/cm, it was discovered that it was saltier than irrigation water. Conductivity measurements rose from 4033 S/cm in 1986 to 6590 S/cm in 2001, indicating that the treated sewage effluent's salinity rates are also increasing (Vella & Camilleri, 2003).

The Maltese landscape, which is characterised by rubble walls, is in itself a testimony of the contribution of terraces to the successful soil management (Gauci et al., 2019). Traditional agricultural practices in the Maltese islands have been quite effective in stabilizing soil erosion. This has been mostly achieved through the construction of terraces which reduce the slope of individual fields, especially in valleys. Such terraces are preserved by the construction of retaining dry rubble walls which have now become a characteristic feature of the Maltese rural landscape. When it comes to the soil depth of Maltese fields, the estimated average is 30cm (Attard & Role, 2007). In some cases, farmers top up their fields with soil or other related material to reach this desired depth, hence making soil profiling more difficult as in some parcels one can have a gradient of different soil types and textures.

2.1.2.4 Soils in Malta and Gozo

Like in many European Countries the first soil survey of the Maltese islands was conducted in post-World War II, in response to the need to increase agricultural production. In fact, in the early 1920's, Dawson Shepard reported that by the time no soil survey of the island had been made. It was in the year 1956 when the first soil survey was conducted by the Colonial Office under the responsibility of D.M. Lang. The publication included a report 'Soils of Malta and Gozo' and a soil map at a scale of 1:31,680 (Lang, 1960). This study described the soils using Kubiena's Kubiëna (1958) classification system in which thirteen mapping units were identified. Nine of the mapping units were characterized by a single soil series out of which four are complexes or sequences. The mapping units were classified into three main categories: Carbonate Raw Soil, Xerorendzinas and Terra Calxis.

The study outlines the characteristics of carbonate raw soils, a category of very young raw soils with minimal humus content, formed on calcareous parent material. Four main series, namely Nadur, Ramla, Fiddien, and San Lawrenz, exhibit varying textures and clay content based on their parent material. Additionally, the Rdum sequence is described, representing soils on coastal slopes with rapidly changing parent material.

Lately in 2002, a soil information system for the Maltese Islands (MALSIS) was developed by the Ministry for Rural Affairs and the Environment as part of a co-financed project under the life third countries program. The project included the establishment of a national soil survey developed according to the FAO guidelines.

The MALSIS program was aligned with the European Classification System and was implemented with the assistance of the National Soil Resources Institute of Cranfield University. Seven soil groups were identified as shown in table 1, with Calcisols being the most common (27 % of rural areas), followed by Regosols (14 %), Leptosols (13 %), Luvisols (13 %), Vertisols (8 %), Cambisols (5 %), and Arenosols.

While the precise extent of salt-affected soils remains insufficiently documented, abundant evidence underscores salinity as a significant constraint on agricultural productivity. The Maltese Islands' hydrogeological characteristics, coupled with the Mediterranean's non-leaching climate and limited freshwater resources, create favourable conditions for salt accumulation, fostering salinity-related issues. Despite the productivity of irrigated lands, a considerable portion has already succumbed to salinity, exemplified by the Pwales valley, where seawater intrusion and excessive groundwater extraction result in visible salt crystal formations on the soil surface (Vella, 2001). Research conducted by the Department of Agriculture highlights greenhouse production systems as particularly vulnerable to soil salinity issues (Camilleri, 1999).

TABLE 1: CHEMICAL PROPERTIES OF SOILS OF MALTA.

Soil Type		***BD*** (g/cm^{-3})	***CaCO*** $_3$ g/kg^{-1}	***CEC*** $(cmol+kg^{-1})$	***EC*** $_{1:5}$ $\mu S/cm^{-1}$	***OC*** g/kg^{-1}	***pH***	***Clay %***
Calcisol	Topsoil	1.11	616	14.41	511	17.67	7.94	28.91
	Subsoil	1.30	609	14.32	497	8.80	8.23	31.78
Regosol	Topsoil	1.07	503	14.37	489	24.28	7.99	29.68
	Subsoil	1.26	601	13.38	307	10.63	8.35	31.58
Leptosol	Topsoil	1.09	414	16.32	364	30.11	7.95	32.36
Luvisol	Topsoil	1.13	415	17.20	515	22.27	7.95	35.74
	Subsoil	1.23	348	16.64	129	12.20	8.17	39.88
Vertisol	Topsoil	1.10	398	16.96	697	13.71	7.95	48.93
	Subsoil	1.44	376	16.09	1111	6.96	8.17	50.59
Cambisol	Topsoil	1.07	617	13.59	554	22.77	A7.98	25.39
	Subsoil	1.33	583	13.08	616	7.55	8.15	28.59

Source: MALSIS (2004)

2.2 Soil Salinity: An Overview.

Salinity in soils is viewed as a threat which is progressively increasing. Approximately one million hectares of land in the EU are contaminated by saline soil (Tóth, et al., 2008). According to Liesh & Al Masoom (2012), saline soils are more common in hot, dry regions of the world where there is little soil salt leaching.

Insoluble salts in the topsoil and subsoil lead to the development of saline soils. The mineral weathering of the parent material is what causes the initial salt content in a soil. The soluble concentration of soluble salts within the aqueous component of a soil sample is referred to as soil salinity in soil science. The most important ions that affect soil salinity are Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_3^{2-}, HCO_3^-, and SO_4^{2-} (Rhoades, 1996). Salinity in soil or ground water implies the presence of salts that are easily soluble in the medium. Calculating the electrical conductivity (EC) of the soil solution allows for the quick measurement and quantification of salinity in soil (Silva & Uchida, 2000). The saturated extract's EC(e), which is used to classify soils, must be 4 dS/cm or greater for a soil to be labelled as saline (FAO, 1999). The standard measure for expressing the salinity of soil

and ground water is parts per million (ppm), which is equal to Mg^{2+}/l (Kotuby-Amacher, Koenig, & Kitchen, 2000).

Salinity in the soil profile can result from several human and natural factors. Regardless of where they come from, salts that are present in the soil, both suspended and undissolved, cause changes to the matrix's mechanical, physical, and chemical components (Junbao, Yunzhao, Guangxuan, Di, Yuqin, et al., 2014).

Parent material, saline groundwater, irrigation, proximity to the coast, excessive fertilisation, and air deposition are the primary sources of salts in soil (Greene, Timms, Rengasamy, Arshad, & Cresswell, 2016; El-Swaify, 2000). In actuality, the key factor affecting soil salinity is not the weather. Soil salinization can be caused by both natural and human causes.

2.2.1 Natural Causes of soil salinity

Natural factors include precipitation from sources outside the soil environment, local salt aggregation, and weathering of rocks and minerals. It is natural for minerals to weather in cycles. This suggests that while the soil is formed, salts are continuously added (El-Swaify, 2000). According to El-Swaify (2000), mineral weathering refers to the weathering of the minerals that create soil. Sedimentary rocks like limestone release a lot of salts during weathering (Lamar & Shrode, 1953). Additionally, during weathering impurities are removed from minerals. Therefore, salinity of a surface is determined by the initial salt content of the parent rock. If the dissolved salts are not leached, they will dissolve into the soil as the rocks weather. Leaching is typically sped up in humid areas, whereas build up occurs in dry, arid areas.

Another reason for salinization is atmospheric precipitation and deposition. This mostly occurs in marine regions. Salty droplets are removed and gathered on the nearby terrain (McDonald, Unni, & Duce, 1982). Most of the atmospheric precipitation is related to water being carried by the wind.

Soil salinity is also influenced by sporadically occurring tidal floods in coastal locations. These factors include natural disasters like tsunamis. Wide areas of land are submerged in the sea when tsunamis occur, creating enormous salt deposits across an inland region. Several years after the tsunami, it was discovered that these areas were affected by salinity (Tóth et al., 2008).

On the other hand, the upward capillary movement of saline groundwater into the soil is related to regional salt deposition. By means of capillary action, ground water rises when the water on the soil surface evaporates, carrying with it salts that will gather close to the soil surface as the water evaporates. (2012); McDonald, Unni, & Duce (1982; Lieth & Al Masoom).

2.2.2 Human causes of soil salinity

Contrarily, human causes include saltwater irrigation and fertilization, two of the most significant contributors to salinization (Provin & Pitt, 2001). Because fertilizers include sizable quantity of salt, improper usage of fertilizer can cause an increase in soil salinity (Diacono & Montemurro, 2015). If an inorganic fertilizer contains a lot of salts, such as KCl or $(NH_4)_2SO_4$, it might especially cause salinity problems. Another influence is the rate at which fertilizers are applied, as inefficient fertilizer use can cause salt levels in the soil to increase (Diacono & Montemurro, 2015). N^+ and K^+ are two common salts found in fertilizers and are utilized in salt form. Additionally, waste sludge discharges also increase soil salinity (Diacono & Montemurro, 2015).

Additionally, irrigation water can increase soil salinity; however, the effect of irrigation water on soil salinity relies on the kind of irrigation water used as well as how quickly it is distributed (Provin & Pitt, 2001; Podmore, 2009). Irrigation water contains several salts, including KCl, $CaCl_2$, $MgSO_4$, Na_2SO_4, and NaCl (Provin & Pitt, 2001). Effective irrigation water helps to reduce salinity, but ineffective salty irrigation water causes salinity or sodicity to increase (Fipps, 2003). In Malta, irrigation using salt water is extremely common (Vella & Camilleri, 2003). Substantial quantity of salt can be distributed over soils by irrigation water that contains a lot of salts (Muscat, 1997).

Infiltration of salt water is one of numerous processes that cause irrigation water to be salty. When sea water enters and combines with ground water in coastal areas, a phenomenon known as saltwater intrusion takes place. (2002) Provin & Pitt the root zone would therefore get salinized in cases where the groundwater supply becomes heavily populated with salts, with the potential to potentially damage the topsoil if the water table becomes more exposed (Junbao, Yunzhao, Guangxuan, Di, Yuqin, et al., 2014).

Additionally, the groundwater bodies in Malta are affected by seawater penetration, which combined with the soils' exposure to sea spray may cause some salinity in certain regions of the island. Because this water is utilized for irrigation, excessive groundwater withdrawal from aquifers near mean sea level contributes to the spread of dissolved salts through cropland (Hillel, 2000). To put this into perspective, it is important to note that the effects of the aforementioned situation may be seen in the aquifers at mid-sea level, which are found across Malta's central and southern areas. The Perched Aquifer and the Mean Sea Level Aquifer (MSLA), which are vertically piled and separated by impermeable rocks, are the two principal aquifers in Malta (Mangion, 2003). Although the elevated perched aquifers are not in contact with saltwater, they get contaminated as a result of some farmers using water for irrigation from the deep mean-sea level aquifer and allowing the salts to leak over time.

Due to its climate, the Mediterranean region is the one in the EU that is most affected by salinity. However, climate change may accelerate the rate of desertification in the EU and may cause an increase in salinity in formerly non-saline regions (Tóth et al., 2008). Remember that this cycle is currently occurring on a worldwide scale (Tóth et al., 2008).

2.3 Introduction to soil types in terms of salinity

There are soils that are saline, sodic, saline-sodic, or non-saline-sodic. Non-saline soils are those that contain little or no salt, whereas saline soils are those that contain a lot of salt (Provin & Pitt, 2001). The quantity of ions like Na^{+}, Mg^{2+}, and Ca^{2+} determines whether the soil is saline, sodic, or saline-sodic (Walworth, 2006).

The build-up of high salt in a soil sample has a negative effect, harming the soil's structure and blocking its pores. As a result of the soil's structure deteriorating, the permeability would decrease as the pores became blocked. Additionally, salt-affected soils are better able to sustain higher water-field efficiency under the same climatic and meteorological conditions, mostly because salt-sensitive plants do not osmose moisture (Bernstein, 1975). The soil's salinity is influenced by its capacity to hold water as well as the quantity of salt that is present in the soil sample. For a given soil solution, a fine textured soil, for instance, may be able to store five times as much soil salinity as a coarse textured soil. As a result, various soil textures may have varying quantity of salt because the texture affects the soil's ability to store water and drain it (Maas, & Grattan, 1999).

2.3.1 Saline Soils

In an aqueous solution, saline soils exhibit electrical conductivities greater than 4 dS/cm (Horneck, Ellsworth, Hopkins, Sullivan, & Stevens, 2007). As the name implies, saline soils have a significant quantity of soluble salts in the root zone (Franzen, 2007). Typically, neutral ions like Na^{+}, Mg^{2+}, Ca^{2+}, Cl^{-}, and SO_4^{2-} are used. Saline soils are often thought to be non-sodic, yet they occasionally turn out to be saline sodic soils. Since saline soils typically do not exceed 8.5 pH, their pH is even lower than that of sodic soils (Horneck, Ellsworth, Hopkins, Sullivan, & Stevens, 2007). Due to differences in osmotic potential, salts in the soil alter the normal process by which plants absorb water (Hasanuzzaman, Nahar & Fujita, 2013). The osmotic ability in the root zone is greater in non-saline soils than it is in other soil sections. More water is absorbed by plants thanks to their increased osmotic capacity (Yadav, Irfan, Ahmad & Hayat, 2011). However, the osmotic capacity of salty soils declines. The osmotic potential thus ends up being higher in the soil than in the area around the roots. It prevents plants from absorbing water, which eventually leads to crop loss (Bauder & Brock, 2001). Water facilitates the movement of soluble salt in the soil since salt is soluble in water. As a result, various horizons have varied salt contents (Parent & Koenig, 2010). When it rains, water percolates vertically

through the earth. A decrease in salinity is caused by the salts in the soil dissolving in water and percolating below as well (Provin & Pitt, 2001).

On the other hand, capillary action forces the soil water upwards because of high temperatures and a lack of precipitation. This increases salinity by causing salt to build up in the topsoil (Provin & Pitt, 2001). Soil remediation techniques like non-salty water irrigation are employed because they lower soil salinity, which improves agricultural yield (Rietz & Haynes, 2003). Saline soils frequently have strong aeration and good flocculation, which causes them to have a higher percolation intensity than non-saline soils under some circumstances (Horneck, Ellsworth, Hopkins, Sullivan, & Stevens, 2007). Such soil has an uneven composition and frequently has white soil crystals or an obviously oily top with little flora (Franzen, 2007). These soils tend to produce smaller plants with thick, oily leaves with a dark green colour. Due to these characteristics, the plant can reduce water loss via evapotranspiration (Shannon, 1997).

2.3.2 Sodic Soil

A soil must have an exchangeable (Na^+) level that surpasses 15 % of its overall cation exchange capacity (CEC) to be classified as sodic (Davis, Waskom & Bauder, 2012). The (Na+) percentage that may be exchanged on clay particles is called the exchangeable (Na+) percentage (ESP), and it is closely related to CEC. Sodic soils do not qualify as salty since their salinity levels are below 4 dS/cm. (Na+) alters the chemical makeup of the soil. Sodic soils have little salt, and most of the salts are insoluble (Provin & Pitt, 2001). Typically, sodic soils have a pH little above pH 9, making them alkaline (Sibbett, 1995). Large levels of Na^+ ions provide the alkalinity, and these ions, together with the carbonate ions, allow and Ca^{2+} to precipitate since they both produce carbonate (Diacono & Montemurro, 2015). The physical characteristics of the soil are frequently greatly influenced by the Na^+ content. Clay and humus colloidal particles can disperse thanks to the high Na^+ content. Clay particles are dispersed, and they combine to fill the soil pores (Johnson & Zhang, 1983). Contrarily, Ca^{2+} and Mg^{2+} work in the other manner by enhancing flocculation (Dontsova & Norton, 2001). When soil is compressed in severely

sodium-affected soils, the physical characteristics of the soil surface alter, and the soil may have a black colour. When the dirt warms up, it also turns gritty and rubbery. Poor soil aeration and low percolation rates cause an increase in surface runoff (Davies & Lacey, 2009). Additionally, this increases the quantity of deterioration caused by aeolian action (Davies & Lacey, 2009).

Sodic circumstances are hazardous to plants. Sodium levels in sodic soil are hazardous for plants that are particularly vulnerable (Davis, Waskom, & Bauder, 2012). This type of soil is inhospitable to plant life due to a lack of aeration and percolation, as well as issues with nutrients in the soil (Hariuandi, 1984). Compared to saline soils, sodic soils have harder and more resilient conditions. Sodic causes can sometimes result in seed failure (Provin & Pitt, 2001). Remediation is sometimes more complicated as the salts in sodic soils, unlike those in salty soils, are not soluble and cannot be washed down. Additionally, the soil's ability to absorb water is seriously hampered (El-Swaify, 2000).

2.3.3 Saline-Sodic Soil

Electrical conductivity more than 4 dS/cm and an exchangeable Na^+ concentration greater than 15 % are both indicators of saline-sodic soils (Seelig, 2000). These soils are made up of a lot of soluble salts and seem to lose a lot of those salts because of water percolation. Mg^{2+} and Ca^{2+} precipitate as a result, increasing the Na^+ level (Bresler, McNeal, & Carter, 2012). However, saline-sodic soils frequently release enough salts to still be referred to be saline. Saline-sodic soils often have a pH of less than 8.5. (Seelig, 2000). These soils look like saline soils. Although the environment for plants is better than in sodic soils, they still need to adapt to the salt concentrations in the soil in a manner similar to how they do in saline soils. These soils' well-aerated makeup allows for greater percolation and prevents erosion through aeolian and surface drainage processes (Horneck, Ellsworth, Hopkins, Sullivan, & Stevens, 2007). But when salt leaching rises, the salinity of soils decreases (Provin & Pitt, 2001). The composition changes when the pores shut if the quantity of Na^+ that may be transferred decreases. Because the soil is less aerated, percolation decreases in a manner comparable to the structure of sodic soil.

Finally, enough soluble salts precipitate, causing the soil to become sodic and lose its saltiness (Seelig, 2000).

2.4 The effect of salinity on plants

There may be direct and indirect effects of sodicity and soil salinity on a variety of soil and crop characteristics. Osmotic, nutritional, toxic, and physiological impacts are the main consequences. Stunting of the plant is one of the first saltwater effects on plants that will have a detrimental effect on its ability to grow. Additionally, the plant's leaves may develop thicker, deeper-coloured leaves. Small leaves on the plant are a result of the stunting cycle, which also results in a lower crop yield. Determining if the plant is not developing properly because of the impacts of salt might be difficult given these changes in the morphology of the plant. Comparing the crop with a healthy crop is typically the most effective approach to determine whether a plant is salt polluted (Bernstein, 1975).

Excessive sodium exposure, whether from irrigation or sea spray, adversely affects plant foliage, leading to discoloration, premature leaf drop, and distinct patterns of damage. Sensitivity varies among plant species, and symptoms worsen with higher salt concentrations. Severe cases can result in the death of buds, twigs, and branches, with subsequent witches' broom growth.

Root exposure to high sodium concentrations impedes water uptake, causing wilted foliage and stunted growth. In broadleaves, salt accumulation leads to yellowing and browning at leaf margins and tips, often starting with older foliage. Conifer needles turn yellow, then brown, and may drop prematurely. Sodic soils, characterized by high sodium relative to calcium and magnesium, exhibit high pH levels and may have visible surface crusts, hindering water penetration and damaging plant roots.

Salt toxicity is prevalent in specific regions such as coastal areas. Sources of salt include irrigation with saline water, recycled municipal wastewater, and other chemical agents. Frequent irrigation of poorly drained soils and excessive fertilization can also induce salt damage. Even moderately low concentrations of certain metallic ions, such as boron, can

harm plants. Understanding and managing salt exposure are critical for preserving plant health and preventing soil degradation.

There may also be natural elements that reduce the salt content of the soil. The most notable of them is the discharge of salt from precipitation. Water percolates through the soil during precipitation, allowing soluble salts to dissolve and progressively drain out of the ground (Gran, et al., 2009). The quantity of effectiveness depends on the salt's solubility as well as the porosity and permeability of the surface. Soils that are porous and permeable increase the rate of percolation and allow soluble salts to move through the soil (El-Swaify, 2000). Additionally, plants have a significant role in reducing soil salinity. The osmotic capacity increases with increasing salinity of the surface, which reduces plant water uptake. Salts from the soil are absorbed by plants to counteract this impact (Hasanuzzaman, Nahar & Fujita, 2013). Plant water absorption increased consequently, and salinity dropped (Taiz & Zeiger, 2006). Osmotic equilibrium is the name of this mechanism (Smith, Palta, & McCown, 1984). The salt tolerance of the plant determines how much salt it can absorb. Plant loss or death is frequently caused by plants' inability to remove salt from the soil. Plants that are immune to salt may not be able to do this. Few plants can survive in soils that are quite salty. They are known as halophytic plants (Blaylock, 1994).

The main goal of irrigation is to supply a crop with sufficient and timely water to prevent yield loss caused by prolonged periods of water stress during sensitive stages of crop growth. However, with repeated irrigations, salts in the irrigation water can accumulate in the soil, diminishing water availability to the crop and accelerating the onset of water shortages. Understanding this process is crucial for identifying strategies to mitigate its impact and decrease the likelihood of yield loss.

Plants draw water from the soil by exerting a greater absorptive force than what holds the water to the soil. If the plant cannot make internal adjustments and exert enough force, it fails to extract adequate water, leading to water stress, particularly when the soil becomes excessively dry. Salt in the soil-water elevates the force required by the plant to extract water, known as the osmotic effect or osmotic potential. For instance, if two soils with the same water content differ in salt levels, the plant can extract more water from the salt-

free soil than from the salty soil, even if their water content is identical. The reasons for this phenomenon are not easily explained, but salts' affinity for water increases the energy expenditure needed for the plant to absorb relatively salt-free water from a relatively salty soil-water solution.

2.4.1 Osmotic effects and plants

The osmosis theory calls for a difference in the total quantity of solutes in two separate regions. According to the hypothesis, water will always go from a region with low solute concentration to one with greater solute concentration. The probability of osmosis increases with the distance between the two sites of concentration (Hasanuzzaman, Nahar, & Fujita, 2013). Osmosis cannot happen without a semi-permeable membrane. It is rare to find a semi-permeable membrane over a soil (Gregory, 2008). Contrarily, a semi-permeable layer exists in plants, and as a result, the osmotic ability has considerable influence on plant development (Tingey & Stockwell, 1977). Depending on the osmotic capacity difference between the plant and the soil, plants will absorb water (Gregory, 2008). In soils with low levels of solute, the osmotic ability is robust, resulting in increased plant water absorption rates (Brady & Weil, 2002). Saline soils have a lower osmotic capacity, nevertheless, since the salts in the soil increase the solute's concentration. Consequently, the plant uses a minimum quantity of water (Brady & Weil, 2002). Osmotic adjustment is a method used by plants to lessen this impact. To increase the concentration of their solutes, plants absorb salts from the soil. As a result, the osmotic capacity rises once more, and plants start to take up more water. The rate of salt absorption depends on the kind of plant (Chen & Jiang, 2010). If plants are unable to absorb enough water, their physiological makeup may change. Although most of the time this increase in water tension does not kill plants, it does slow down their growth and reduce agricultural yields (Bernstein, 1975).

High concentrations of salts in the soil can produce effects that are like those of drought. Despite the plentiful precipitation, the limited osmotic capacity prevents plants from absorbing much water (Brady & Weil, 2002). A decrease in plant output is one of the

effects of a lack of water intake. Plants' stems or leaves will be harmed by the excessive quantity of salt (Bernstein, 1975). The plant can frequently produce dark green, thick waxy leaves. The plant will also exhibit signs of withering. These symptoms are easier to spot in the initial stages of plant growth (Gregory, 2008).

the scientific aspect reveals that the additional energy required to absorb water from saline soil, known as osmotic potential, adds to the energy needed for water absorption from salt-free soil (soil-water potential). This cumulative effect leads to a significant reduction in water available to the crop as soil salinity increases. The impacts of salinity closely resemble those of drought, resulting in water stress and reduced growth, with noticeable stunting, leaf damage, and necrosis after prolonged exposure to high salinity.

The concentration of salts in the soil varies with leaching fraction and depth in the root zone, increasing as leaching fraction decreases or depth in the root zone increases. As the soil dries, the plant faces changing water availability in different portions of the rooting depth, as soil-water content and soil-water salinity fluctuate between irrigations. The plant's absorptive force operates throughout the rooting depth, with water uptake occurring where it is most readily available the upper root zone, frequently replenished by irrigation and rainfall.

The water extraction pattern corresponds to the irrigation frequency, with infrequent irrigations resulting in a pattern of 40-30-20-10, and more frequent irrigations leading to a skewed pattern favouring greater uptake from the upper root zone. The crop's rooting depth tends to be shallower with more frequent irrigations. Timely irrigation is crucial to supply sufficient water, preventing crop moisture stress between irrigations, particularly when soil salinity affects water availability.

In scientific terms, the availability of water in the upper rooting depth diminishes the significance of salinity in the lower root zone. However, during extended periods between irrigations, when a substantial portion of water extraction occurs from the lower depths, the salinity in the deeper root zone becomes crucial. This becomes particularly important in the later stages of a 'dry-down' period between irrigations, especially on hot, windy days with high crop water demand, where slow absorption and water movement toward

the roots can lead to severe water stress. Reduced yields or crop damage is anticipated when there is a prolonged water shortage.

It is assumed that salinity affects water availability uniformly for all plants, but different crops exhibit varying degrees of sensitivity to soil salinity. Some crops can better extract or absorb water from salty soil, making them more tolerant to salinity. The reasons for these differences in tolerance are not fully understood, but tolerance data indicate an 8 to 10-fold range in salt tolerance among agricultural crops. In regions where irrigation management cannot control salinity within the tolerance of a preferred crop, yield loss is likely unless an alternative crop, more tolerant to the expected salinity, is cultivated.

2.4.2 The plant's hormonal changes due to salinity

Since less kinetin is transmitted from the roots to the leaves by salinity in the soil that the plant absorbs, this might result in hormonal imbalance. Additionally, the plant's leaves will produce more abscisic acid. The salinity-related alterations might result in the plant's stomata openings being smaller, which can result in less evapotranspiration. If the relative humidity in the environment is between 45 % and 95 %, the plant's osmotic ability is reduced. A higher hormonal imbalance would also be caused by water stress brought on by a decrease in relative humidity and/or an increase in soil salinity (Munns, 2002).

2.4.3 Salinity effects on plant nutrition

Salinity of the soil and cation nutrition may interact during the cation exchange cycle. Due to the ability of tiny particles that come together to form aggregates, which decrease the composition and quality of the soil, the salinity of soil water can affect the physical qualities of soil. As the interchange of nutrient cations declines, this strategy would harm the plant's ability to absorb cations. Most typically, when a mixture of salts is present in the soil, the cation nutrient shortage can self-regulate. The types of Ca^{2+} and Na^{+} will rise and K^{+} will decrease when NaCl and $CaCl_2$ occur (Maas, & Grattan, 1999).

Excessive salinity adversely affects crop growth by diminishing soil-water availability, retarding crop development, and impeding root expansion. In the presence of higher salinity water, the likelihood of sodium and chloride toxicity increases. Additional nutrient application to combat salinity effects does not enhance yield if the crop is well-fertilized. However, when certain nutrients, such as nitrogen, are deficient, supplementing them can improve yield. Saline areas in fields typically exhibit a dark green to blue-green hue, indicating sufficient nitrogen supply. If these areas appear yellow, additional nitrogen application may boost yield. It is crucial to consider the salinity impact of water-soluble salt fertilizers, with placement and rates adjusted accordingly.

For annual crops, plant tissue analysis is valuable to confirm calcium deficiency. In the case of potatoes, petioles or leaf material from the most recently fully formed leaves are commonly utilized. Calcium levels below 0.15 percent (dry weight basis) likely indicate a deficiency, while values ranging from 0.15 to 0.20 percent are suspect. The Cax value can predict a probable calcium deficiency, with Cax values less than approximately 1 me/l often associated with deficiency.

The Ca/Mg ratio or the calcium to total cations (Ca/TC) ratio in soil-water may also predict potential calcium deficiency, with ratios less than 1 (Ca/Mg) or less than 0.15 (Ca/TC) being linked to calcium deficiencies, according to Rhoades (1982).

Salinity may have a negative effect on soil and crops, but it can be reduced by increasing soil fertility using artificial or natural fertilizers. Fertilizers can enhance soil conditions by addressing the nutritional shortage brought on by salt (Maas, & Grattan, 1999).

2.4.3.1 Specific ion toxicity

Ion toxicity in plants arises from the absorption of harmful ions rather than from water scarcity, distinguishing it from osmotic effects often seen in saline conditions (Sosa, Llanes, Reinoso, Reginato, & Luna, 2005). Harmful ions such as Na^+ and Cl^- are commonly introduced through irrigation, and plants absorb these ions to improve water uptake. However, this can lead to toxic ion accumulation within plant tissues (Ferguson

& Grattan, 2005). To aid safe irrigation practices, Table 2 provides recommended maximum concentrations of trace elements in irrigation water, supporting the management of ion toxicity risks.

Trace elements generally occur in water supplies at low concentrations, often below 100 μg/L. Elevated levels of these elements are frequently linked to human activities, such as wastewater use. Routine testing of trace elements in irrigation water is not typically necessary unless toxicity is suspected. However, for projects utilizing wastewater, more rigorous testing is advisable to ensure trace element levels stay within safe limits for crop health (Table 2).

Chloride (Cl^-) and sodium (Na^+) are among the most common toxic ions in irrigation water. Chloride moves freely with soil water and can easily accumulate in plant leaves, causing leaf burn that starts at the tips and progresses inward with increased concentration (White & Broadley, 2001; Xu, Magen, Tarchitzky, & Kafkafi, 2000). Sodium toxicity, although less visually apparent than chloride toxicity, can cause leaf scorch along the edges of leaves, especially in sensitive crops. Symptoms typically emerge when leaf Na^+ concentration exceeds 0.25-0.50 % on a dry weight basis, and sensitive crops, including deciduous fruits and avocados, are particularly affected (Robbins, Meyer, Prathapar, & White, 1991; Davis, Waskom, & Bauder, 2012).

Table 2: This table was adapted from National Academy of Sciences (1972) and Pratt (1972).

Recommended maximum concentrations of trace elements in irrigation water.		
Element	Recommended Maximum Concentration[2] (mg/l)	Remarks
Al(aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn (manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni (nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Sn (tin)		
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
W (tungsten)		
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

Boron, while essential for plant growth in trace amounts, becomes toxic at concentrations exceeding 1-2 mg/L. High levels of boron cause symptoms such as leaf yellowing and tissue drying, which spreads from the edges inward as toxicity progresses (Benson, Woodbridge, & Bartram, 1994). Table 2 specifies recommended maximum concentrations for boron in irrigation water to help prevent toxicity, particularly in sensitive crops.

In addition to chloride, sodium, and boron, other trace elements are crucial in small quantities for plant growth but can become toxic if overapplied, especially through the use of wastewater. Monitoring the concentrations of trace elements, as outlined in Table 1, aids in avoiding toxic buildups, preserving soil productivity, and protecting the health of irrigated crops.

2.5 Salinity effects on Microbial Activity

Elevated salinity levels have a detrimental impact on soil microbial communities, leading to a reduction in their overall activity. This inhibition is particularly concerning as soil microbes play a crucial role in sustaining soil structure by facilitating organic matter decomposition and secreting substances vital for the stability of aggregates. Conversely, lower salinity levels create an environment conducive to microbial activity, fostering the growth and stability of soil aggregates.

In a study on Soil Microbial Biomass, Metabolic Quotient, and Community Structure, it was observed that there were no significant trends in soil total Phospholipid Fatty Acid Analysis (PLFA) contents or the biomasses of PLFA-distinguishable bacteria, Gram-positive bacteria, or fungi as salinity increased in the Sandy Loam and Sandy Clay Loam soils. However, the biomass of Gram-negative bacteria exhibited a linear increase with rising salinity in these two soils. In the Sandy Clay soil, total PLFA contents, and the biomasses of PLFA-distinguishable bacteria and Gram-positive bacteria exhibited a logarithmic decrease with increasing salinity. The impact of salinity on the fungi-to-bacteria ratio varied with soil texture. The fungi-to-bacteria ratio demonstrated a linear decrease with increasing soil salinity in the Sandy Loam and Sandy Clay Loam soils,

while no significant relationship with salt content was observed in the Sandy Clay soil. The microbial metabolic quotient, represented by cumulative CO_2 emissions per PLFA, decreased with increasing salinity. The sensitivity analysis indicated that the microbial metabolic quotients in the Sandy Loam and Sandy Clay Loam soils were more influenced by salinity compared to those in the Sandy Clay soil. (Ruihuan She et al., 2021)

2.6 Soil texture and Salinity

Soil texture is the percentage proportion of sand, silt and clay particles. A soil's texture is crucial since it influences the soil properties that have an impact on plant development. Structure, chemistry, water holding capacity, permeability, infiltration, and soil workability are a few of these characteristics. A soil's capability to retain water is referred to as its water-holding capacity. Most plants need a consistent flow of water, which comes from the soil. Furthermore, plants require air in the root zone in addition to water. The soil's permeability refers to how easily water and air may travel through it. How easy the soil is tilled, and the time of the labour required are two aspects of soil workability.

Big proportions of sand make soils simpler to work with than large proportions of clay. Sandier soils are looser, but clay soils tend to be tighter, making them more challenging to break up or cultivate. Additionally, following a rain, a clay soil takes longer to dry than a sandy soil. A sandy soil may be managed sooner due to greater drainage. The farmer must wait longer for a moist clay soil to dry out enough. Which crops may be cultivated may be restricted by soil texture. For instance, because sandy soil is loose and allows plants to grow, root crops like carrots and onions thrive there. In contrast, a sandy soil may cause some crops to develop too slowly because it is incapable of retaining nutrients and water.

The intricate relationship between soil texture and salinity constitutes a pivotal factor in soil health and ecosystem sustainability. This relationship is reciprocal that define how soil texture influences soil salinity and, conversely, how soil salinity profoundly shapes soil texture. As a matter of fact, clayey soils are characterized by a heightened surface

area, clay particles exhibit superior water-holding capacity. The protracted retention of water in clayey soils contributes to an increased likelihood of salt accumulation. As the water evaporates, salts concentrate within the soil solution, influencing salinity dynamics. On the other hand, sandy soils, distinguished by larger particles, a diminished water-holding capacity coexists with enhanced drainage. While this facilitates the leaching of salts below the root zone, the accelerated movement of water through the soil matrix poses the risk of carrying salts to deeper layers.

2.6.1 Impact of Soil Salinity on Soil Texture and Structure

Increased salinity, characterized by elevated concentrations of salts, especially Na^+, causes significant dispersion of clay particles in soils. This dispersion disrupts soil aggregates, leading to the breakdown of soil structure, which in turn creates issues with porosity, water movement, and aeration (Laird, 1996). The presence of sodium ions on the surfaces of clay particles displaces other essential cations, such Mg^{2+} and Ca^{2+}, weakening the electrostatic forces / forces that normally help soil particles clump together. As a result, soil particles repel one another, causing dispersion and a loss of aggregate stability (Sumner, 1995). This process impairs the soil's ability to retain its structure, reducing its porosity and capacity to facilitate water and air infiltration, which are essential for plant growth and soil health (Rengasamy & Olsson, 1991).

In contrast, lower levels of salinity promote more stable soil structure by preserving aggregates and promoting optimal soil porosity. Reduced salt levels encourage the formation of a flocculated soil structure, in which particles cluster together, creating larger and more stable aggregates that enhance water movement, aeration, and root penetration. This soil environment is favourable for plant growth, as it supports a more balanced distribution of nutrients, water, and air (Curtin et al., 1994).

Salinity’s effect on soil structure can notably impact water infiltration and percolation. High salt concentrations lead to the formation of a surface crust, which reduces water infiltration by compacting soil particles and restricting water entry at the soil surface. Additionally, in high-salinity conditions, a hardpan layer can develop beneath the soil

surface. This dense, impermeable layer hinders the downward movement of water and contributes towards drainage issues, further complicating crop cultivation in saline soils (Quirk & Schofield, 1955). In contrast, soils with lower salinity levels experience better water infiltration and percolation, as the absence of a crust and hardpan layer allows for uninterrupted water movement through the soil profile (Ayers & Westcot, 1985).

Understanding the interplay between soil texture and salinity is essential for effective soil management. Various practices, such as precise irrigation techniques, enhanced drainage systems, and careful application of soil amendments, can help mitigate the detrimental effects of salinity on soil texture and vice versa. Tailoring these practices to the specific characteristics of each soil type and environmental context is crucial to developing sustainable strategies that support soil health and agricultural productivity in salt-affected regions (Oster & Jayawardane, 2008).

Soil particles, including sand, silt, clay, and organic matter, mix to form larger structures known as aggregates, which vary in size and shape depending on the environmental and biological factors involved. These aggregates, formed through natural processes such as wetting and drying, freezing and thawing, fungal activity, and root growth, are essential for defining soil structure, which is critical to plant health and soil productivity (Wong et al., 2009). Soil structure can be categorized into various forms, such as crumb, granular, platy, single grain, blocky, columnar, massive, and prismatic, each of which impacts water flow, root growth, and microbial activity differently. For example, granular structures, which feature larger gaps between aggregates, are particularly conducive to water and air movement and thus beneficial for root development (Rengasamy, 2010).

The structure of the soil plays a critical role in several ecological and agricultural functions. Soil structure directly influences nutrient availability, water retention, root growth, and microbial diversity within the soil matrix. Soils with good structure facilitate healthy root growth, air circulation, and efficient water retention, all of which are critical for plant development. Soil aggregates improve the soil's capacity to retain water and nutrients, making them accessible to plants over time (Pankhurst et al., 2001). However, heavy machinery can disrupt this structure by compacting soil and creating plough pans, which are dense, impermeable layers that restrict root growth and water infiltration.

Similarly, high salt concentrations compromise soil structure by increasing clay dispersion and aggregate breakdown, leading to soil compaction and decreased porosity (Shainberg & Levy, 1992).

In salt-affected soils, the dispersive effects of sodium result in structural degradation by altering the soil's natural aggregation processes. Sodium ions in high concentrations displace calcium and magnesium on clay surfaces, inducing repulsion between clay particles and causing them to lose cohesion. This phenomenon disrupts the soil's structural integrity and inhibits natural aggregation, undermining essential functions like water infiltration, nutrient retention, and microbial activity (Rahman & Singh, 2020). Addressing these issues through targeted soil management practices is therefore essential to maintaining productive, healthy soils in saline environments.

2.6.2 Soil Hydrology

The Natural Resource Conservation Service (USDA) divides soils into four Hydrologic Soil Groups depending on the potential of runoff in the soil. A, B, C, and D are the four groups of hydrologic soils. Where A's typically have the least potential for runoff, and D's have the most.

Sand, loamy sand, or sandy loam kinds of soils are in Group A. Even when very wet, they have a minimal propensity for runoff and a high rate of infiltration. They primarily consist of profound, well to excessively drained gravels or sands and transmit water quickly. These soils, which include sand and sandy loam, have high infiltration rates. Water moves through them quickly, carrying salts away from the surface and root zones. This leaching process reduces the risk of salinity buildup, making Group A soils less prone to salinity issues.

Group B consists of loam or silt loam. It mostly comprises of deep to deep and relatively well to well drained soils with moderately fine to moderately coarse textures, and it has a moderate penetration rate when completely moist. Loam and silt loam soils allow

moderate water infiltration, which can facilitate some salt leaching but may not be as efficient as Group A soils. In areas with high salt inputs, these soils may experience moderate salinity buildup, though with appropriate drainage and irrigation, they can often manage salinity better than groups with lower infiltration.

Sandy clay loam is in Group C. They mostly consist of soils with a layer that prevents water from moving downhill and soils with a fine-to-fine structure, and they have poor infiltration rates when moist. Sandy clay loam soils have poor infiltration due to finer textures and impermeable layers. Slow water movement limits salt leaching, and salts tend to stay in the root zone, especially in arid climates or when using saline irrigation water. Group C soils are therefore more prone to salinity problems over time.

Sandy clay, silty clay loam, clay loam, silty clay or clay are all members of group D. These types of soils have the greatest potential for runoff. They mostly consist of clay soils with a high swelling potential, soils with a clay pan or a clay layer near or at the surface, a persistently high-water table, and shallow soils atop impermeable material, all of which have extremely poor infiltration rates when saturated. Clay and clay loam soils are highly susceptible to salinity because of very low infiltration rates and a high tendency for runoff. With limited drainage, salts accumulate in the upper soil layers, particularly in dry regions or with poor-quality irrigation. Group D soils are thus at high risk of salinity, often requiring intensive management to control salt buildup.

When looking at the three types of classification, DM Lang classification (Kubiena), Malsis classification (FAO / European), USDA classification system one can notice that they are remarkably similar in principle even though they use different methods to determine the type of soil texture. Soil is characterised by parent material, topography, climate, vegetation (biota), and time. These tend to reflect the qualities of soil such as its texture, colour, and structure, the thickness of horizons and its drainage characteristics. All the make up the soil fertility potential that we can generalise as salts (minerals) in soil.

2.7 Soil remediation

Salinity remediation methods aim to reduce harmful salts in the soil, and each ion requires specific treatment. Thus, an appropriate approach should be planned based on soil needs (Cha-um & Kirdmanee, 2011). The most common method for managing saline soils is leaching, which involves flushing soil with non-saline water, allowing salts to drain out of the root zone to protect plants (Franzen, 2007; Ayars, Hoffman & Corwin, 2011). Effective fertilizer application also helps by balancing salt inputs, considering contributions from other sources like manure (Salim, 2015).

Remediating sodic soils, however, is different. Since sodium (Na^+) binds to clay in a hydrated form, flushing with water is ineffective and can damage soil structure (Davies & Lacey, 2009; Horneck et al., 2007). Gypsum, containing calcium (Ca^{2+}), can replace sodium on exchange surfaces, enhancing drainage and reducing sodicity (Oster, 1993; Provin & Pitt, 2001). Calcium chloride ($CaCl_2$) may be more effective in cases of high soil sulphate levels, often requiring less water for activation (Franzen, 2007). In some cases, extensive sodic soil remediation can be costly, even requiring soil removal (Horneck et al., 2007).

Before planting, excess salts in a field should be flushed by applying fresh water, and gypsum or sulphur should be added for sodic soils to prevent salt buildup. Evaluating soil properties like water retention and porosity helps enhance leaching efficiency. Additional irrigation may be needed to maintain low salt levels in the root zone, especially with saline water sources (Blaylock, 1994).

Adjusting irrigation techniques can help manage salinity by providing a consistent water supply to the roots, using low-salinity water through methods like trickle irrigation (Bernstein, 1975; Mass & Grattan, 1999). Choosing salt-tolerant crops may also be beneficial, though it can be challenging to find suitable varieties (Qadir, Ghafoor & Murtaza, 2000).

$$\mathrm{LR}_{(\mathrm{CI})} = \frac{C_{1w}}{5\,C_{1e} - C_{1w}}$$

$LR_{(Cl)}$	**=** The minimum leaching requirement needed to control chloride with ordinary surface methods of irrigation.
C_{lw}	= Chloride concentration in the applied irrigation water in milliequivalents per litre (me/l).
C_{le}	= Chloride concentration tolerated by crop as determined in the soil saturation extract, in milliequivalents per litre (me/l).

FIGURE 3: RHOADES' LEACHING REQUIREMENT MODEL 1972.

Toxic ions such as chloride, sodium, and boron accumulate similarly to salts in the root zone. Leaching is effective for chloride management, with a leaching requirement (LR) based on crop tolerance (C_{le}) and water chloride levels (C_{lw}) as shown in figure 3. However, higher leaching fractions may be required for sodium management, potentially affecting soil aeration and drainage (C_{le} & SAR control). For boron, which moves slowly through soil, up to three times more leaching water may be required (Blaylock, 1994).

To manage toxicity, regular monitoring through plant symptoms and soil, plant, and water analysis is essential. Adjustments like increased irrigation frequency can dilute salt concentrations and alleviate toxicity. Fertilization, especially nitrogen, can help manage boron toxicity by promoting leaf growth and photosynthesis (Blaylock, 1994). In cases of sodium toxicity, gypsum or other amendments can be added to correct issues in soils with high salinity or clay content.

Leaching toxic ions like sodium, chloride, and boron generally requires increased water depth. For severe toxicity, crop changes or alternative water sources may be necessary to reduce toxic levels effectively.

2.8 Measurements of Salinity

In most cases, "measures" of salt content are really estimates based on the electrical conductivity of the soil and water solution. Calculating the total dissolved solids in a sample allows one to estimate the salt content of soil in a lab setting. This also depends on the soil's texture, which is directly connected to its ability for cation exchange (CEC).

2.8.1 Electrical Conductivity

Cation exchange capacity (CEC), drainage conditions, soil texture, quantity of organic matter, salinity, and subsoil characteristics are a few examples of soil properties that have an influence on crop yield and are measured by electrical conductivity (EC). Electrical conductivity (EC), which indicates the capacity of an aqueous solution to manage electric current, is the most often used indicator of soil salinity. Because of high soil salts in certain locations and excessive exchangeable Na^+ in other soils, plants suffer negative chemical and physical effects in those areas. The elevated CEC of clay soils enables them to retain an abundance of cations, including essential nutrients and salts. However, the susceptibility to excessive sodium influx can lead to the displacement of other cations on exchange sites, culminating in soil salinity. Sandy soils, characterized by a lower CEC, confront limitations in cation retention, potentially resulting in leaching of nutrients and salts. Simultaneously, this characteristic renders the soil more susceptible to salinity if salts are not effectively leached away.

Depending on how much moisture is present in the soil particles, the electrical conductivity of the soil varies. Sands, silts, and clays all have various levels of conductivity. Sands have a low level, silts are medium, and clays are high. The density of soil particles and the texture have an impact on electrical conductivity. The ability of a material to conduct an electrical current is known as electrical conductivity (EC), of which measure is often expressed in millisiemens units per meter (mS/m). It is also possible to express soil electrical conductivity in decisiemens per meter (dS/m), which

equals the mS/m measurement divided by one hundred. Salinity is the result of salts, such as NaCl and KNO_3 that are dissolved in water or in this case the soil solution.

2.8.2 Total Dissolved Solids (TDS)

TDS measures the quantity of anions and cations in water. Any ion present can be added to the total quantity of ions that make up TDS, which often consists of K^+, Na^+, Mg^{2+}, Ca^{2+}, NO_3^-, PO_4^{3-}, SO_4^{2-}, F, Cl^-, HCO_3^-, and CO_3^{2-}.

TDS also includes components of soil organic matter like fulvic and humic acids. TDS may be measured in many methods. The easiest method for measuring TDS is to filter the water sample and then evaporate it in a dish that has already been pre-weighed at 180 ° C until the dish's weight stays constant. The weight of the dish serves as a representation of the TDS, which is measured in mg/l.

Additionally, a linear correlation equation based on a particular conductivity from the sample's electrical conductivity may be used to compute the TDS of a sample of water with reasonable accuracy. The individual ions may be measured, and then the total dissolved solids (TDS) can be determined. Total dissolved solids are a generalized, quantitative assessment of the quantity of dissolved inorganic compounds that does not provide much information on the composition of those substances.

2.8.3 Different techniques in measuring soil electrical conductivity

The electrical conductivity (EC) of a soil-water extract or a soil solution is often used to determine the concentration of soluble salts in soils. The capacity of a substance or solution to carry electrical current is known as electrical conductivity. Electrical conductivity rises because of the increase in soluble salts in the soil, which improves the soil solution's ability to conduct electricity. The soil solution becomes a better electrical conductor as the total quantity of soluble salts increases, and EC rises. Mmhos cm^{-1} is the most often used unit for EC measurements in surface-water extractor soil solutions,

however siemens per meter is the recognized international unit for EC (S m-1). 0.1 S m-1 is equal to one A mmho cm-1. To quantify the soluble salts found in soil, the following methods can be used:

(1) Measuring EC using a conductivity meter in the saturated paste extract of soil and water.

(2) Using a conductivity meter to measure EC in a soil-water extract using a set soil: solution ratio (e.g.,1:2 or 1:5).

The saturated paste method provides a more precise estimate of the total soluble salts in the soil solution because it more nearly approximates the soil's water content under field circumstances (Karen L. Gartley, 2011). However, due to differences in how analysts prepare the saturated paste, saturated paste computations take longer and are more prone to mistake. Most soil testing labs where a lot of samples need to be analysed prefer to measure EC at a predetermined and more diluted soil: water ratio. This is due to the procedure's demonstrated quickness, brevity, and reproducibility across a range of soils. Since EC results may vary depending on the method used, care must be given to measure EC outcomes using the proper interpretative scale (Rhoades, 1982).

2.8.4 Measuring Soil Salinity

Until the 1950s, the saturated soil paste technique was used to measure the salt content of soil. Later, it was discovered that plants react to the salt concentration of the soil solution rather than the overall salt content of the soil due to scientific advancements made in the knowledge of saline soils. Therefore, it is recommended to use the saturation extract's conductivity as a general way to calculate soil salinity in connection to plant development (USDA, 1954; Rhoades et al.,1989). Using saturation extracts to measure and reference salinity provides a direct link with the field moisture range for most soils. On the other hand, making soil:water suspension in different ratios, such as 1:1, 1:2, 1:5, and 1:10, is a simpler method than getting saturation extracts.

It is not advisable to use extraction techniques with various soil to water ratios to mimic natural circumstances. Due to the nature of the procedure and the consistency in the quantity of water utilized, several challenges in sample preparation and reproducibility can be addressed when utilizing extraction methods of soil to water ratios (USDA, 1954). Electrical conductivities and ion concentrations are often lower in extracts of soil to water ratios than in saturated paste extracts because of the greater dilution impact. Several commercial laboratories use extraction methods of various soil to water ratios to analyse soil salinity samples even though the findings from these procedures vary. This is because it is easier to do and needs less time and money commitment (Franzen, 2003; Zhang et al., 2005). Using multiple models that depend on a variety of variables, such as soil texture, soil organic matter content, and soil salinity levels, the findings produced from the extracts of varied soil to water ratios may then be translated back and forth to saturated paste extracts (Aboukila and Abdelaty, 2007; Rhoades et al., 1989; Kargas et al., 2018). The discussion of this dissertation will make use of these models. According to Franzen (2003), results of soil water ratios are not exact and dependable when they are adjusted to saturated paste extractions, despite publications claiming that the link between these two procedures correlates.

When evaluating various soil salinity extraction methods, several factors need to be considered, including accuracy, efficiency, and applicability in different field conditions. Among the most common techniques are the saturated paste (SP) method, soil-to-water extraction ratios (such as 1:1, 1:5), and other modified approaches like brine extraction or varying lixiviation durations. The SP method is widely regarded as the most reliable for determining soil salinity as it mimics natural field conditions more accurately. It involves mixing soil with water to saturation and then extracting the electrical conductivity (EC) of the resulting solution. Since it directly measures soluble salts in the soil solution, which are biologically relevant for plant growth, it is considered the standard for salinity assessment (Rhoades et al., 1989; Mbah et al., 2011). However, due to its labour-intensive and time-consuming nature, the SP method is less practical for routine, large-scale analysis.

In contrast, soil-to-water extraction methods, such as those using ratios like 1:1 or 1:5, provide a simpler and more cost-effective alternative, especially for commercial laboratories. In these methods, soil is mixed with water in specific ratios, and the EC of the resulting solution is measured. Studies have shown that soil-to-water ratios of 1:1 and 1:5 can produce salinity readings that closely correlate with those obtained using the SP method, though they typically yield lower EC values because of the dilution effect from the added water (Chatzigiakoumis et al., 2018). These methods are quicker and less expensive, making them more accessible for routine analysis, although their accuracy can vary depending on soil properties.

The effectiveness of soil-to-water extraction methods is influenced by soil texture. Coarse-textured soils, for example, often exhibit weaker correlations with the SP method, due to their lower water retention and slower salt dissolution rates when compared to fine-textured soils (Chatzigiakoumis et al., 2018). On the other hand, the SP method is less affected by texture as it measures the total available salts in the soil solution, providing a more reliable estimate of soil salinity across different soil types. When it comes to ion concentrations such as Na+, Cl-, K+, and Ca2+, studies have shown that soil-to-water extraction methods, especially those with ratios like 1:1 and 1:5, produce comparable results to the SP method (Franzen, 2003; Mbah et al., 2011). However, the efficiency of these extractions can vary depending on factors such as lixiviation time and the soil's salinity levels. Higher extraction ratios (e.g., 1:3 or 1:5) tend to be more efficient in extracting salts, but they still show lower ion concentrations due to greater dilution (Mbah et al., 2011). Moreover, extraction efficiency improves with longer lixiviation times, as the salts have more time to dissolve into the solution (Zhang et al., 2005).

While soil-to-water extraction methods provide a practical alternative, they may not always accurately reflect the salt availability in the soil solution, particularly in highly saline soils or soils with specific chemical properties (Zhang et al., 2005; Chatzigiakoumis et al., 2018). Even though studies indicate a strong linear relationship between the EC measured by the SP method and the EC from soil-to-water extracts, this relationship is not always perfect, especially with coarse-textured soils or under high

salinity conditions (Franzen, 2003). Despite this, the simplicity, speed, and lower cost of soil-to-water extraction methods make them valuable tools for routine salinity analysis.

In conclusion, while the saturated paste method remains the gold standard for measuring soil salinity, soil-to-water extraction methods offer a more practical, cost-effective alternative for large-scale or routine analysis. However, careful consideration of soil properties, such as texture and salinity level, along with the specific objectives of the study, is necessary to ensure reliable results. However, when it comes to soils of Malta, there is not enough data and information about soil salinity, sodicity, and the relationship between these two soil characteristics and other soil factors such as soil texture. There has been limited research done on the conversion variables that allow the data collected via soil: water suspension to be converted to equivalents in soil paste. The study's objectives are to gather information on these conversion variables and to increase local understanding of the soil's recent salinity and sodicity on soils of the Maltese islands.

Methodology

3.0 Methodology

3.1 Introduction

The main objective of this dissertation was to collect soil data to get an assessment on the state of local soils and have a better understanding whilst observing variability patterns in salinity and sodicity in soils from Malta, compare the various extraction methodologies for the measurement of EC and determine a conversion factor, establish whether the conversion factor was dependent on soil textural class and organic matter content, measure and compare the various water extraction methodologies for the measurement of individual metals and determine their behaviour.

Soils from 140 different locations around the island of Malta and Gozo were sampled and the EC was measured using the saturated paste method and the soil : water suspension method in soil to water ratios of 1:1; 1:2 and 1:5. The soil's sand, silt and clay content were determined according to the hydrometer method based on the ISRIC publication "procedures for soil analysis" 5th addition 1995 and the ISO standard 11277:1998, carbonate content was measured with Allison, L.E. and Moodie, C.D. (1965) Carbonate. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9, 1379-1396 and the organic matter according to the Walkley and Black, (1934) method. Additionally, pH in water and metal content in the water extracts where measured.

3.2 Chemicals

Unless otherwise stated, only reagents of recognized analytical grade were used, while deionized water had a specific conductivity of lower than 2µS/cm at 25°C (grade 2 water).

3.3 Equipment

The following equipment was used in this project:

Conductivity meter: Measurements of electrical conductivity were carried out with a Thermo Scientific Orion Star Conductivity meter, fitted with a calibrated respective conductivity probe with automated temperature correction and having an accuracy of 1µS/cm at 20°c.

pH meter: Measurements of pH were carried out with a Thermo Scientific Orion Star A111 pH meter fitted with a calibrated respective probe with automated temperature correction and having an accuracy of ±0.01 pH units.

Metal analysis: soil extracts were filtered with a 0.22µm syringe filter and diluted accordingly, measurement was taken using Agilent 4100 Microwave Plasma-Atomic Emission Spectrometer Model 4100 which has a high sensitivity with detection limits down to sub ppb levels.

Texture analysis: the sand, silt and clay content were determined according to the hydrometer method using Eijkelkamp Soil & Water Hydrometer Set equipped with automated water temperature control and measuring within a range of 0.995 - 1.035 g/ml at a reading accuracy 1 g/l.

3.4 Sampling Strategy

All soil sample points were taken from the Maltese islands of Malta and Gozo. Specific points were spread across all the islands, to have a variety of soil types, and obtain a representative study of the actual soils found on the islands. In this research soils were collected in a strategic manner to include agricultural, non-agricultural, inland, shoreline soils from different topographic areas. The 140 samples were taken from the points indicated in figure 1. The samples were collected between February and July 2021 and were all collected after obtaining permission from the farmers concerned, the location of

every sample was recorded by GPS coordinates to make it possible for a replication of the study in years to come.

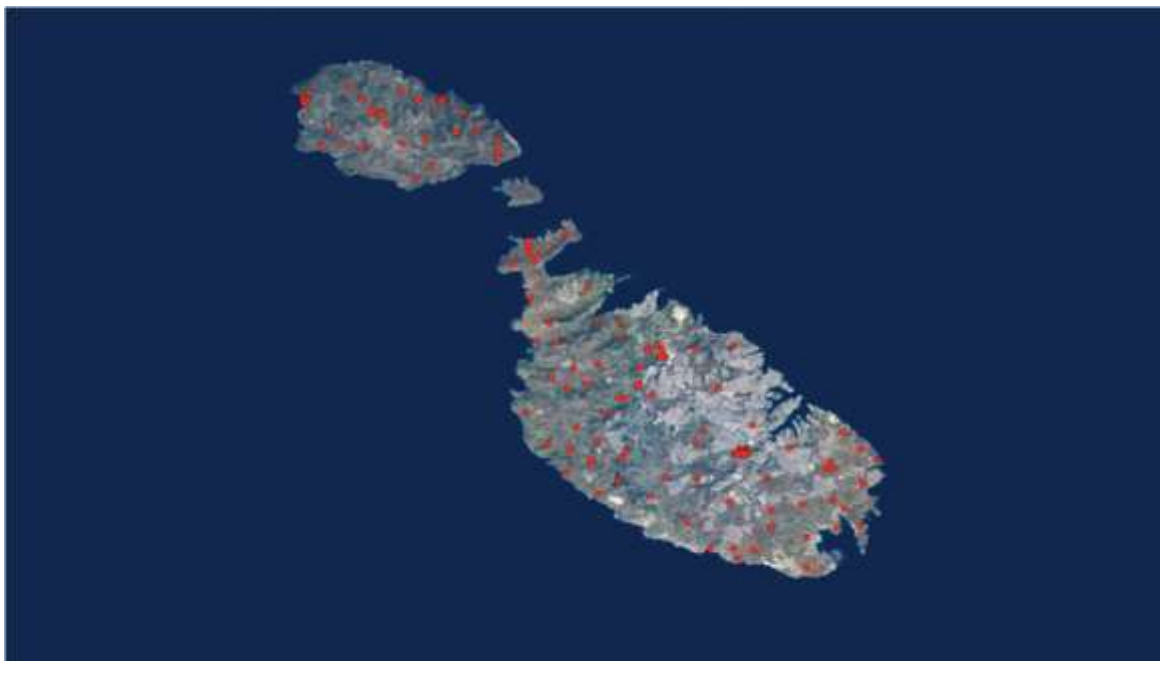


FIGURE 4: MAP PLOTTING SOIL LOCATIONS, GOOGLE MAPS.

3.5 Soil Sampling

Every parcel of land was systematically divided into segments. This was done to collect a representative sample of the area to be studied represented in figure 5. The following strategy was used to collect the samples.

- The land was theoretically divided into sections and six to ten samples were gathered from the points of intersection.
- With the use of a trowel, soil was gathered from the top soil and sub soil by digging to a depth of approximately 15cm to 20cm, without including any living vegetation and litter.

- The composite sample was then placed in a large, labelled plastic bag, mixed thoroughly and transported to the lab at ambient temperature.
- A total quantity of 10 kg of soil was taken from each field.
- The soil was set to air dry so that it could be worked properly.
- A representative sub- sample from each bag was taken for further laboratory analysis.

FIGURE 5: W CONFIGURATION OF SOIL SAMPLING, GOOGLE MAPS.

3.6 Sample Preparation

Before the soil was tested it was assigned a code and transferred to a tray to air dry at 30°C for 24 hours in line with the laboratory's standard operating procedure pre-treatment of soil for Physio-Chemical parameters in line with ISO11464:1994. The soil aggregates were broken down with a mortar and pestle, but excessive grinding was avoided. The soil was passed through two sieves. The first sieve had a 1 cm gauge, which blocked stones and vegetation present in the soil. This was important since these should not be part of the soil being tested. Then the remaining soil was passed through a 2mm sieve. The sieving process is important since having a soil which is very fine ensures that the soil

will mix better during the testing process (Gartley, 1995). This allows for a more representative result, since fine soil will be more readily mixed than if left as larger aggregates. The subsamples were then stored in sealed plastic containers at room temperature.

3.7 Field Water Content

Field water content was analysed to assess the moisture status of the soil whilst sampling.

5g from each sample were accurately weighed and heated at 105°C until the weight stabilized. The following days the samples were weighed again, and the moisture content was calculated from the difference in mass. The results were expressed as % water content according to the following equation:

$$\text{Water content (\%)} = \frac{\text{Mass of wet soil} - \text{Mass of dry soil}}{\text{Mass of dry soil}} \times 100$$

A full description of the method is given in Appendix 1.

3.8 Determination of Electrical Conductivity (1:1, 1:2, 1:5 & soil saturated extract)

Electrical conductivity was measured using 4 methods: 1:1, 1:2 and 1:5 soil water suspension m/m and soil saturated paste based on ISO 11265:1994. For each soil sample, the EC was determined using 3 replicates. Air-dry soil is extracted with water depending on the extraction ratios of mass/volume, by which the electrolytes are dissolved. In the filter extract the electrical conductivity is measured and the calculation converted to specific electrical conductivity at 25°C as µS/cm units.

- For the 1:1 method 20 g of 2mm sieved soil were placed in a 50 ml Falcon tube to which 20 ml distilled water was added.
- For the 1:2 method 13 g of 2mm sieved soil were placed in a 50ml Falcon tube to which 26 ml distilled water was added.
- For the 1:5 method 7 g of 2mm sieved soil were placed in a 50ml Falcon tube to which 35 ml distilled water was added.

The tubes were shaken on an orbital shaker at 180 rpm for 60 min. Following mixing, the tubes were centrifuged at 2000 rpm for 2 min to settle the soil solids. The EC of the supernatant was measured using a calibrated conductivity meter. The three readings were used to produce a mean EC for each site sampled.

For the soil saturated paste 300 g of 2mm, sieved, air dried soil was placed in glass containers and distilled water was gradually added to the soil until the soil was nearly saturated. The paste was left to set overnight for the water to be absorbed by the soil and dissolve the soluble salts. The day after, a little bit of water was added to the paste so that uniformity of the saturated soil water paste was achieved. At this point, the soil paste was glistening as it reflected light, flowed lightly when the container was shaken, slid freely and clean off the spatula and consolidated easily when the container was tapped after a trench was formed. The mixture was left to stand for another 2 hours. At this point it was made sure that no free water was on the soil surface. It was also made sure that the mixture did not solidify. In both cases soil or water were added so that the paste was ready for extraction. The saturated soil paste was transferred to a filter funnel with a high retentive filter paper. Vacuum was applied so the filtrate of the paste was collected in a test tube.

The filtration process was finished once air began to pass through the filter. The filtrate from every soil paste was passed through a calibrated conductivity meter. Three replicates for every sample were produced to achieve replicability. A mean of the results of the three replicates was calculated.

A full description of the method is given in Appendix 1.

3.9 Soil Texture Analysis

For textural analyses, the sand fraction was determined using a 62µm sieve and to obtain an accurate determination of the particle size distribution of the smallest fractions such as colloidal clay particles, the hydrometer method was used. Of paramount importance in this analysis was the pre-treatment of the sample, aimed at complete dispersion of the primary particles. Therefore, the possibility of removing cementing materials such as organic matter and calcium carbonate arose. However, another argument that for agricultural purposes it is often not relevant or even fundamentally wrong to remove these components also arose. Thus, in this study, with regards to the removal of organic matter it was decided to remove it, however the removal of calcium carbonate was not performed. Calcium carbonate was not removed because previous studies showed that the sand and silt fraction of local soils are calcareous, and carbonate based hence removing carbonates would lead to a false result making all soils heavy clays. (Spiteri, 2020)

In this method the sample was initially cleaned from organic matter using H2O2. Then after being dispersed with a dispersing agent, the soil suspension was passed through a 62µm sieve to collect the sand fraction. The solution that passed through the sieve was transferred to a measuring cylinder, which was topped to 1L with water and after shaking, hydrometer readings were taken after regular intervals. Sedimentation time and hydrometer readings were used to determine the grain size content according to Stoke's Law. The mineral part of the soil was separated into various size fractions and the proportion of these fractions was determined. This analysis comprises all material, that is < 2mm in size.

The full procedure of the method is shown in Appendix 1.

3.10 Soil Organic Matter

Soil organic matter was determined by wet oxidation using the Walkley and Black Dichromate Oxidation Method, (1934) based on BS 1377:1990. For each soil 5 replicates were used. A full description of the method is given in Appendix 1.

The Walkley and Black chromic acid wet oxidation method is used to determine soil organic matter. The soil's oxidizable organic carbon is oxidized by 0.167 M potassium dichromate ($K_2Cr_2O_7$) solution in concentrated sulphuric acid. Temperature rises due to the heat of the reaction which induces oxidation. Chemical reaction is as follows:

$$2Cr_2O_7^{2-} + 3C + 16H^+ \rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O$$

During the reaction with soil, the $Cr_2O_7^{2-}$ decreases and is proportional to the oxidizable organic C found in the sample. By measuring the remaining unreduced dichromate, the organic carbon can then be estimated by back-titrating with ammonium ferrous sulphate or ferrous sulphate with the use of diphenylamine or o-phenanthroline-ferrous complex as an indicator. Alternately, a colorimetric procedure measuring absorbance at 588 nm can be used which calculates the organic carbon from the quantity of chromic ion (Cr^{3+}) formed (after Sims and Haby 1971). Since an accurate standardization of the $Cr_2O_7^{2-}$ solution is not required, this method has an advantage of the titrimetric method. Points to be noted:

When using this method generally 75 – 90 % of total soil organic carbon in surface soils is recovered. This percentage varies according to the soil type and depth. According to Walkley and Black, by the heat of the dilution procedure, on average 77 % of the organic C is recovered, thus they suggested that to account for unrecovered organic C, a correction factor of 1.3 is used.

1. Certain soil constituents may interfere when this method is used, as with certain soils these lead to false results. It has been shown that higher oxides of Mn (manganese), ferrous iron and chloride in chromic acid mixtures undergo oxidation-reduction reactions which lead to incorrect organic C values. A positive error results when there are significant quantities of Fe^{2+} or Cl^- in soil, while a negative error and lower organic C values result when reactive MnO_2 is present in the soil samples. Interferences from the ferric ion that may be present in the soil sample can be eliminated with the addition of H_3PO_4 after the sample has cooled. Furthermore, when the soil is washed free of Cl^- before analysis or

when Cl^- is precipitated as AgCl with the addition of Ag_2SO_4 to the digestion acid, chloride interference can be eliminated.

2. Soil which has a high percentage of organic carbon due to the incomplete oxidation of organic carbon present in the sample, the Walkley and Black method may result in low test results. When samples have high quantity of carbon content, smaller weight of samples should be used.

3. This method is used to determine organic carbon in soils and does not apply to soils which contain a significant quantity of carbonized materials.

3.11 Soil pH

Soil pH was determined from the water that was extracted in the soil paste method and from the water suspensions of 1:1, 1:2 and 1:5 respectively as described in section 3.8. A full description of the method is given in Appendix 1.

3.12 Carbonate Content Analysis

Allison, L.E. and Moodie, C.D. (1965) Carbonate. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9, 1379-1396.

A full description of the method is given in Appendix 1.

3.13 Metal Analysis

The metal analysis was performed on the extract of the soil saturated paste and from the water suspensions of 1:1, 1:2 and 1:5 respectively as described in section 3.8. One of the main objectives of this research was to determine a conversion factor for specific metals and their behaviour in different textured soils compared to different extraction methods. Each extract was centrifuged at 2000 rpm for 3 min to settle the soil solids and passed through a 0.22µm syringe filter to remove any suspended particles. Adequate dilution was performed using calibrated pipettes to achieve the desired concentrations as stated in the Agilent 4100 Microwave Plasma-Atomic Emission Spectrometer Model 4100 manual.

Specific individual metal readings were recorded from every sample in a triplicate manner. The metals analysed were Ca, Mg, Na, Mn, K, Fe, Cu, Cr, Cd, Zn, Ni, Sr and Ba. These readings were also used to work the Sodium adsorption ratio (SAR) of every soil. SAR is calculated using the following formula (Rowell, 1994):

$$\text{SAR} = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

The importance of SAR lies in its ability to indicate the potential negative effects of using water with high sodium content for irrigation. When water with a high SAR is used to irrigate soil, it can lead to a series of problems collectively known as "sodicity." These problems include soil structure degradation, reduced water availability and decreased nutrient uptake. A full description of the method is given in Appendix 1.

3.14 Statistical Analysis and Modelling

Statistical analyses of the results obtained from the study were performed using Sigma Plot Statistical Software Version 14.0. Statistical analysis included descriptive statistics, correlations, regression analysis and test for significance.

Spearman rank correlation analysis was conducted to examine the associations among EC_e, $EC_{(1:1;\ 1:2;\ 1:5),}$ sand, silt, clay, organic matter (OM), and carbonate content in the soils. The relationship between EC_e and $EC_{(1:1,\ 1:2,\ 1:5)}$ was further evaluated by linear regression using a random subset of 114 soil samples drawn from the total of 136 samples. As the data did not meet the assumptions of normality, $\log^{10}$ transformation was applied prior to regression analysis to satisfy the requirements for linear modelling. This transformation was also applied to the dataset corresponding to selected extracted metals.

Additionally, to assess whether variations in textural classes, carbonate content, and OM content influence the relationship between EC_e and $EC_{(1:1,\ 1:2,\ 1:5)}$, the regression analysis was repeated after grouping the data accordingly. Specifically, soil samples were

categorized into fine, medium, and coarse textures; carbonate content groups of (0-35 %), (35-50 %), and (50-80 %); and OM content groups of (0-2.5 %) and (2.5-4.2 %).

Validation of the regression model equations was performed using the remaining 22 soil samples not included in model development. Model performance was assessed using the root mean square error (RMSE) and Nash-Sutcliffe prediction efficiency (NSE), calculated as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{m=1}^{N}(mECe - pECe)^2}$$

$$\mathrm{NSE} = 1 - \frac{\sum_{m=1}^{N}(mECe - pECe)^2}{\sum_{m=1}^{N}(mECe - \overline{mECe})^2}$$

Where N is the number of samples, pEC_e is the predicted electrical conductivity of the saturated paste extract (EC_e) from the regression models, mEC_e is the measured EC_e, and $\{mEC_e\}$ represents the arithmetic mean of the measured EC_e across all N observations.

The developed model equations were also compared with corresponding models reported in the literature for other soils. All statistical analyses were conducted using Sigma Plot statistical software (Systat Software, Inc., San Jose, CA).

3.15 Ethical Issues

Ethics are the fundamental base of every research project, ethical approval is premised on notations of protection/confidentiality and anonymity of the subjects, hence the location of specific land parcels and farmer data will not be disclosed in this study and only indicative locations will be portrayed. Having said this permission from participants/farmers was granted prior to sample collection and the possibility to refuse participation was given. The commencement of this research was also submitted for the approval of the University of Malta Research Ethics Committee, which the Board appointed approved.

Results and Discussion

4.0 Results & Discussion

The primary aim of this study was to investigate the potential correlation between the electrical conductivity of soil, measured by soil-to-water extracts, and the electrical conductivity obtained from a soil paste. Additionally, the study aimed to gain deeper insights into the behaviour of individual metals within the soil and to establish a conversion factor between the different measurement methods specifically for soils in Malta. The significance of salinity in crop production was emphasized by Kruse et al. (1990). In this context, electrical conductivity (EC) serves as a fundamental parameter to quantify soil salinity, as recognized by the USDA in 1954. Various techniques are employed to measure EC, including those based on soil water extracts and saturated paste extracts. Among these, the saturated paste method, as outlined by Rhoades et al. (1989), is considered the recommended standard laboratory approach. However, the use of soil water extracts is more common and preferred due to its practicality over the saturated paste method. Nonetheless, it is essential to convert EC values from soil water extracts to EC values from saturated paste extracts, as the latter provides a more accurate representation of soil salinity.

This dissertation aims to develop and validate predictive models capable of estimating the electrical conductivity (EC) of soil paste from EC values derived through 1:1, 1:2, and 1:5 soil-to-water extracts. Priority was given to the formulation and statistical evaluation of these models, with a focus on their applicability across distinct soil textural classes found within the Maltese Islands. To strengthen the correlation and reliability of results, several key parameters were measured and incorporated into the analysis, including soil pH, organic matter content, and soil texture. These variables are known to influence soil salinity behaviour and were essential in refining model accuracy. In addition to salinity modelling, the study also explored the behaviour of metals in the tested soils. A complementary set of predictive models was developed to estimate the mobility or concentration trends of selected metals, based on similar extract-based approaches. By integrating metals analysis with EC and soil property data, the research provides a more comprehensive framework for understanding both salinity and metal dynamics in local

soils. The combination of these datasets and models contributes to a robust, multidimensional understanding of soil chemical behaviour, offering practical tools for agricultural and environmental monitoring in Malta.

4.1 Texture and Carbonate Analysis

Soil texture refers to the composition of various-sized particles present in the soil, including clay, silt, and sand. This characteristic holds significant importance as it influences several key aspects of the soil's behaviour. It affects the soil's workability, its capacity to retain air and water, the speed at which water can penetrate and move through it, its drainage capabilities, and the development of roots within the soil. Additionally, since texture impacts the movement of water in the soil, it may also influence the rate at which nutrients and pesticides travel through it.

To determine the soil texture classification, the proportions of clay, silt, and sand in a soil sample must be known. This classification can be achieved using a soil texture triangle, as depicted in Figure 6. Both the WRB soil classification and the USDA soil taxonomy systems employ 12 textural classes to categorize soil based on their respective percentages of clay, silt, and sand.

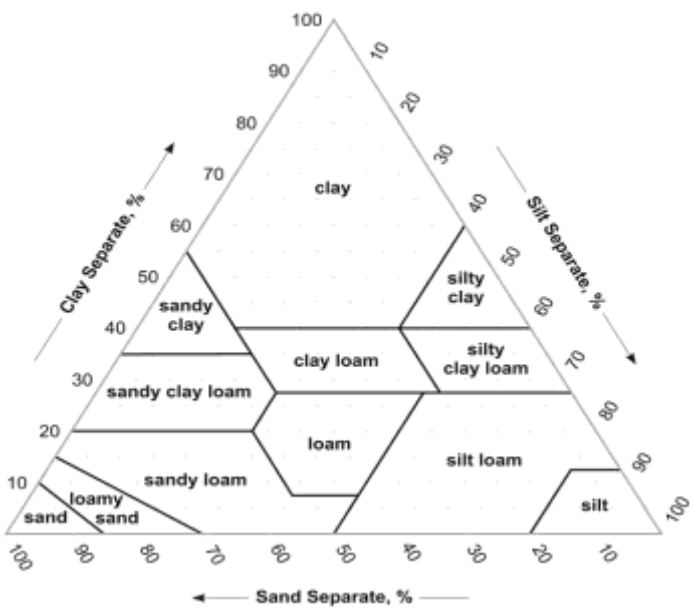


FIGURE 6: SOIL TEXTURE TRIANGLE

The results obtained from this study clearly indicated that the carbonate content in Malta's soil varies, with the mean average of the 134 soil samples collected not exceeding 38 % with a range of almost 80 %. Consequently, removing clay-cementing carbonate using acid would also dissolve and destroy the sand and silt fractions, disproportionately increasing the clay fraction. For calcareous soils, it is advisable not to remove carbonates during textural analysis. As a result, the soils utilized in this study exhibit a specific textural class, as indicated under the "Soil Texture" column in table 3 and demonstrated in the textural triangle shown in figure 7.

Based on the data collected in this investigation, most of the examined soils were identified as clay loam. Among the 134 samples analysed, 44 of them were classified as clay loam, 21 samples were classified as Loam, whilst 38 samples equally split between the clay and silt loam textural classes. The distribution of all soil samples is presented in Table 4.

Throughout this study, the most significant challenge encountered while using the hydrometer method was whether to remove carbonates from the soil samples or not. The carbonate present in local soils comes from the parent material. Local soils are deemed to have a high $CaCO_3$% as indicated by Lang (1960). As per the soil analysis procedures outlined in the ISRIC publication (1995), cementing materials, including organic matter and $CaCO_3$, which are typically of secondary origin, may require elimination. Nevertheless, for agricultural objectives, it could be contended that removing these components is not significant or inherently incorrect.

Carbonates can influence the soil's texture, leading to aggregation and stability, thereby altering the soil's overall structure. Acting as a potent cementing agent, carbonates are capable of binding clay particles together, forming larger units (Zhang and Norton, 2002). This impact on the physical properties of the soil is evident through the formation of secondary sand and silt-sized granules that mimic primary particles. Such changes in

particle size distribution (PSD) and soil structure also have implications for soil development, affecting aeration and infiltration rates (Kishchuk, 2000). Critical properties of soil carbonates that influence soil pedogenesis, as well as chemical and rhizosphere processes, encompass the distribution of particle size, surface area, and activity. Upon the removal of carbonates from soils, including the destruction of carbonate coating layers or removal of cementing agents in aggregates, there is a reduction in the abundance of sand and silt particles, while the clay content increases.

Asgari Hafshejani (2019) indicates that carbonates are dispersed across various fractions of soil, such as clay (< 2 µm), sand (2000-50 µm), silt (50-2 µm), and soil fractions. Furthermore, Moore et al. (1990) point out that carbonates are particularly active in the fine silt and clay fraction (2-5 µm). In the investigation of the impact of carbonates on soil textural classification, the findings by Francis and Aguilar (1995) demonstrated a substantial increase in clay particles following the removal of $CaCO_3$ from the soil. In these soils, carbonates were predominantly accumulated in the clay size fraction. Conversely, Sabbah et al. (1999) presented results indicating a significant decrease in clay content when carbonates were removed. Due to the divergent perspectives, $CaCO_3$ for the purpose of this study was not removed. The decision was based on a local study, which showed that removing carbonate from soil samples led to a drastic change in the texture classification, resulting in a considerable increase in clay content with results similar to Francis and Aguilar (1995). The soil texture results of this study are shown in Table 3.

In the context of soils from Malta and similar calcareous soil types, it is crucial to highlight that the sand and silt fractions originate from calcareous parent material, resulting in a composition predominantly consisting of carbonate. The proportion of carbonate in these soils is notably high, as reported by Lang and evident from tables 4 and 5. According to Lang's findings (1960), Carbonate Raw Soil (now represented by types of Regosols, Arenosols and Vertisols) and some Xerorendzinas (Calcisols and Luvisols) contain over 70 % of $CaCO_3$.

Even though the soil samples used in this study were collected from 134 different sites across the Maltese islands, Figure 7 illustrates that representative examples from each soil textural class were included. Comparisons were made between this study and previous research conducted by Lang (1960) and MALSIS (2004), revealing similar data patterns across all three studies.

Table 3: the texture of the studied soils and their respective carbonate content

Soil Texture					
Code	**Sand %**	**Silt %**	**Clay %**	**Classification**	**Carbonate %**
M20RBT1	22	62	16	Silt Loam	56%
M20MST1	35	39	26	Loam	65%
M20MST2	22	55	23	Silt Loam	77%
G20SLW1	46	49	5	Sandy Loam	64%
G20SLW2	16	34	50	Clay	41%
G20SLW3	69	29	2	Sandy Loam	62%
G20SLW4	52	31	17	Loam	53%
M20BRM2	22	67	11	Silt Loam	20%
M20QRM2	20	46	34	Silty Clay Loam	29%
M20ZJT1	15	43	42	Silty Clay	6%
M20QRM3	28	30	42	Clay	41%
M20QRM4	41	49	10	Loam	52%
M20QRM5	51	30	19	Loam	51%
M20QRM6	47	43	10	Loam	60%
M20MLL2	60	24	16	Sandy Loam	74%
M20RBT3	25	20	55	Clay	34%
M20RBT4	26	26	48	Clay	31%
M20BRM1	26	54	20	Silt Loam	30%
M20QRM7	25	36	39	Clay Loam	45%
M20QRM9	41	37	22	Loam	59%
M20QRM10	40	56	4	Silt Loam	67%
M20QRM11	36	37	27	Clay Loam	56%

Table 3: the texture of the studied soils and their respective carbonate content

Soil Texture					
Code	**Sand %**	**Silt %**	**Clay %**	**Classification**	**Carbonate %**
M20QRM12	44	32	24	Loam	56%
M20QRM13	22	52	26	Silt Loam	38%
G20RML1	63	17	20	Sandy Clay Loam	53%
G20RML2	100	0	0	Sand	74%
G20RML3	98	0	2	Sand	76%
G20RML4	81	7	12	Sandy Loam	61%
G20RML5	82	10	8	Loamy Sand	66%
G20RML6	53	30	17	Sandy Loam	56%
M20MLL3	24	53	23	Silt Loam	11%
M20MLL4	64	20	16	Sandy Loam	60%
M20MLL5	13	68	19	Silt Loam	5%
M20DGL1	45	33	22	Loam	49%
M20MLL6	18	58	24	Silt Loam	1%
M20QRM15	41	39	20	Loam	54%
M20QRM16	31	36	33	Clay Loam	43%
M20QRM17	32	44	24	Loam	33%
G20RBT3	5	34	61	Clay	19%
M21MST1	32	37	31	Clay Loam	37%
M21MST2	30	30	40	Clay	36%
M21MST4	35	38	27	Clay Loam	41%
M21MST5	51	32	17	Loam	48%
M21SPB1	23	43	34	Clay Loam	29%
M21QRM1	83	10	7	Loamy Sand	39%
M21QRM2	21	35	44	Clay	34%
M21WRD1	46	39	15	Loam	36%
M21MST6	60	22	18	Sandy Loam	44%
M21MST7	50	28	22	Loam	41%
M21RBT1	24	36	40	Clay	41%

Table 3: the texture of the studied soils and their respective carbonate content

Soil Texture					
Code	**Sand %**	**Silt %**	**Clay %**	**Classification**	**Carbonate %**
M21GDJ1	44	34	22	Loam	45%
M21HFR1	39	34	27	Clay Loam	38%
M21BBG1	29	36	35	Clay Loam	40%
M21MRX1	33	39	28	Clay Loam	44%
M21MRX3	36	40	24	Loam	81%
M21GXQ1	36	32	32	Clay Loam	31%
M21MRC1	38	33	29	Clay Loam	36%
M21ZBR1	45	31	24	Loam	34%
M21XJR1	30	41	29	Clay Loam	27%
M21HMR1	45	36	19	Loam	46%
M21ZJT1	30	36	34	Clay Loam	33%
M21ZBR3	15	50	35	Silty Clay Loam	39%
G21QLA2	44	30	26	Loam	38%
G21NDR1	10	64	26	Silt Loam	40%
G21NDR2	15	64	21	Silt Loam	39%
G21XGR1	41	29	30	Clay Loam	33%
G21MRS1	39	32	29	Clay Loam	40%
G21GRB2	18	38	44	Clay	27%
G21GSR1	39	31	30	Clay Loam	41%
G21GRB3	42	28	30	Clay Loam	48%
G21SLW1	15	60	25	Silt Loam	43%
G21MNX1	48	24	28	Sandy Clay Loam	41%
G21XLN1	25	30	45	Clay	29%
M21IMG1	24	36	40	Clay	43%
M21IMG2	20	28	52	Clay	35%
M21MST8	32	34	34	Clay Loam	32%
M21STL1	36	31	33	Clay Loam	39%
M21SFI1	39	25	36	Clay Loam	35%

Table 3: the texture of the studied soils and their respective carbonate content

Soil Texture					
Code	**Sand %**	**Silt %**	**Clay %**	**Classification**	**Carbonate %**
M21ZRQ1	31	36	33	Clay Loam	27%
M21ZRQ3	45	25	30	Clay Loam	35%
M21ZRQ4	8	59	33	Silty Clay Loam	20%
M21MQB1	34	33	33	Clay Loam	37%
M21GRG1	25	40	35	Clay Loam	34%
M21KLN1	14	54	32	Silty Clay Loam	9%
M21QRM4	42	29	29	Clay Loam	31%
M21PLA1	25	45	30	Clay Loam	32%
M21SGW1	63	20	17	Sandy Loam	35%
M21QRN1	56	26	18	Sandy Loam	36%
M21ZBJ1	42	25	33	Clay Loam	35%
M21RBT2	27	33	40	Clay	33%
M21BSK1	53	33	14	Sandy Loam	35%
M21DGL1	6	72	22	Silt Loam	14%
M21MTR1	24	39	37	Clay Loam	31%
M21RBT3	57	25	18	Sandy Loam	37%
M21RBT4	23	31	46	Clay	33%
M21BHR1	33	36	31	Clay Loam	34%
M21BNG1	28	33	39	Clay Loam	34%
M21SPB2	28	25	47	Clay	36%
M21SPB3	23	49	28	Clay Loam	23%
M21SPB4	16	39	45	Clay	14%
M21MLL1	27	42	31	Clay Loam	18%
M21MLL2	29	43	28	Clay Loam	27%
M21MLL3	80	6	14	Sandy Loam	35%
M21MLL4	14	60	26	Silt Loam	34%
G21SNT1	33	35	32	Clay Loam	27%
G21RBT1	22	27	51	Clay	27%

Table 3: the texture of the studied soils and their respective carbonate content

Soil Texture					
Code	**Sand %**	**Silt %**	**Clay %**	**Classification**	**Carbonate %**
G21RBT2	45	19	36	Clay Loam	32%
G21RML2	96	0	4	Sand	30%
G21RML3	98	1	1	Sand	32%
G21RML5	96	0	4	Sand	29%
G21XWK1	28	36	36	Clay Loam	38%
M20RBT2	11	74	15	Silt Loam	14%
M20QRM8	32	52	16	Silt Loam	41%
M21SGW2	28	43	29	Clay Loam	32%
M20QRM1	35	48	17	Loam	63%
M20BRM1	26	67	7	Silt Loam	38%
M20TFF1	29	33	38	Clay Loam	42%
M20MLL1	39	24	37	Clay Loam	29%
M20QRM14	33	65	2	Silt Loam	31%
M21MST3	51	34	15	Loam	49%
M21MRX2	42	29	29	Clay Loam	44%
M21ZBR2	20	46	34	Silty Clay Loam	41%
G21QLA1	41	25	34	Clay Loam	31%
G21QLA3	23	31	46	Clay	28%
G21RML1	68	14	18	Sandy Loam	40%
G21KRC1	13	59	28	Silty Clay Loam	44%
G21GJN1	22	33	45	Clay	12%
M21IMG3	45	27	28	Clay Loam	42%
M21ZRQ2	13	63	24	Silt Loam	42%
M21PMR1	39	23	38	Clay Loam	25%
M21QRM3	36	40	24	Loam	36%
M21SGW3	27	35	38	Clay Loam	34%
M21RBT5	51	27	22	Sandy Clay Loam	35%
G21RML4	93	2	5	Sand	29%

TABLE 4: SOIL TEXTURE FREQUENCY TABLE.

Frequency table of soil types.	
Soil Type	**Frequency**
Clay Loam	44
Loam	21
Clay	19
Silt Loam	19
Sandy Loam	13
Sand	6
Silty Clay Loam	6
Sandy Clay Loam	3
Loamy Sand	2
Silty Clay	1
Total Samples	134

TABLE 5: CARBONATE % STATISTICAL INFORMATION.

Statistical information on carbonate percentage from the 134 samples taken from this study.	
Mean	38 %
Mode	35 % appeared 8 times
Median	36 %
Range	80 %
Minimum	1 %
Maximum	81 %
Standard Deviation	14.5
Count	134

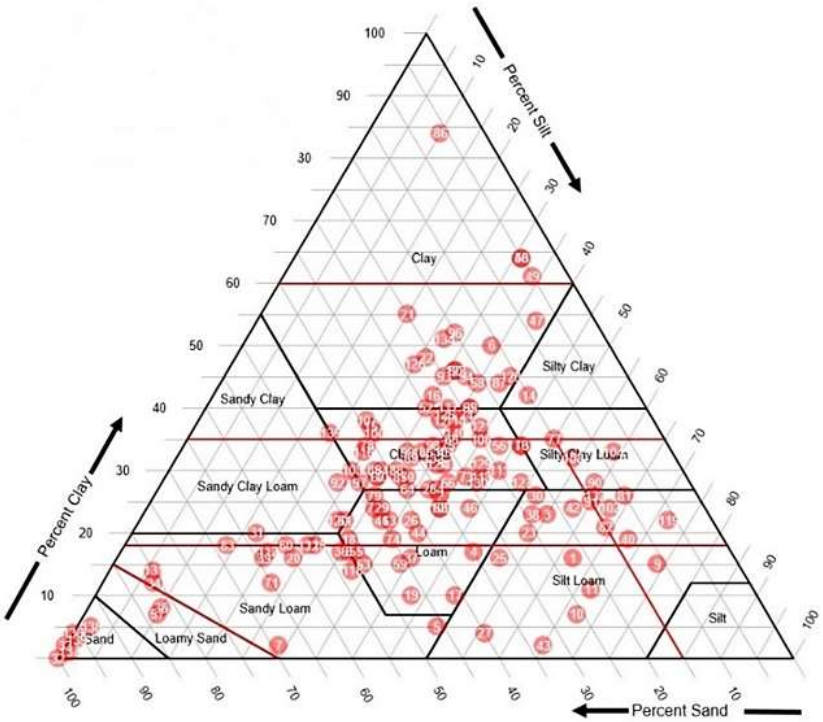


FIGURE 7: SOIL TEXTURE TRIANGLE WITH RESULTS

4.3 Organic Matter

The primary source of carbon (organic matter) and energy in the soil is derived from the decomposition of animal and plant material. This decomposition process releases plant and microbial nutrients into the soil. Soil organic carbon has been defined as the most suitable indicator to monitor soil quality from an agro-environmental perspective.

It was assumed that considering the climatic characteristics of the region and soil management practices, the levels of organic matter in the soil would be low. Upon analysing the data, the results revealed an average organic matter level of 2.28%, with minimum and maximum levels of 0.02% and 7.19%, respectively. Despite these levels being consistent with findings from other local studies, the overall average is still considered to be low.

According to the European Environment Agency (2005) the soil's organic carbon levels indicate the state of the soil, with high levels of carbon corresponding to a more fertile soil. Additionally, the European Commission identified five soil functions for soil protection out of four of which are directly linked to soil organic carbon content (COM, 2006, 231). The abundance and diversity of microorganisms, as well as their activity, are influenced and regulated by the type and quantity of organic matter present in the soil. Lal (2005) and Brown and Huggins (2012) emphasize that organic matter serves as a vital carbon source and acts as the primary nutrient supplier for plants and bacteria, particularly in non-agricultural soil. A threshold of 2% (20g/kg) of soil organic carbon which is equivalent to approximately 34g/kg of organic matter has been recognized as a baseline below which potentially serious decline in soil quality will occur (Rusco, Jones & Bidoglio, 2001). Moreover, organic matter plays a pivotal role in governing various crucial soil processes.

Organic matter plays a significant role in soil particle aggregation, binding together inner particles and enhancing soil structure (Boyle et al., 2013). This process improves the overall strength and stability of the soil. In both environmental and agricultural contexts, clay aggregation and dispersion in the soil hold great importance. The undesirable physical properties of soil, such as structure collapse, pore sealing, and surface crusting, arise when clay colloids disperse. Soil organic matter significantly contributes to the soil's cation exchange capacity (Helling et al., 1964). Notably, soil organic matter has a greater impact on the cation exchange capacity compared to clay, which ultimately affects soil fertility.

Additionally, organic matter, including both humus and plant residues, plays a critical role in controlling soil water retention. Soils with higher organic matter content can hold more water compared to soils with similar texture composition but lower organic matter levels (Boyle et al., 2013). The presence of organic matter significantly improves soil porosity, leading to enhanced aeration, drainage, and water filtration. In cultivated soils, the moisture characteristics differ considerably between soils that receive manure and those that do not. The influence of organic matter on soil-water interactions indirectly affects soil salinity. As more water is absorbed by the soil, the salts become more diluted. Moreover, improved porosity and drainage facilitate a faster leaching process, removing salts in solution. Table 6 provides a statistical overview of the data, while table 7 displays the organic matter levels in the studied soils.

TABLE 6: STATISTICAL INFORMATION ON ORGANIC MATTER %.

Statistical information on organic matter percentage from the 134 samples taken from this study.	
Mean	2.28%
Mode	2.48%, 2.66%, 1.40%, each appeared 3 times
Median	2.18 %
Range	7.17 %
Minimum	0.02%
Maximum	7.19 %
Standard Deviation	1.09
Count	134

TABLE 7: ORGANIC MATTER % IN SOIL.

Code	Organic Matter %	Code	Organic Matter %	Code	Organic Matter%
M20RBT1	0.45	M21QRM2	2.76	M21BSK1	0.80
M20MST1	1.86	M21WRD1	3.95	M21DGL1	2.14
M20MST2	1.86	M21MST6	0.70	M21MTR1	1.40
G20SLW1	2.35	M21MST7	2.33	M21RBT3	1.62
G20SLW2	1.45	M21RBT1	3.65	M21RBT4	1.48
G20SLW3	3.19	M21GDJ1	2.13	M21BHR1	2.32
G20SLW4	0.71	M21HFR1	2.42	M21BNG1	2.26
M20BRM2	1.37	M21BBG1	2.11	M21SPB2	3.22
M20QRM2	2.82	M21MRX1	3.18	M21SPB3	2.58
M20ZJT1	2.80	M21MRX3	1.68	M21SPB4	3.46
M20QRM3	3.89	M21GXQ1	2.94	M21MLL1	2.68
M20QRM4	3.87	M21MRC1	1.88	M21MLL2	3.42
M20QRM5	1.21	M21ZBR1	2.40	M21MLL3	2.66
M20QRM6	0.71	M21XJR1	2.66	M21MLL4	2.24
M20MLL2	0.54	M21HMR1	2.48	G21SNT1	3.00
M20RBT3	1.01	M21ZJT1	2.90	G21RBT1	1.60
M20RBT4	1.24	M21ZBR3	3.10	G21RBT2	1.52
M20BRM1	0.82	G21QLA2	3.74	G21RML2	0.76
M20QRM7	0.31	G21NDR1	2.76	G21RML3	1.42
M20QRM9	2.18	G21NDR2	2.86	G21RML5	1.16
M20QRM10	2.18	G21XGR1	3.96	G21XWK1	1.92
M20QRM11	2.58	G21MRS1	1.44	M20RBT2	3.24
M20QRM12	2.30	G21GRB2	0.82	M20QRM8	3.83
M20QRM13	3.92	G21GSR1	1.64	M21SGW2	1.48
G20RML1	1.22	G21GRB3	0.96	M20QRM1	2.62
G20RML2	0.11	G21SLW1	1.50	M20BRM1	1.43
G20RML3	0.02	G21MNX1	2.66	M20TFF1	2.00
G20RML4	1.15	G21XLN1	2.08	M20MLL1	2.00
G20RML5	1.13	M21IMG1	1.14	M20QRM14	7.19
G20RML6	1.40	M21IMG2	1.82	M21MST3	1.74
M20MLL3	2.24	M21MST8	3.30	M21MRX2	2.48
M20MLL4	1.91	M21STL1	3.46	M21ZBR2	3.16
M20MLL5	1.44	M21SFI1	3.40	G21QLA1	3.66
M20DGL1	3.50	M21ZRQ1	2.48	G21QLA3	1.82
M20MLL6	1.95	M21ZRQ3	1.36	G21RML1	1.64
M20QRM15	1.61	M21ZRQ4	3.70	G21KRC1	1.20
M20QRM16	4.21	M21MQB1	3.16	G21GJN1	3.96
M20QRM17	4.00	M21GRG1	4.06	M21IMG3	2.68
G20RBT3	0.36	M21KLN1	4.08	M21ZRQ2	2.84
M21MST1	2.12	M21QRM4	2.10	M21PMR1	1.92
M21MST2	4.00	M21PLA1	2.84	M21QRM3	3.40
M21MST4	3.36	M21SGW1	1.30	M21SGW3	1.22
M21MST5	1.80	M21QRN1	2.16	M21RBT5	4.06
M21SPB1	2.29	M21ZBJ1	1.76	G21RML4	1.40
M21QRM1	3.03	M21RBT2	2.70		

4.4 pH

Soil reaction, referred to as soil pH, is measured in pH units and serves as an indicator of the alkalinity or acidity of the soil. The pH values in this study were determined from the water solution of the 1:1, 1:2, 1:5, and soil paste. As shown in Table 9, the pH in these soils varies from 6.96 to 8.83, with an overall average of 7.94.

It is evident from these data that local soils are consistently alkaline, with pH values always exceeding 7.0. This outcome aligns with expectations, considering the calcareous nature of the soils. This is attributed to the dry climate and the presence of calcareous parent material.

These results align with the findings of Portelli (2015), Montanaro (2018), and the MALSIS report (2004). According to a soil survey conducted in 2003, the mean pH $CaCl_2$ of local soils is 7.9 (MALSIS, 2004). The MALSIS report from 2004 provides the following pH (1:5) distribution ranges for soils in the Maltese Islands: > 8.5 (alkaline) - 1%; 8.5 to 8 (slightly alkaline) - 56%; 8 to 7.5 - 43%; 8.5 (alkaline) - 0%; 8.5 to 8 (slightly alkaline) - 39%; 8 to 7.5 - 61%.

The findings indicate that both conventional and organic practices result in similar pH levels, which fall within the local average (Portelli, 2015). A detailed statistical breakdown of these pH data is presented in table 8.

TABLE 8: STATISTICAL INFORMATION ON THE PH OF SOIL.

Statistical information on pH in water Value of soil paste from the 134 samples taken from this study.	
Mean	7.94
Mode	7.96, 7.80, 7.98, each appeared 5 times
Median	7.96
Range	1.87
Minimum	6.96
Maximum	8.83
Standard Deviation	0.30
Count	134

TABLE 9: SOIL PH IN WATER.

pH in Water Results				
Sample Code	1:1 pH	1:2 pH	1:5 pH	Soil Paste pH
M20RBT1	8.00	8.05	8.73	7.72
M20MST1	7.31	7.55	7.81	7.80
M20MST2	6.86	7.15	7.67	7.58
G20SLW1	7.10	7.11	7.75	6.99
G20SLW2	7.71	7.52	8.14	7.32
G20SLW3	7.21	7.11	7.25	7.22
G20SLW4	7.72	7.88	8.90	7.58
M20BRM2	7.88	7.79	8.01	7.72
M20QRM2	7.23	7.32	7.45	7.78
M20ZJT1	7.50	7.43	8.05	8.03
M20QRM3	7.33	7.38	7.65	8.11
M20QRM4	7.40	6.98	7.47	7.83
M20QRM5	7.23	7.33	8.10	7.65
M20QRM6	7.73	7.99	8.69	7.79
M20MLL2	8.25	8.37	8.80	7.77
M20RBT3	7.48	7.49	8.40	8.44
M20RBT4	7.52	7.85	8.43	8.31
M20BRM1	7.66	7.45	8.19	7.80
M20QRM7	7.66	7.78	8.74	7.93
M20QRM9	7.18	7.25	8.21	7.64
M20QRM10	7.36	7.17	7.97	7.59
M20QRM11	7.56	7.66	8.13	7.87
M20QRM12	7.30	7.33	7.64	7.93
M20QRM13	6.64	6.70	7.18	7.58
G20RML1	7.75	7.53	8.09	7.51
G20RML2	8.60	8.70	9.64	8.14
G20RML3	8.93	9.02	9.25	8.08
G20RML4	7.21	7.53	8.08	7.76
G20RML5	7.60	7.71	8.27	8.03
G20RML6	7.33	7.74	8.53	7.89
M20MLL3	8.00	7.95	8.29	8.83
M20MLL4	7.64	7.56	7.88	8.30
M20MLL5	7.82	7.59	8.21	8.13
M20DGL1	7.20	7.14	8.04	7.96
M20MLL6	7.81	7.55	8.27	7.80
M20QRM15	7.37	7.54	7.76	7.53
M20QRM16	7.21	7.19	7.45	7.59
M20QRM17	7.14	6.83	6.92	7.84
G20RBT3	8.02	7.49	8.10	8.09
M21MST1	7.57	7.65	8.08	7.91
M21MST2	6.95	7.21	6.97	7.67
M21MST4	7.51	7.43	7.73	8.23
M21MST5	7.56	7.70	8.01	8.04
M21SPB1	7.64	7.54	7.59	8.09
M21QRM1	7.22	7.59	7.85	7.94

pH in Water Results				
Sample Code	1:1 pH	1:2 pH	1:5 pH	Soil Paste pH
M21QRM2	7.44	7.44	7.66	8.25
M21WRD1	7.17	7.19	7.09	7.96
M21MST6	8.19	8.62	8.83	8.07
M21MST7	7.77	7.91	8.07	7.93
M21RBT1	7.25	7.52	7.67	8.01
M21GDJ1	7.38	7.66	7.91	7.96
M21HFR1	7.37	7.65	7.79	7.98
M21BBG1	7.41	7.62	7.92	8.08
M21MRX1	7.11	7.50	7.75	7.87
M21MRX3	7.73	7.98	8.24	8.00
M21GXQ1	7.29	7.17	7.34	8.35
M21MRC1	7.47	7.50	7.85	7.69
M21ZBR1	7.42	7.67	7.89	7.99
M21XJR1	7.50	7.75	7.56	8.17
M21HMR1	7.48	7.54	7.74	7.34
M21ZJT1	7.83	7.96	8.28	8.31
M21ZBR3	6.88	7.31	7.42	8.18
G21QLA2	7.41	7.50	7.83	8.22
G21NDR1	7.00	7.44	7.82	8.41
G21NDR2	7.17	7.25	7.68	8.17
G21XGR1	7.19	7.15	7.64	7.94
G21MRS1	7.50	7.57	7.69	7.95
G21GRB2	7.21	7.70	8.04	8.04
G21GSR1	7.35	7.43	7.46	7.96
G21GRB3	7.31	7.44	7.87	7.88
G21SLW1	7.28	7.57	7.73	7.80
G21MNX1	7.83	7.89	7.93	8.03
G21XLN1	7.61	7.87	7.91	7.21
M21IMG1	7.67	7.95	8.15	8.06
M21IMG2	7.67	7.88	8.06	8.17
M21MST8	7.37	7.42	7.69	7.81
M21STL1	7.41	7.28	7.68	7.97
M21SFI1	7.45	7.52	7.77	8.04
M21ZRQ1	7.61	7.64	7.75	7.99
M21ZRQ3	7.84	8.02	8.18	7.89
M21ZRQ4	6.94	7.40	7.31	7.77
M21MQB1	7.51	7.57	7.79	8.12
M21GRG1	7.63	7.63	7.52	7.98
M21KLN1	7.33	7.58	7.54	8.08
M21QRM4	6.80	7.54	7.90	7.81
M21PLA1	7.29	7.82	8.17	7.98
M21SGW1	7.96	7.95	8.16	8.00
M21QRN1	7.21	7.82	7.79	7.99
M21ZBJ1	7.14	7.74	7.78	7.76
M21RBT2	7.14	7.49	7.84	8.16
M21BSK1	7.21	7.49	7.62	7.86
M21DGL1	7.69	7.83	7.93	8.16
M21MTR1	7.66	7.52	7.86	7.82
M21RBT3	7.16	7.51	7.65	8.32

pH in Water Results				
Sample Code	**1:1 pH**	**1:2 pH**	**1:5 pH**	**Soil Paste pH**
M21RBT4	7.63	7.75	8.12	8.39
M21BHR1	7.30	7.68	7.84	8.60
M21BNG1	7.63	7.69	7.85	8.64
M21SPB2	7.74	7.31	7.77	8.64
M21SPB3	7.50	7.69	7.87	8.42
M21SPB4	7.65	7.34	7.64	7.71
M21MLL1	7.26	7.48	7.74	8.01
M21MLL2	7.35	7.61	7.68	7.93
M21MLL3	7.24	7.80	8.02	7.88
M21MLL4	7.41	7.51	7.71	7.97
G21SNT1	7.18	7.61	7.88	8.21
G21RBT1	7.27	7.49	7.17	8.00
G21RBT2	6.95	7.70	7.80	8.02
G21RML2	7.21	7.97	8.30	7.84
G21RML3	7.25	7.97	8.03	7.98
G21RML5	7.07	7.97	8.05	7.65
G21XWK1	7.60	7.91	8.09	8.27
M20QRM8	6.95	6.92	7.64	7.44
M20RBT2	6.81	7.26	6.90	7.37
M21SGW2	7.09	7.70	7.87	7.96
M20QRM1	7.17	7.17	7.38	7.38
M20BRM1	7.94	7.68	8.05	7.72
M20TFF1	7.55	7.54	8.29	7.80
M20MLL1	7.40	7.42	7.40	7.48
M20QRM14	7.10	6.77	7.39	6.96
M21MST3	7.39	7.62	8.05	8.17
M21MRX2	7.21	7.70	7.88	8.06
M21ZBR2	7.43	7.45	7.83	8.22
G21QLA1	7.16	7.29	7.74	8.35
G21QLA3	7.51	7.47	7.96	8.50
G21RML1	7.39	7.50	7.81	7.69
G21KRC1	7.41	7.62	8.21	7.71
G21GJN1	7.65	7.46	7.83	8.20
M21IMG3	7.58	7.60	7.93	8.03
M21ZRQ2	7.25	7.54	7.72	7.98
M21PMR1	7.56	7.69	7.76	7.89
M21QRM3	7.14	7.65	7.64	7.91
M21SGW3	7.15	7.70	7.67	8.08
M21RBT5	7.17	7.19	7.10	7.87
G21RML4	7.07	7.74	8.00	7.81

4.5 Soil Metals

Heavy metals are non-biodegradable and cannot be broken down. Organisms detoxify metal ions by binding them to proteins or storing them in insoluble forms, leading to bioaccumulation, which can cause physiological and biological complications (Gautam et al., 2016). Some heavy metals, essential for life, can become toxic in large quantities (Duffus, 2002). These elements, used extensively in medicine, agriculture, and other sectors, are now widespread (Wang, 2009; Tchounwou et al., 2012). Essential elements are categorized as major elements, macrominerals, and trace elements, each playing critical roles in biological functions (Villanueva and Bustamante, 2006).

Soil contamination with heavy metals can be intentional, such as through animal manure, pesticides, fertilizers, and wastewater irrigation, or unintentional, like flooding with sewage-contaminated water (Alloway and Jackson, 1991; Muchuweti et al., 2006; Masindi and Muedi, 2018). These metals persist in the soil due to their non-biodegradable nature, affecting the bioavailability of other pollutants (Rodriguez-Eugenio, McLaughlin, and Pennock, 2018). Consequently, heavy metals entering the food chain pose significant health risks and alter soil properties, impacting overall soil and water quality (Masindi and Muedi, 2018; Gupta, Khan, and Santra, 2012).

In this study it was decided to test soil metals using soil saturated paste and soil-to-water suspensions with ratios of 1:1, 1:2, and 1:5. The metals tested are: calcium, strontium, barium, sodium, zinc, cadmium, magnesium, copper, nickel, iron, chromium, potassium and manganese. The initial intention for the analysis for the metal content was to record the metal concentration in all the 143 soil samples then compare and contrast the methods chosen to come up with a model suitable to convert between concentration using different methods. However, this was not possible for all metals, since when reviewing the results, some concentrations were way below the detection limit of the equipment available hence this conversion model could not work for some of the metals. The selected extraction was carried out solely with water to mimic soil conditions and look at the available metals in

the soil matrix when irrigating. This has also shown us that water alone will not dissolve the majority of metals hence an extractant is needed to determine the potential soil metal concentration for some of the above-mentioned metals. Additionally, as described by Di Bonito et al. (2008) varying the soil-to-solution ratio had a marked effect on the concentration and speciation of extracted metals. This is primarily because hydration ratio influences the equilibrium between soil-bound and soluble metal species. At high dilution ratios (e.g., 1:100), the solution phase becomes more dominant, favouring the release of free ionic species especially for metals like Cu^{2+} and Zn^{2+} that are more mobile and have weaker bonds with soil colloids. These conditions more closely reflect the bioavailable fraction in the soil pore water under natural conditions.

In contrast, lower dilution ratios (e.g., 1:2) create more concentrated suspensions, which can disrupt soil aggregates and release organically complexed or colloid-bound metals. Metals such as Pb and Cd, which tend to form stable complexes with organic matter or bind strongly to clay particles, show increased extraction under these concentrated conditions not because they are more bioavailable, but because the chemical environment allows these bound forms to enter solution. This can artificially inflate their apparent mobility if not interpreted correctly. The response to hydration ratio is therefore metal-specific, driven by each element's chemical affinity for, cation exchange sites, organic matter concentration, pH-dependent solubility and colloidal associations.

Water is generally not considered a good extractant for determining the available and total concentrations of heavy metals in soils, as demonstrated by Ivezić et al. (2013). The study found that water extraction yields significantly lower concentrations of metals such as Cd, Cu, Fe, Mn, and Zn compared to chelating agents like DTPA or EDTA, or strong acid digestion methods like aqua regia. This is because water, being a neutral solvent with low ionic strength, is unable to effectively desorb metals bound to soil particles, organic matter, or exchange sites (Ivezić et al., 2013).

Unlike chelating agents, which can complex with metals and mobilize them from soil matrices, water primarily extracts the truly soluble fraction, which often represents only a small and variable portion of the total or bioavailable metals. Consequently, water extraction underestimates the pool of metals potentially available for plant uptake or environmental mobility, limiting its utility in risk assessment or soil fertility evaluations (Ivezić et al., 2013).

Moreover, the study highlighted that the metal concentrations extracted by water showed poor correlation with those extracted by more effective methods, indicating its limited representativeness of metal bioavailability (Ivezić et al., 2013). Therefore, water is insufficient as a sole extractant for comprehensive assessment of metal availability in soils. This gives a better understanding of why some elements such as Sr, Ba, Zn, Cd, Cu, Ni, Cr, Mn and Fe where not possible not solely on the sensitivity gradient of the MPAES used but also the hydration potential required to make these metals available in solution. It was noted that prominent metals such as Na, Mg, K and Ca shown a better correlation and readability. This behaviour mirrors patterns observed in soil electrical conductivity studies, where extractable EC is highly sensitive to dilution. Hence it was decided to try and develop a predictive model to convert Na, Mg, K and Ca values obtained from 1:1, 1:2, or 1:5 dilutions into equivalent saturated paste extract values (EC_e), improving cross-study comparability. Applying this logic to trace metal extraction suggests that similar correction models may be necessary to harmonize results obtained with different hydration ratios and provide more ecologically meaningful estimates of bioavailability. The obtained data are presented in figures 8-11, and a statistical analysis for the metal concentration in the saturated paste is displayed in table 10.

TABLE 10: STATISTICAL INFORMATION ON THE METAL CONTENT OF SOIL.

Statistical information on Ca, Na, Mg and K concentration in soil paste from the 134 samples taken from this study.				
Metal	**Ca ppm**	**Na ppm**	**Mg ppm**	**K ppm**
Mean	308.23	276.23	63.14	69.74
Mode	63.7 appeared 3 times	83.0, 52.3, 71.3, each appeared 3 times	12.3, appeared 4 times	0.0, appeared 39 times
Median	191	114	25.7	13
Range	1888.4	3605	601.4	1202
Minimum	32.3	28.3	1.3	0.0
Maximum	1920.7	3633.3	602.7	9344.7
Standard Deviation	355.40	567.60	107.09	156.08
Count	134	134	134	134

Given that the metal results from soil paste and soil to water ratios were verified and validated, the regression model equations were carried out using the remaining 22 soil samples that were not included in the initial model generation. Linear regression relationships between metal concentration in the extract and measured in soil:water suspensions at different ratios were developed using $\log_{10}$-transformed EC data (n = 114). The resulting model equations are presented in figures 8-11. Strong correlations were observed between the metal concentration in the extract vs soil:water ratios. The r^2 for Ca measured at various soil:water ratios was as follows: 1:1 ($r^2 = 0.92$, $p < .001$), 1:2 ($r^2 = 0.90$, $p < .001$), and 1:5 ($r^2 = 0.86$, $p < .001$), for K 1:1 ($r^2 = 0.85$, $p < .001$), 1:2 ($r^2 = 0.73$, $p < .001$), and 1:5 ($r^2 = 0.82$, $p < .001$), for Mg 1:1 ($r^2 = 0.90$, $p < .001$), 1:2 ($r^2 = 0.95$, $p < .001$), and 1:5 ($r^2 = 0.91$, $p < .001$), and for Na 1:1 ($r^2 = 0.94$, $p < .001$), 1:2 ($r^2 = 0.92$, $p < .001$), and 1:5 ($r^2 = 0.83$, $p < .001$).

The soil-to-water ratio significantly affected both the slope and intercept of the regression models. Specifically, as the dilution increased (i.e., higher water content), both the slope and intercept values increased, indicating that greater dilution leads to an amplified adjustment in the regression parameters. This phenomenon reflects the dilution effect inherent to the use of increasing volumes of water in suspension measurements.

Verification was carried out by comparing the metal concentration in the extract of the 22 soils that was predicted by the general models, with the actual measured metal concentration using a paired t-test and linear regression. The data were not that statistically different. The linear regression between measured and the predicted by the models for 1:1, 1:2 and 1:5 showed that the slopes of the regression were close to 1, the Ca measured at soil:water ratios of 1:1 ($r^2 = 0.94$, $p < .001$), 1:2 ($r^2 = 0.96$, $p < .001$), and 1:5 ($r^2 = 0.88$, $p < .001$), the K measured at soil:water ratios of 1:1 ($r^2 = 0.83$, $p < .001$), 1:2 ($r^2 = 0.76$, $p < .001$), and 1:5 ($r^2 = 0.83$, $p < .001$), the Mg measured at soil:water ratios of 1:1 ($r^2 = 0.95$, $p < .001$), 1:2 ($r^2 = 0.97$, $p < .001$), and 1:5 ($r^2 = 0.96$, $p < .001$), the Na measured at soil:water ratios of 1:1 ($r^2 = 0.97$, $p < .001$), 1:2 ($r^2 = 0.96$, $p < .001$), and 1:5 ($r^2 = 0.93$, $p < .001$), this is portrayed in figures 8-11.

When looking at a similar study by Zhang et al. (2005) a set of predictive models to estimate the electrical conductivity (EC) and ion concentrations of saturated paste extracts from 1:1 soil-to-water suspensions, based on data from 170 soils. Their results demonstrated strong linear correlations between the measured and predicted concentrations of major cations, including Na^+, Ca^{2+}, Mg^{2+}, and K^+. The regression slopes were generally close to 1, and coefficients of determination (r^2) were particularly high for Na^+ ($r^2 = 0.97$) and Mg^{2+} ($r^2 = 0.95$), indicating reliable predictability from 1:1 extract. In this study, suspension models were developed using $\log_{10}$-transformed EC data from 114 samples. Strong and statistically significant correlations were observed between metal concentrations and the soil:water extract ratios ($_{1:1,\ 1:2,}$ and $_{1:5}$), confirming the suitability of dilution-based extractants for modelling extractable ion behaviour.

The reported results closely align with those reported by Zhang et al. (2005), particularly for Na^+ and Mg^{2+}, which again showed the strongest predictability across all dilution levels. The slightly lower r^2 values observed for K^+ and Ca^{2+} particularly at the 1:2 ratio could reflect inherent differences in soil chemistry, mineral composition, or extractant dynamics specific to Mediterranean soils.

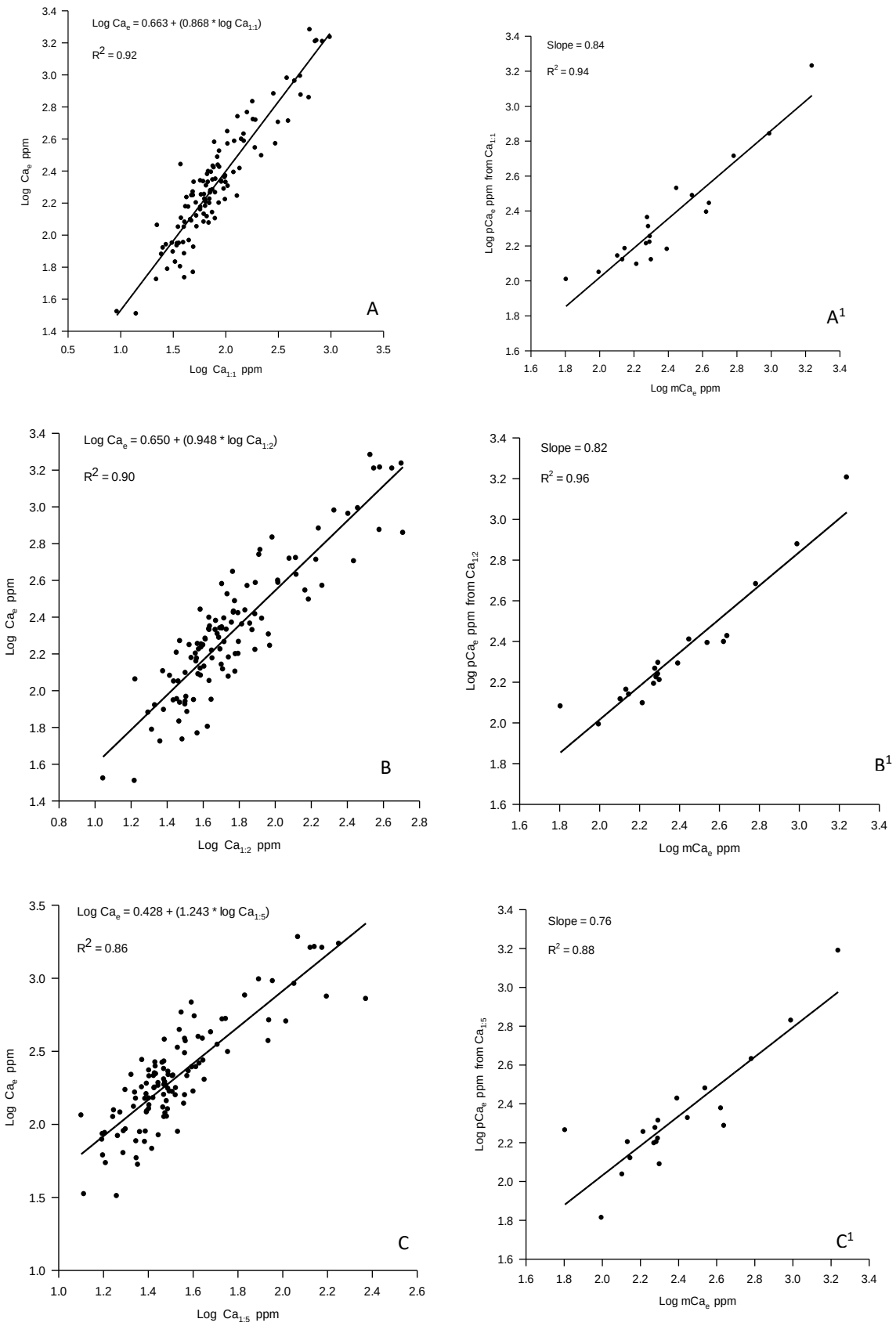


FIGURE 8: RELATIONSHIPS OF CA_E WITH THE CA1:1(A), CA1:2(B) AND CA1:5(C), AND VALIDATION OF THE LINEAR REGRESSION EQUATIONS FOR CA_E VS CA1:1(A'), CA_E VS CA1:2(B') AND CA_E VS CA1:5(C').

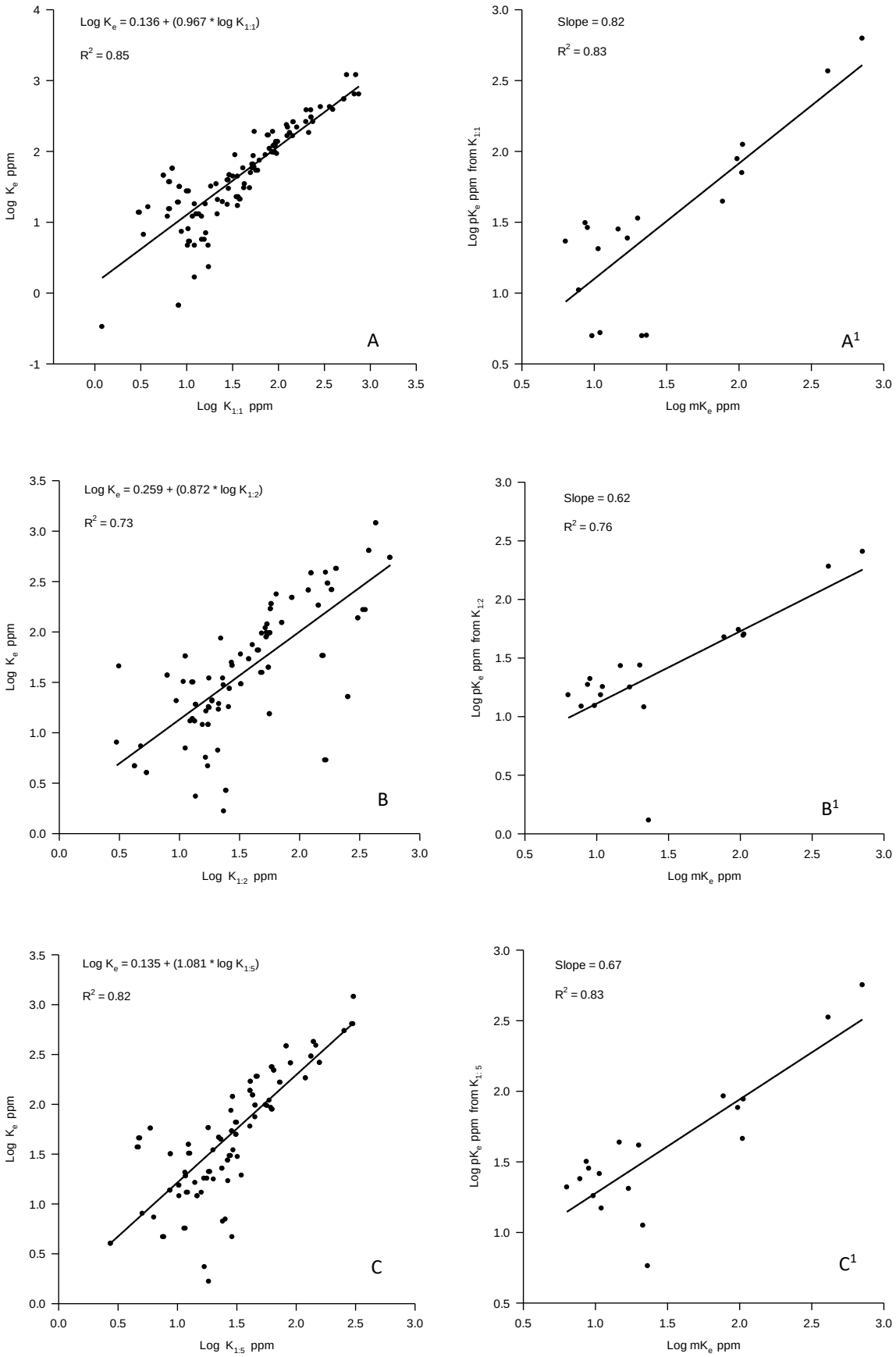


FIGURE 9: RELATIONSHIPS OF K_E WITH THE K1:1(A), K1:2(B) AND K1:5(C), AND VALIDATION OF THE LINEAR REGRESSION EQUATIONS FOR K_E VS K1:1(A'), K_E VS K1:2(B') AND K_E VS K1:5(C').

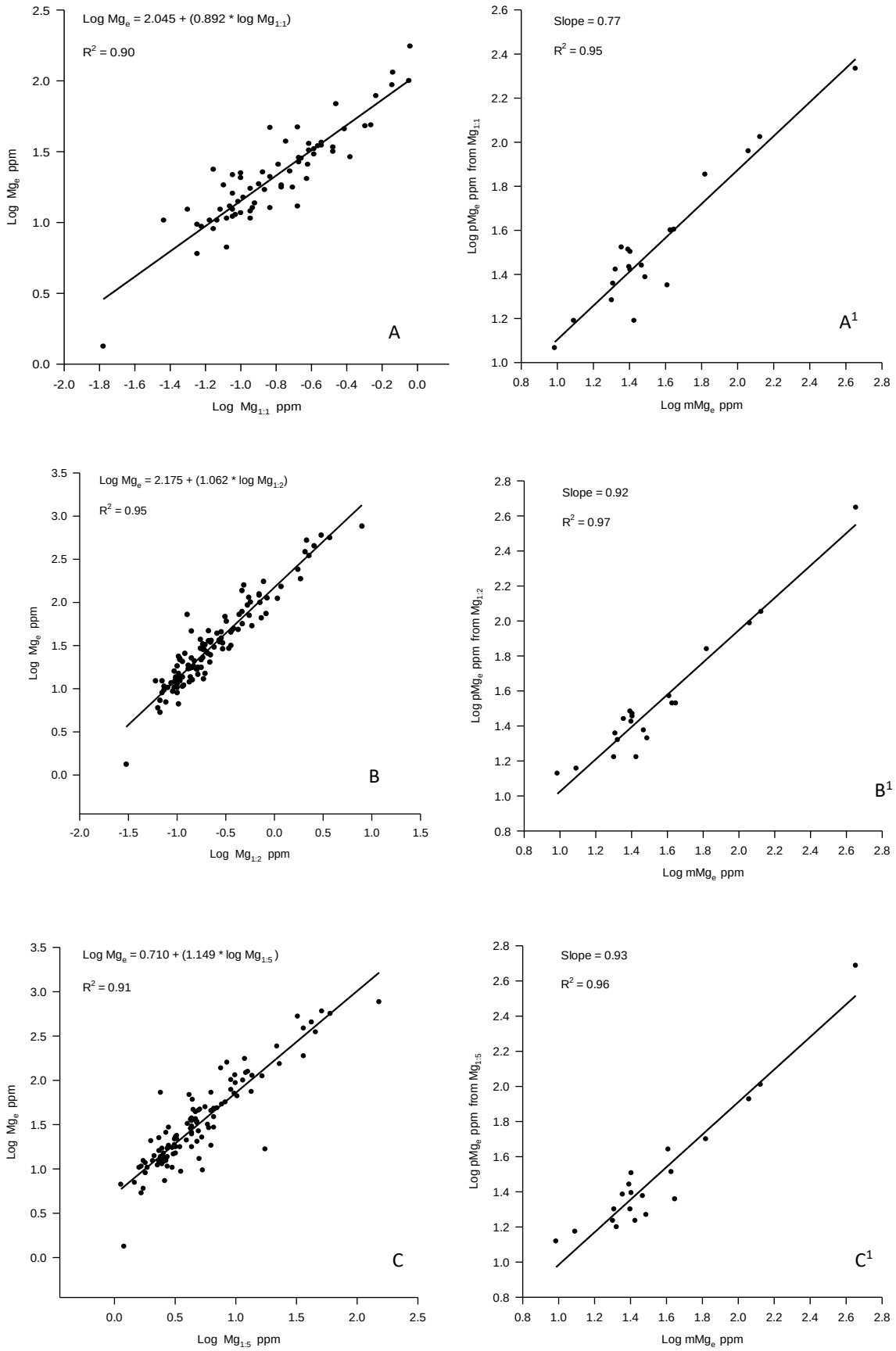


FIGURE 10: RELATIONSHIPS OF MG$_E$ WITH THE MG1:1(A), MG1:2(B) AND MG1:5(C), AND VALIDATION OF THE LINEAR REGRESSION EQUATIONS FOR MG$_E$ VS MG1:1(A'), MG$_E$ VS MG1:2(B') AND MG$_E$ VS MG1:5(C').

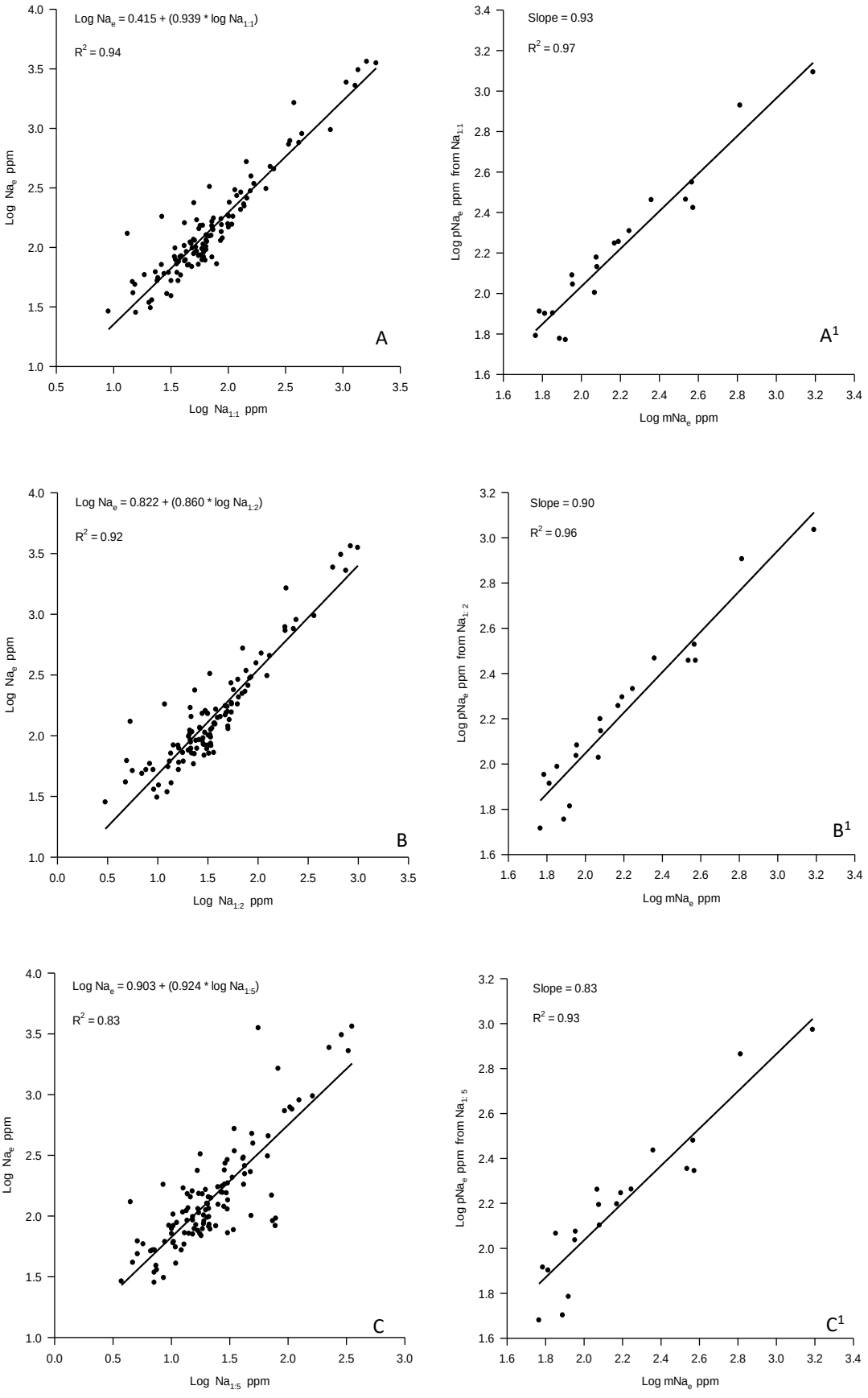


FIGURE 11: RELATIONSHIPS OF NA_E WITH THE NA1:1(A), NA1:2(B) AND NA1:5(C), AND VALIDATION OF THE LINEAR REGRESSION EQUATIONS FOR NA_E VS NA1:1(A'), NA_E VS NA1:2(B') AND NA_E VS NA1:5(C').

Overall, the consistency in model performance between this study and that of Zhang et al. affirms the reliability of using diluted soil:water extracts to estimate EC and soluble ion concentrations. Moreover, the inclusion of multiple extract ratios ($_{1:1,\ 1:2,}$ and $_{1:5}$) and the application of log-transformed EC data in this study contribute to a more flexible and scalable framework for local and regional soil salinity assessment.

The findings of this study demonstrate that the developed general models are effective for estimating metal concentrations from soil-to-water extracts at 1:1, 1:2, and 1:5 ratios in calcareous soils of the Maltese Islands. Each of the tested suspension ratios yielded a reliable degree of accuracy, confirming their suitability for practical application in local soil monitoring and salinity assessments.

4.6 SAR and Sodic Soil

Sodium adsorption ratio measures the quantity of Na^+ relative to Ca^{2+} and Mg^{2+} in the water extract from saturated soil paste. It is the ratio of the Na^+ concentration divided by the square root of one-half of the sum of Ca^{2+} and Mg^{2+} concentration. Soils with SAR values of 13 or more might have the following characteristics: a general degradation of soil structure, reduced saturated hydraulic conductivity and aeration, and an increased dispersion of organic matter and clay particles. SAR is thus linked with sodicity.

The SAR was calculated for the soils sampled, and the values are shown in table 12, relative statistical information is represented in table 11. The SAR of the sampled soils ranges from 0 to 23. The median is 2 and the mean is 3. The majority of soils which are well below the 13 benchmark do not exhibit problems related to sodicity (L. Rollins, 2007). This shows that there are no serious issues with regards to sodicity in the soils that were investigated. However, there are some of the soils where the SAR is either close to

13 or in some cases well above 13. As the SAR approaches 13, problems of sodicity will become evident. These may include clay dispersion, soil compaction which will eventually lead to impaired water infiltration, percolation, and aeration.

The soils with a relatively high SAR have a clay, a sand a loam and clay loam texture. The sandy soil has an SAR of 23 and an EC (e) of 8770 μS/cm with a pH of 8.14. This is clearly a saline-sodic soil with normal pH, however due to the sandy nature of the soil it might not exhibit the adverse conditions that characterize sodic soils. The clay content is low and thus dispersion would be minimal. Moreover, the fact that the sand content is high, leaching of the salts would be easy. The loam soils have an SAR of 14 and 17 and an EC (e) of 19,880 μS/cm and 24,070 μS/cm with a pH values of 7.53 and 7.65 respectively. Again, these are both saline-sodic soils and as the sand content is 41% and 51 % and the clay content is 20% and 19 %, problems related to sodicity might not be high in these soils. However, one should pay extra attention when remediating this soil in order not to revert the conditions to non-saline sodic with the possibility of causing dispersion and an increase in pH. The clay loam and clay soils both have an SAR of 19 with a corresponding EC (e) of 24,980 μS/cm and 26,727 μS/cm and with a pH of 7.69 and 7.67 respectively. The SAR in these soils is quite high especially in the clay soil due to their high clay amounting to 29% and 40% respectively. Due to this high clay content these soils might experience a slight degree of dispersion if it was not for the high salinity. Again, here care should be taken when these soils are remediated.

As a general note soils from Malta, although at times they could exhibit certain degree of salinity and although in certain cases the Na+ content could be high, as this Na+ generally originates from sea water and also due to the fact that the soils are calcareous, problems of sodicity and high alkalinity should be remote. This scenario agrees with what was reported by Minhas et al. (1999). In his paper on changes in hydraulic conductivity of soils, results obtained by Minhas et al. show that SAR in calcareous soils tends to be higher than non-cancerous soils since clays may disperse and move downwards. The

dynamic equilibrium between the SAR of the soil, inherent infiltration characteristics and salt release will determine the quantity and depth to which dispersed clay can migrate and consequently cause permeability problems. Furthermore, structural changes in soils can be more accurately described on the basis of quality parameters of water as well as the soil, climate, and other management parameters.

TABLE 11: STATISTICAL INFORMATION ON SAR IN SOIL.

Statistical information on SAR from the 134 samples taken from this study.	
Mean	3.
Mode	2, appeared 49 times
Median	2
Range	23
Minimum	0
Maximum	23
Standard Deviation	3.5

Table 12: SAR table of soils showing Ca2+, Mg2+ and Na+ concentrations in soil paste extract.

Sample Name	Ca^{2+} ppm	Mg^{2+} ppm	Na^{+} ppm	SAR
M20RBT1	53.00	5.33	51.33	2
M20MST1	158.33	24.67	29.00	1
M20MST2	313.67	66.33	88.00	1
G20SLW1	516.33	153.00	475.67	5
G20SLW2	229.67	56.67	221.67	3
G20SLW3	507.00	74.33	103.00	1
G20SLW4	127.67	72.67	323.00	6
M20RBT2	985.33	242.33	296.67	2
M20BRM2	87.33	13.67	84.33	2
M20QRM2	261.33	38.67	125.33	2
M20ZJT1	84.33	16.67	75.67	2
M20QRM3	213.67	50.00	143.00	2
M20QRM4	167.00	60.67	130.33	2
M20QRM5	1640.67	602.67	3091.33	17
M20QRM6	68.00	7.00	48.67	1
M20MLL2	76.00	7.33	152.67	4
M20RBT3	58.67	15.00	70.67	2
M20RBT4	54.33	14.67	60.00	2
M20BRM3	63.67	9.00	28.33	1
M20QRM7	132.00	21.67	126.67	3
M20QRM8	918.00	349.67	395.67	3
M20QRM9	202.33	71.00	160.00	2
M20QRM10	763.67	101.33	151.67	1
M20QRM11	266.33	44.00	116.00	2
M20QRM12	246.67	45.33	110.33	2
M20QRM13	1619.67	386.67	270.33	2

Table 12: SAR table of soils showing Ca2+, Mg2+ and Na+ concentrations in soil paste extract.

Sample Name	Ca^{2+} ppm	Mg^{2+} ppm	Na^{+} ppm	SAR
G20RML1	125.00	36.33	164.33	3
G20RML2	115.33	159.00	1635.33	23
G20RML3	33.33	12.00	169.33	6
G20RML4	175.67	53.67	62.00	1
G20RML5	78.67	17.00	58.67	2
G20RML6	194.33	72.67	342.33	5
M20MLL3	61.33	17.67	175.33	5
M20MLL4	381.00	137.33	522.33	6
M20MLL5	218.67	29.33	303.00	5
M20DGL1	351.33	111.67	107.33	1
M20MLL6	86.00	13.67	135.00	4
M20QRM15	1619.67	452.67	2429.33	14
M20QRM16	523.67	125.33	151.33	2
M20QRM17	750.67	188.00	757.00	6
G20RBT3	89.33	29.33	98.33	2
M21MST1	76.67	6.67	55.33	2
M21MST2	1724.33	564.33	3531.00	19
M21MST4	138.67	48.00	230.33	4
M21MST5	113.00	25.67	173.00	4
M21SPB1	119.33	12.67	100.33	2
M21QRM1	232.00	11.67	41.33	1
M21QRM2	158.67	17.67	115.00	2
M21WRD1	372.67	29.00	83.00	1
M21MST6	32.33	1.33	71.33	3
M21MST7	92.67	12.67	92.33	2
M21RBT1	127.00	20.33	58.33	1
M21GDJ1	159.33	10.67	106.00	2
M21HFR1	178.67	13.67	101.33	2
M21BBG1	112.33	9.00	40.67	1
M21MRX1	247.33	34.67	207.00	3
M21MRX3	88.67	6.00	119.33	3
M21GXQ1	387.00	48.67	155.67	2
M21MRC1	1920.67	527.00	3633.33	19
M21ZBR1	549.67	114.67	784.33	8
M21XJR1	221.33	18.33	186.00	3
M21HMR1	444.00	25.67	143.00	2
M21ZJT1	83.33	11.33	78.33	2
M21ZBR3	397.67	34.00	140.33	2
G21QLA2	240.00	32.33	91.67	1
G21NDR1	270.00	36.67	114.33	2
G21NDR2	168.00	33.00	52.33	1
G21XGR1	386.00	45.67	36.00	0
G21MRS1	371.67	93.33	454.67	5
G21GRB2	151.67	31.67	86.00	2
G21GSR1	307.33	78.33	258.00	3
G21GRB3	528.00	113.00	182.00	2
G21SLW1	150.67	21.00	124.00	3
G21MNX1	216.33	28.67	154.33	3
G21XLN1	682.67	175.33	731.67	6
M21IMG1	112.33	17.33	90.33	2
M21IMG2	90.00	11.00	68.67	2
M21MST8	190.00	14.00	85.00	2
M21STL1	234.67	35.00	61.33	1
M21SFI1	224.00	36.00	111.67	2
M21ZRQ1	161.00	12.33	91.00	2
M21ZRQ3	179.67	10.33	76.67	2
M21ZRQ4	274.00	26.67	113.67	2
M21MQB1	218.33	23.00	95.33	2
M21GRG1	149.67	12.33	52.33	1

Table 12: SAR table of soils showing Ca2+, Mg2+ and Na+ concentrations in soil paste extract.

Sample Name	Ca^{2+} ppm	Mg^{2+} ppm	Na^{+} ppm	SAR
M21KLN1	121.00	17.67	77.67	2
M21QRM4	583.67	68.67	899.33	9
M21PLA1	168.00	18.67	78.33	2
M21SGW1	249.67	20.67	78.67	1
M21QRN1	177.33	18.33	72.33	1
M21ZBJ1	186.33	12.33	98.33	2
M21RBT2	144.33	15.00	83.00	2
M21BSK1	214.33	16.00	61.33	1
M21DGL1	120.67	9.67	81.67	2
M21MTR1	150.00	10.33	34.33	1
M21RBT3	335.33	37.33	289.33	4
M21RBT4	215.00	30.33	157.00	3
M21BHR1	192.00	28.33	147.67	3
M21BNG1	135.33	12.00	39.00	1
M21SPB2	165.33	17.00	97.00	2
M21SPB3	123.00	9.33	71.33	2
M21SPB4	957.33	121.67	970.67	8
M21MLL1	264.67	22.67	181.33	3
M21MLL2	184.00	13.00	71.67	1
M21MLL3	214.33	47.00	237.67	4
M21MLL4	184.33	13.00	72.33	1
G21SNT1	130.67	10.67	82.67	2
G21RBT1	428.00	100.00	310.33	3
G21RBT2	203.67	46.67	235.67	4
G21RML2	276.67	23.67	181.00	3
G21RML3	172.00	21.67	52.33	1
G21RML5	177.00	22.33	83.33	2
G21XWK1	89.00	10.33	31.00	1
M21SGW2	162.00	9.67	63.67	1
M20QRM1	976.00	114.67	374.33	3
M20BRM1	99.00	21.00	90.33	2
M20TFF1	186.67	42.33	117.00	2
M20MLL1	606.00	133.00	343.33	3
M20QRM14	1726.33	450.33	1543.67	9
M21MST3	63.67	9.67	83.00	3
M21MRX2	135.67	12.33	61.00	1
M21ZBR2	435.00	44.33	368.67	4
G21QLA1	196.33	24.67	155.33	3
G21QLA3	127.00	22.67	119.33	3
G21RML1	418.67	30.67	58.33	1
G21KRC1	164.00	29.33	120.33	2
G21GJN1	280.33	66.00	651.33	9
M21IMG3	140.00	25.33	71.33	1
M21ZRQ2	192.00	25.00	148.00	3
M21PMR1	195.67	20.33	228.67	4
M21QRM3	246.67	40.67	176.00	3
M21SGW3	189.33	25.33	65.00	1
M21RBT5	346.33	20.00	89.67	1
G21RML4	199.33	26.67	77.33	1

4.7 Salinity

4.7.1 Overall Situation

Soil salinity was valued using soil saturated paste and soil-to-water suspensions with ratios of 1:1, 1:2, and 1:5. The obtained data are presented in Table 14, and a statistical analysis for the saturated paste is displayed in Table 13. The recorded values ranged from 727 µS/cm to 26,727 µS/cm, with a median of 2,132.5 µS/cm and a mean of 3,772.80 µS/cm. These results indicate a considerable variability in salinity levels among the sampled soils. Out of the 134 different soils analysed, 104 can be classified as non-saline, with an electrical conductivity (e) less than 4,000 µS/cm. The remaining 30 soils are classified as saline soils, with 10 of them categorized as severely saline, with an electrical conductivity (e) exceeding 10,000 µS/cm. Among the non-saline soils, 44 soils with conductivity value bigger than 2,000 µS/cm where further classified as moderately saline.

The soils with extremely high salt content are those obtained from specific locations, which are part of sand dunes, areas in close proximity to the sea, or intensive agricultural areas. The latter may be attributed to the excessive application of fertilizer or the use of highly brackish water for irrigation.

TABLE 13: STATISTICAL INFORMATION ON CONDUCTIVITY OF SOIL PASTE.

Statistical information on conductivity from soil paste from the 134 samples taken in this study values in µS/cm.	
Mean	3772.82
Mode	1521, 1773, each appeared 2 times.
Median	2132.50
Range	26000
Minimum	727
Maximum	26,727
Standard Deviation	4670.07
Count	134

Table 14: ***Conductivity results in soil paste, 1:1, 1:2 and 1:5.***

Sample Code	EC 1:1	EC 1:2	EC 1:5	EC SP
M20RBT1	384	239	141	727
M20MST1	1101	659	371	2253
M20MST2	2672	1567	680	4087
M20QRM1	4570	2487	1083	10277
G20SLW1	4903	2263	1165	7247
G20SLW2	1594	1121	524	3410
G20SLW3	3063	2220	1034	4967
G20SLW4	710	451	218	2857
M20RBT2	6040	3247	1539	10890
M20BRM1	734	488	243	1743
M20BRM2	575	424	202	1529
M20TFF1	1123	647	319	2937
M20QRM2	1946	1002	536	3503
M20ZJT1	956	608	359	2037
M20MLL1	3267	1824	838	7680
M20QRM3	2045	1198	540	3797
M20QRM4	1491	944	394	2902
M20QRM5	10893	6333	2715	24070
M20QRM6	532	315	166	1113
M20MLL2	549	369	182	1391
M20RBT3	980	561	287	1244
M20RBT4	802	479	251	1178
M20BRM1	638	394	225	961
M20QRM7	998	571	301	2090
M20QRM8	7340	4060	2065	13650
M20QRM9	1820	1379	674	4330
M20QRM10	3423	1939	860	8323
M20QRM11	1341	795	382	3330
M20QRM12	1628	1002	493	3470
M20QRM13	8063	4327	1943	16607
G20RML1	1108	614	306	2528
G20RML2	2198	1309	564	8770
G20RML3	412	250	126	1136
G20RML4	1766	1051	445	2957
G20RML5	452	326	164	1323
G20RML6	2408	1206	520	4480
M20MLL3	679	464	236	1765
M20MLL4	1949	1061	509	6090
M20MLL5	1181	852	393	3633
M20DGL1	2718	1690	701	4607
M20MLL6	871	518	302	1773
M20QRM14	10317	6440	2913	20270
M20QRM15	10747	6033	2504	19880
M20QRM16	3560	1883	877	7067
M20QRM17	6557	4166	2145	9997
G20RBT3	923	728	404	1863
M21MST1	627	381	198	1083
M21MST2	16033	8777	4093	26727
M21MST3	589	344	166	1260
M21MST4	2221	1252	603	3270

Table 14: ***Conductivity results in soil paste, 1:1, 1:2 and 1:5.***

Sample Code	EC 1:1	EC 1:2	EC 1:5	EC SP
M21MST5	1114	639	313	2118
M21SPB1	1068	661	310	1790
M21QRM1	1043	597	290	2057
M21QRM2	1191	673	313	2199
M21WRD1	2439	1359	799	3290
M21MST6	347	198	124	872
M21MST7	795	461	236	1564
M21RBT1	1171	685	313	1884
M21GDJ1	790	465	194	1575
M21HFR1	1001	547	264	1689
M21BBG1	531	324	209	1004
M21MRX1	1378	779	352	2614
M21MRX2	685	399	201	1206
M21MRX3	769	441	209	1170
M21GXQ1	2357	1359	572	3240
M21MRC1	11377	6320	2597	24980
M21ZBR1	3033	1678	829	6517
M21XJR1	1421	763	354	2167
M21HMR1	1362	763	379	3190
M21ZJT1	548	336	173	929
M21ZBR2	2325	1275	582	4707
M21ZBR3	1792	1071	520	2789
G21QLA1	1328	720	345	2050
G21QLA2	1167	608	304	2248
G21QLA3	1039	590	287	1543
G21NDR1	1244	747	365	2228
G21NDR2	935	435	224	1874
G21RML1	1146	656	311	2470
G21XGR1	1317	684	354	2297
G21MRS1	2465	1341	653	4530
G21GRB2	1238	809	363	1709
G21GSR1	1966	1126	540	3640
G21GRB3	2521	1465	712	4003
G21KRC1	943	497	246	1847
G21SLW1	817	451	249	1611
G21MNX1	1452	812	446	2554
G21XLN1	3273	1839	838	7633
G21GJN1	4670	2639	1196	6260
M21IMG1	717	399	205	1300
M21IMG2	635	404	187	987
M21IMG3	942	532	266	1521
M21MST8	870	507	254	1539
M21STL1	1444	840	389	2260
M21SFI1	1258	731	352	2341
M21ZRQ1	730	441	239	1489
M21ZRQ2	1181	683	316	2003
M21ZRQ3	756	427	222	1306
M21ZRQ4	1251	718	365	2147
M21MQB1	1276	691	351	1956
M21GRG1	653	377	210	1218
M21PMR1	1378	792	388	2178

Table 14: *Conductivity results in soil paste, 1:1, 1:2 and 1:5.*

Sample Code	EC 1:1	EC 1:2	EC 1:5	EC SP
M21KLN1	967	588	318	1467
M21QRM3	843	696	345	2321
M21QRM4	3213	1798	796	7027
M21PLA1	754	407	206	1415
M21SGW1	990	602	294	2306
M21SGW2	652	356	191	1348
M21SGW3	1288	716	343	1760
M21QRN1	609	351	189	1473
M21ZBJ1	638	325	187	1453
M21RBT2	845	509	275	1403
M21BSK1	774	457	232	1616
M21DGL1	633	397	203	1228
M21RBT5	1143	621	334	2291
M21MTR1	474	425	174	1174
M21RBT3	1386	785	354	3563
M21RBT4	1233	745	354	2333
M21BHR1	1125	623	293	2014
M21BNG1	819	472	223	1219
M21SPB2	969	599	271	1579
M21SPB3	592	328	193	1137
M21SPB4	9280	4713	2018	12317
M21MLL1	1256	755	340	2468
M21MLL2	819	470	229	1512
M21MLL3	1144	630	295	2656
M21MLL4	1145	656	307	1787
G21SNT1	934	508	247	1278
G21RBT1	2927	1666	725	4617
G21RBT2	915	501	240	1652
G21RML2	582	351	169	1697
G21RML3	581	291	145	1521
G21RML4	660	366	187	1848
G21RML5	701	395	197	1773
G21XWK1	572	354	177	933

4.7.2 Salinity Modelling

Several attempts have been made to develop a model that allows for the conversion of soil electrical conductivity (EC) measured using different soil/water suspension methods to the standard soil paste method (Aboukila; Abdelaty, 2017). It has been found that these conversion factors are influenced by various soil properties, including texture, organic matter content, type of salts, and the concentration of salts themselves (P. G. Slavich; G. H. Petterson, 1993). However, no study has been conducted on soils from Malta to investigate this factor. This factor is of significance as it provides a quick measure of EC

(e). Measuring EC (e) is time-consuming and is not commonly performed in routine soil analysis.

The equations derived from the linear regression models of the log10-transformed EC data (n = 114) are illustrated in Figure 12 and Table 15. Strong correlations were observed between ECe and EC1:1 ($r^2 = 0.93$, $p < .001$), EC1:2 ($r^2 = 0.93$, $p < .001$), and EC1:5 ($r^2 = 0.91$, $p < .001$). It was found that different soil-to-water ratios influenced both the slope and intercept of the regression models, with increasing dilution resulting in higher slopes and intercepts, indicating that greater water content leads to higher dilution. This trend aligns with findings from previous studies (Table 15), which similarly reported increasing slopes and intercepts with higher dilution ratios.

All the studies mentioned in table 15 have a high correlation co-efficient, therefore they are all valid. Any differences as reported by various researchers in regression equations, may all be due to the soil's clay content and clay type (Sonmez et al., 2008), gypsum content (Khorsandi and Yazdi, 2007, 2011), type of salts present (Richard and Gouny, 1965; Le Brusq and Loyer, 1982), equilibration times and equilibration methods (He et al., 2013) and the ECe range of soil samples used to determine the conversion equations (Aboukila and Norton, 2017). Sonmez et al. (2008); and Franzen (2006) concluded that each soil type (coarse, medium or fine) should have a different correlation equation so that the conversion will be more accurate.

Given that soil texture influences the EC of soil-water suspensions (Hogg and Henry, 1984), soils were categorized into three textural groups: coarse-textured soils (n = 7) with ECe ranging from 1.136 to 8.77 dS m−1, medium-textured soils (n = 85) with ECe from 0.727 to 24.98 dS m−1, and fine-textured soils (n = 22) with ECe from 0.987 to 26.73 dS m−1. No significant difference in mean ECe was found among the groups ($p = .565$). Linear regression models were developed for each group, and the models specific to each soil-to-water ratio (Table 15) were compared with the general models derived from all 114 soil samples using analysis of covariance. Notably, the regression models for coarse-

textured soils differed significantly from both the general models and those of the medium and fine-textured soil groups. This difference is reflected in the slope and intercept values, with the coarse-textured soils exhibiting much higher values across all soil-to-water ratios, suggesting that the general models may underestimate ECe for sandy soils. However, the small sample size for coarse-textured soils (n = 7) may limit the reliability of this finding.

Study	N	Equation	r^2	RMSE dS m^{-1}	NSE
This study (All soil 1:5)	114	$EC_e = 10^{1.023*\log(EC1:5) + 0.838}$	0.91	0.93	0.96
	114	$EC_e = 10^{0.972*\log(EC1:2) + 0.515}$	0.93	0.87	0.97
This study (All soil 1:1)	114	$EC_e = 10^{0.945*\log(EC1:1) + 0.292}$	0.93	0.97	0.96
This study (Fine Textured Soil 1:5)	22	$EC_e = 10^{1.101*\log(EC1:5) + 0.801}$	0.96	1.07	0.95
This study (Fine Textured Soil 1:2)	22	$EC_e = 10^{1.048*\log(EC1:2) + 0.456}$	0.96	1.03	0.96
This study (Fine Textured Soil 1:1)	22	$EC_e = 10^{0.992*\log(EC1:1) + 0.231}$	0.96	1.16	0.94
This study (Medium Textured Soil 1:5)	85	$EC_e = 10^{1.043*\log(EC1:5) + 0.849}$	0.93	0.98	0.96
This study (Medium Textured Soil 1:2)	85	$EC_e = 10^{0.985*\log(EC1:2) + 0.521}$	0.94	0.85	0.97
This study (Medium Textured Soil 1:1)	85	$EC_e = 10^{0.960*\log(EC1:1) + 0.292}$	0.94	0.90	0.97
This study (Coarse Textured Soil 1:5)	7	$EC_e = 10^{1.261*\log(EC1:5) + 1.162}$	0.91	15.29	−3.23
This study (Coarse Textured Soil 1:2)	7	$EC_e = 10^{1.160*\log(EC1:2) + 0.729}$	0.93	7.19	−1.18
This study (Coarse Textured Soil 1:1)	7	$EC_e = 10^{1.131*\log(EC1:1) + 0.460}$	0.92	6.40	−0.73
This study (Carbonate 0–35% 1:5)	51	$EC_e = 10^{0.985*\log(EC1:5) + 0.796}$	0.88	1.18	0.94
This study (Carbonate 0–35% 1:2)	51	$EC_e = 10^{0.941*\log(EC1:2) + 0.488}$	0.90	1.22	0.94
This study (Carbonate 0–35% 1:1)	51	$EC_e = 10^{0.908*\log(EC1:1) + 0.271}$	0.90	1.44	0.91
This study (Carbonate 35–50% 1:5)	40	$EC_e = 10^{1.026*\log(EC1:5) + 0.834}$	0.95	0.93	0.96
This study (Carbonate 35–50% 1:2)	40	$ECe = 10^{0.977*\log(EC1:2) + 0.514}$	0.96	0.88	0.97
This study (Carbonate 35–50% 1:1)	40	$EC_e = 10^{0.968*\log(EC1:1) + 0.278}$	0.97	0.94	0.96
This study (Carbonate 50–80% 1:5)	23	$EC_e = 10^{1.009*\log(EC1:5) + 0.891}$	0.90	1.20	0.90
This study (Carbonate 50–80% 1:2)	23	$EC_e = 10^{0.95*\log(EC1:2) + 0.564}$	0.91	0.90	0.91
This study (Carbonate 50–80% 1:1)	23	$EC_e = 10^{0.914*\log(EC1:1) + 0.360}$	0.91	0.93	0.91
This study (OM 0–2.5% 1:5)	70	$EC_e = 10^{1.078*\log(EC1:5) + 0.884}$	0.90	1.42	0.92
This study (OM 0–2.5% 1:2)	70	$EC_e = 10^{1.005*\log(EC1:2) + 0.539}$	0.91	0.97	0.96
This study (OM 0–2.5% 1:1)	70	$EC_e = 10^{0.970*\log(EC1:1) + 0.314}$	0.91	0.86	0.97
This study (OM 2.5–4.2% 1:5)	44	$EC_e = 10^{0.995*\log(EC1:5) + 0.796}$	0.95	1.17	0.94
This study (OM 2.5–4.2% 1:2)	44	$EC_e = 10^{0.936*\log(EC1:2) + 0.486}$	0.96	1.26	0.93
This study (OM 2.5–4.2% 1:1)	44	$EC_e = 10^{0.963*\log(EC1:1) + 0.251}$	0.97	1.19	0.94
Aboukila and Abdelaty (2017)	-	$EC_e = 7.46*EC_{1:5} + 0.43$	0.97	1.19	0.94
Aboukila and Abdelaty (2017)	-	$EC_e = 5.04*EC_{1:5} + 0.37$	0.93	1.86	0.85
Chi and Wang (2010)	-	$EC_e = 11.68*EC_{1:5} - 5.77$	0.94	4.36	0.20
Franzen (2007)	-	$EC_e = 3.01*EC_{1:1} - 0.77$	-	3.5	0.48
Gharaibeh, Albalasmeh, and El Hanandeh (2021)	-	$EC_e = 8.467*EC_{1:5}$	0.83	1.67	0.88
Hogg and Henry (1984)	-	$EC_e = 2.75*EC_{1:1} - 0.69$	0.98	2.68	0.70
Kargas et al. (2018)	-	$EC_e = 6.53*EC_{1:5} - 0.11$	0.93	1.06	0.95
Kargas et al. (2018)	-	$EC_e = 1.83*EC_{1:1} + 0.117$	0.97	0.86	0.97
Khorsandi and Yazdi (2011)	-	$EC_e = 5.43*EC_{1:5} + 0.43$	0.95	1.52	0.90
Klaustermeier et al. (2016)	-	$EC_e = 10^{1.256*\log(EC1:5) + 0.766}$	0.91	1.4	0.92
Klaustermeier et al. (2016)	-	$EC_e = 10^{1.2533*\log(EC1:1) + 0.3533}$	0.97	6.40	−0.73
Ozcan et al. (2006)	-	$EC_e = 5.97*EC_{1:5} - 1.17$	0.94	2.21	0.79
Ozcan et al. (2006)	-	$EC_e = 1.93*EC_{1:1} - 0.57$	-	1.00	0.96
Park et al. (2019)	-	$EC_e = 8.70*EC_{1:5}$	0.90	1.86	0.85
Sonmez et al. (2008) (Sandy soil)	-	$EC_e = 8.22*EC_{1:5} - 0.33$	0.98	1.34	0.92
Sonmez et al. (2008) (Sandy soil)	-	$EC_e = 2.72*EC_{1:1} - 1.27$	0.99	2.36	0.77
Sonmez et al. (2008) (Loam)	-	$EC_e = 7.58*EC_{1:5} - 0.06$	0.99	1.09	0.95
Sonmez et al. (2008) (Loam)	-	$EC_e = 2.15*EC_{1:1} - 0.44$	0.99	1.07	0.95
Sonmez et al. (2008) (Clay soil)	-	$EC_e = 7.36*EC_{1:5} - 0.24$	0.99	0.96	096
Sonmez et al. (2008) (Clay soil)	-	$EC_e = 2.03*EC_{1:1} - 0.41$	0.99	0.92	0.96
USDA (1954)	-	$EC_e = 3.00*EC_{1:1}$	-	3.94	0.35
Visconti Reluy and De Paz (2012)	-	$EC_e = 5.70*EC_{1:5} - 0.20$	0.89	1.67	0.88
Zhang et al. (2005)	-	$EC_e = 1.79*EC_{1:1} + 1.46$	0.85	1.44	0.91

TABLE 15: RELATIONSHIP BETWEEN ECE AND EC1.5, EC1:2, EC1:1 FOR ALL THE SAMPLED SOIL (GENERAL MODEL) AND FOR SOIL GROUPED ACCORDING TO CONTRASTING CHARACTERISTICS (PARAMETER SPECIFIC MODEL), AND COMPARISON OF VALIDATION RESULTS FOR THIS STUDY AND STUDIES REPORTED BY OTHER RESEARCHERS.

For the medium and fine-textured soils, the general models closely matched the parameter-specific models, with no significant differences in any soil-to-water ratio. This outcome was expected, as the majority of the samples used to develop the general models came from medium and fine-textured soils. Nonetheless, the parameter-specific models demonstrated slightly higher r^2 values, potentially offering improved prediction for their respective texture classes. The differences between the coarse and medium/fine-textured models can likely be attributed to factors such as clay content, which affects ion retention and saturation percentage. Higher clay content results in greater ion retention and reduced dilution, while sandy soils, with lower ion retention, experience higher ion release into solution. Previous studies have similarly noted increasing slopes and intercepts with higher sand content (Chi and Wang 2010; Franzen 2007; Hossain et al. 2020; Sonmez et al. 2008).

The soils were further classified into three groups based on their carbonate content. The "low" carbonate content group (<35% carbonate; n = 51) had ECe values ranging from 0.929 to 12.32 dS m−1, the "medium" carbonate content group (35-50% carbonate; n = 40) had ECe values ranging from 0.872 to 26.73 dS m−1, and the "high" carbonate content group (>50% carbonate; n = 23) had ECe values ranging from 0.727 to 24.07 dS m−1. The mean ECe of the high carbonate group was significantly greater than that of the low carbonate group ($p = .023$).

The linear regression model equations (Table 15) and analysis of covariance showed that the models for soils with low and medium carbonate content were similar to the general model derived from all 114 soil samples for the various soil-to-water ratios. In contrast, the model for soils with high carbonate content differed significantly from the general model at the 1:5 and 1:1 soil-to-water ratios, though no significant difference was observed at the 1:2 ratio, despite some drift in the regression line at this ratio. The slopes and intercepts of the equations did not show large differences from the general models, particularly in the case of the medium carbonate group, where both the slope and intercept closely matched those of the general model.

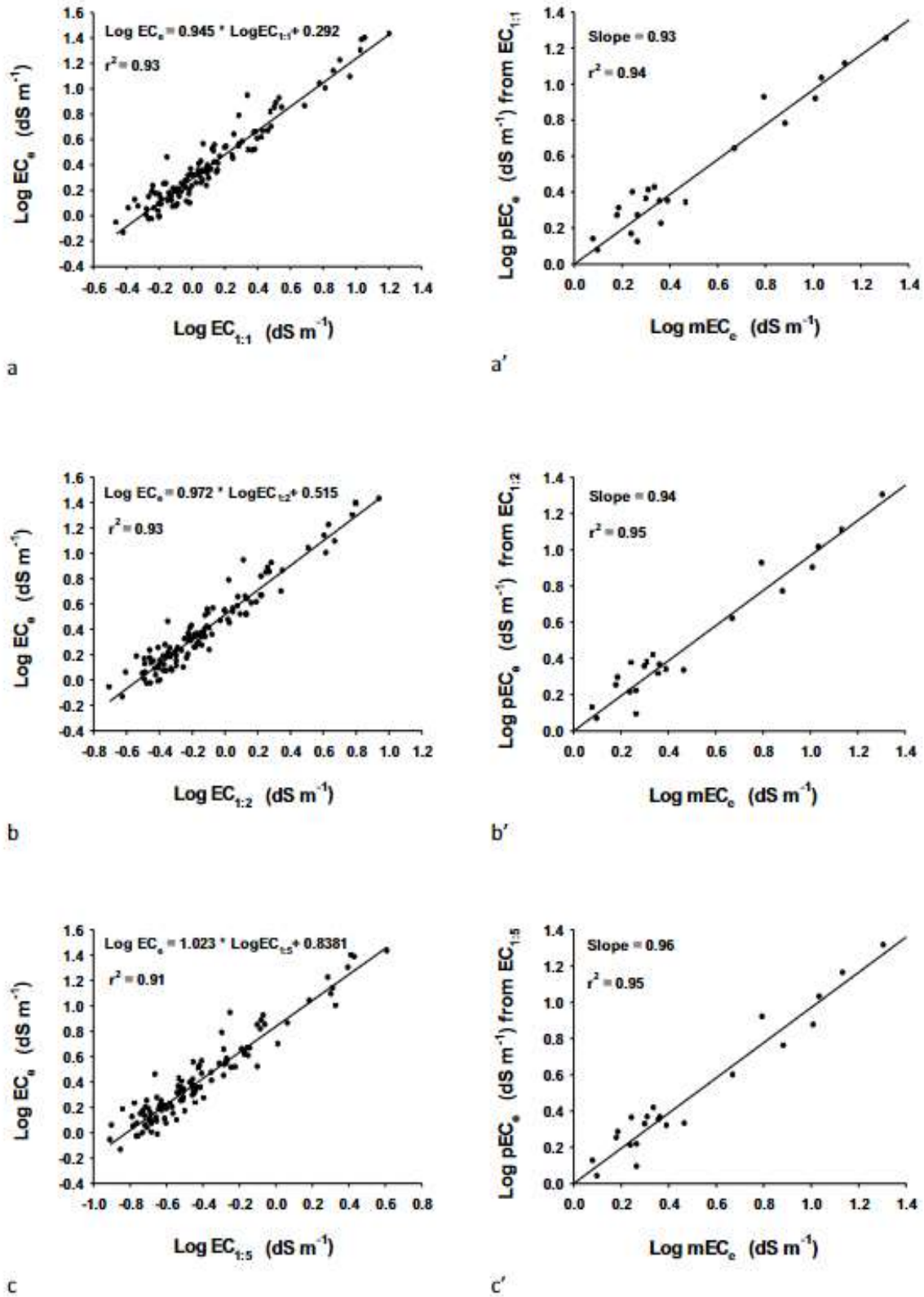


FIGURE 12: RELATIONSHIPS OF EC_E WITH THE $EC_{1:1}$(A), $EC_{1:2}$(B) AND $EC_{1:5}$(C), AND VALIDATION OF THE LINEAR REGRESSION EQUATIONS FOR EC_E VS $EC_{1:1}$(A'), EC_E VS $EC_{1:2}$(B') AND EC_E VS $EC_{1:5}$(C').

For soils with low carbonate content, the slopes were slightly lower, though the intercepts remained similar to the general model. For soils with high carbonate content, the slopes were also similar, but the intercepts were slightly higher, suggesting that the general model may underestimate EC soil to ECe conversions for soils with high carbonate content. This underestimation is less pronounced but analogous to the trend observed in sandy soils. This similarity may be explained by a positive correlation between sand and carbonate content, indicating that increased carbonate content may be associated with higher sand content.

To assess the potential influence of organic matter (OM) on the models, the soil samples were further divided into two groups based on their OM content. The "low" OM content group, which included soils with less than 2.5% OM (n = 70), had ECe values ranging from 0.727 to 24.98 dS m−1. The "high" OM content group, with OM levels between 2.5% and 4.2% (n = 44), had ECe values ranging from 0.928 to 26.73 dS m−1.

Although the mean ECe in the high organic matter (OM) content group was larger, the difference between the two groups was not statistically significant ($p = .51$). Linear regression model equations for each group (Table 15), along with an analysis of covariance, indicated that the models generated from soils with varying OM content closely resembled the general model derived from all 114 soil samples, regardless of soil-to-water ratios. Thus, within the range of salinity and soil types considered in this study, OM levels appear to have minimal impact on the model.

In this research, the electrical conductivity (EC) at the 1:5 soil-to-water ratio ranged from 124 µS/cm to 4093 µS/cm, consistent with findings from previous studies. ERA (2006) reported EC (1:5) values in the Maltese Islands ranging from <500 µS/cm to >1500 µS/cm, while Montanaro (2018) recorded values between 174 µS/cm and 1299 µS/cm. Similarly, Portelli (2015) found values between 190 µS/cm and 16,340 µS/cm. The

MALSIS report (2004) noted a range of 197 µS/cm to 2914 µS/cm, and Camilleri (2013) reported values between 170 µS/cm and 1001 µS/cm.

In terms of mean EC values, MEPA (2013) reported a mean EC (1:5) of 756 µS/cm, MALSIS (2004) found a mean of 545 µS/cm, and Camilleri (2013) recorded a higher mean of 2099 µS/cm. In contrast, the mean EC (1:5) observed in this study was 532 µS/cm. Additionally, Camilleri (1999) predicted a mean average EC value of 2703 µS/cm, whereas the mean average EC value recorded in this study was 4747 µS/cm. It is worth noting that, except for the MALSIS study, most of these previous studies were based on relatively small sample sizes, which may account for some of the observed variation in results.

4.7.3 Validation of equations.

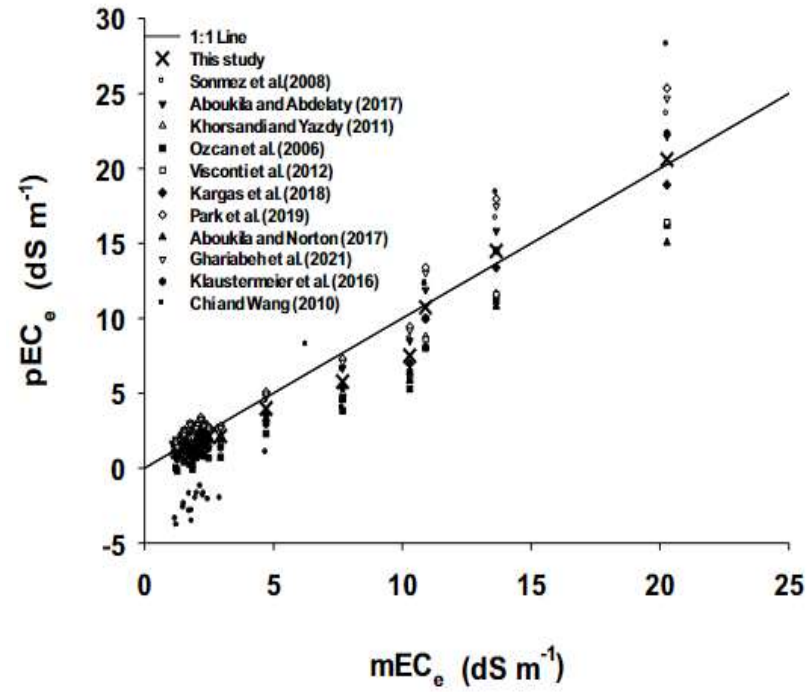
The general models were verified and validated using the measured ECe (mECe) of 22 independent soil samples that were not included in the development of these models. The characteristics of these 22 samples are presented in Table 14. Verification was conducted by comparing the predicted ECe (pECe), obtained from the general models, with the actual measured ECe (mECe) for these samples using a paired t-test and linear regression analysis. The mECe values were not significantly different from the pECe values ($p = .302$, .317, and .524 for EC1:1, EC1:2, and EC1:5, respectively). Linear regression of mECe against pECe for EC1:1, EC1:2, and EC1:5 yielded regression slopes close to 1, with r^2 values exceeding 0.96 (Figure 13).

Validation was further assessed using the root mean square error (RMSE) and Nash-Sutcliffe efficiency (NSE). An NSE value close to 1 indicates a model that perfectly matches the observed data, while smaller RMSE values suggest better model performance. The RMSE and NSE values are listed in Table 15, showing that the general models perform very well across all three soil-to-water ratios, with NSE values above

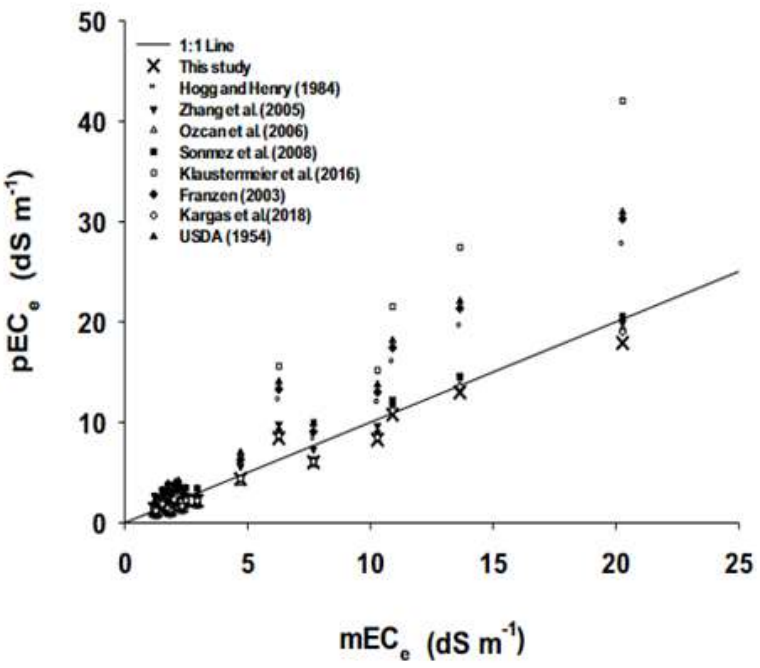
0.98 and RMSE values below 0.97 dS m−1. The 1:2 soil-to-water ratio appears to provide the best conversions, with NSE and RMSE values of 0.97 and 0.87 dS m−1, respectively.

The models developed for parameter-specific soil groups based on texture, carbonate content, and OM content were also validated using these methods. With the exception of the model for coarse-textured soils, the parameter-specific models performed well according to both NSE and RMSE. However, the general models performed better overall than most of the parameter-specific models, except for medium-textured soils at the 1:1 and 1:2 ratios, although the differences in NSE and RMSE were small. The higher RMSE and lower NSE values for the coarse-textured soils support the earlier observation that the small sample size (n = 7) likely affected the performance of the models for sandy soils.

The general models for the 1:1 and 1:5 soil-to-water ratios were also compared to models from other studies (Figure 13, Table 15). Due to limited data, the 1:2 model was not included in this comparison. The RMSE values of the models from this study were lower, and the NSE values were closer to unity, compared with other reported models. For the 1:5 ratio, the RMSE and NSE were comparable to those reported by Kargas et al. (2018), while for the 1:1 ratio, the results were similar to those of Sonmez et al. (2008) and Ozcan et al. (2006). However, the models reported by Chi and Wang (2010) for the 1:5 ratio, and by Klaustermeier et al. (2016), USDA (1954), and Franzen (2007) for the 1:1 ratio, were less accurate in predicting ECe for soils with these characteristics. These differences are likely due to variations in soil properties such as texture, salinity levels, and mineral composition, as well as differences in analytical methodologies. The similarity between the models in this study and those of Kargas et al. (2018) may be attributed to the fact that the soils studied originate from the Mediterranean region and share similar properties.



a



b

FIGURE 13: COMPARISON OF MODELS DEVELOPED BY OTHER RESEARCHERS WITH THOSE DEVELOPED FROM THIS STUDY. THE MEASURED VALUES ARE FROM 22 SOIL SAMPLES SELECTED AT RANDOM FROM THE 136 SAMPLED SOILS. FIG A REFERS TO $EC_{1:5}$, AND FIGURE B REFERS TO $EC_{1:1}$.

4.8 Soil results overview and comparisons

In this study, Spearman rank correlation was used to assess the relationships between electrical conductivity (ECe), EC at different soil-to-water ratios (EC1:1, EC1:2, EC1:5), and soil properties such as sand, silt, clay, organic matter (OM), and carbonate content as visible in tables 16 and 17. Linear regression was further employed to examine the relationship between ECe and EC at various dilutions, using 114 randomly selected soil samples as shown. Since the data were not normally distributed, a log10 transformation was applied to satisfy the assumptions of linear regression. To investigate whether soil texture, carbonate content, and OM influenced the ECe-EC relationship, additional linear regressions were conducted after grouping the data based on texture, carbonate content, and OM levels.

TABLE 16: DESCRIPTIVE STATISTICS OF THE SALINITY, TEXTURE, OM AND CARBONATE CONTENT OF THE SOILS USED IN THIS STUDY.

	EC_e (dS m^{-1})	$EC_{1:1}$ (dS m^{-1})	$EC_{1:2}$ (dS m^{-1})	$EC_{1:5}$ (dS m^{-1})	OM %	Carbonate %	Sand %	Silt %	Clay %
Mean	3.75	1.96	1.12	0.53	2.3	38.8	37.6	35.5	26.9
Median	2.13	1.13	0.66	0.31	2.2	36.1	33.0	34.5	27.5
Max	26.73	16.03	8.78	4.09	4.2	80.6	100.0	74.4	61.
Min	0.73	0.35	0.20	0.12	0.0	1.1	5.0	0.0	0.0
n	114	114	114	114	114	114	114	114	114

TABLE 17: SPEARMAN RANK ORDER CORRELATION BETWEEN EC_E AND SAND, SILT, CLAY, OM AND CARBONATE CONTENT.

	Sand	Silt	Clay	OM	Carbonate	EC_e
Sand	1.00	***−0.705	***−0.610	*−0.235	*** 0.516	0.134
Silt		1.00	0.0419	***0.306	*−0.225	−0.0202
Clay			1.00	*0.218	***−0.419	−0.152
OM				1.00	*−0.194	**0.269
Carbonate					1.00	*0.216
EC_e						1.00

*** denotes ($p < .001$), ** denotes ($p < .01$), * denotes ($p < .05$).

The accuracy of the regression models was validated using the remaining 22 soil samples not included in the initial model development. Model performance was evaluated using root mean square error (RMSE) and Nash-Sutcliffe efficiency (NSE) (figure 14). These models were also compared to similar models developed by other researchers. Statistical analyses were conducted using Sigma Plot software using the equations below.

$$RMSE = \sqrt{\frac{1}{N}\sum_{m=1}^{N}(mEC_e - pEC_e)^2}$$

$$NSE = 1 - \frac{\sum_{m=1}^{N}(mEC_e - pEC_e)^2}{\sum_{m=1}^{N}(mEC_e - m`EC_e)^2}$$

FIGURE 14: ROOT MEAN SQUARE ERROR (RMSE) AND THE NASH-SUTCLIFFE PREDICTION EFFICIENCY (NSE) EQUATIONS.

The soils sampled were primarily calcareous with low OM content. Most of the soils were classified as Calscisols, although other soil types, such as Regosols, Leptosols, Luvisols, Vertisols, and Cambisols, were also present. More than 57% of the soils had clay content above 25%, and the USDA classification indicated a predominance of medium to fine-textured soils, particularly clay loam (33%), loam (16%), and clay (14%). These findings are consistent with previous studies on island soils (Lang, 1960).

Salinity levels across the samples varied significantly, with approximately 45% of the soils having an ECe below 2.0 dS m^{-1}, 33% between 2.0 and 4.0 dS m^{-1}, and 22% exceeding 4.0 dS m^{-1}. Notably, 8% of the samples had an ECe greater than 10 dS m^{-1}. The mean ECe was significantly higher than EC values at each dilution ratio, being 1.9, 3.4, and 7.1 times greater than EC1:1, EC1:2, and EC1:5, respectively ($p < .001$), indicating a strong dilution effect as water content increased. This phenomenon has been noted in previous studies (Hogg & Henry, 1984; Kargas et al., 2018; Ozcan et al., 2006), though with slightly different dilution ratios.

The results revealed moderate positive correlations between carbonate content and sand ($rs = 0.516$, $p < .001$) and weak negative correlations with clay ($rs = -0.419$, $p < .001$) and silt ($rs = -0.225$, $p < .05$). Organic matter displayed a weak negative correlation with sand ($rs = -0.235$, $p < .05$) and weak positive correlations with silt and clay ($rs = 0.306$, $p < .001$). These findings align with previous studies, which suggest that soils with higher clay content typically retain more organic matter due to slower decomposition rates and

better aggregate formation (Rice, 2002). Coarse-textured soils, such as sandy soils, generally exhibit lower OM content, two to four times lower than fine-textured soils under similar conditions (Prasad & Power, 1997).

However, despite these trends, no significant correlation between ECe and the levels of sand, silt, and clay was observed, nor were significant differences in EC found across contrasting textural classes ($p = .465$). Weak positive correlations were detected between EC and both carbonate ($r_s = 0.216$, $p < .05$) and OM content ($r_s = 0.269$, $p < .05$). These results suggest that salinity in these soils is not primarily governed by physical properties like texture. Instead, external factors such as agricultural management, irrigation practices, low precipitation, high evapotranspiration, and proximity to the coast may play more significant roles.

Organic matter levels, when plotted against sand and clay content, showed no significant correlation, indicating that factors other than texture, such as tillage practices and erosion, may be limiting OM accumulation. As noted by Angers, Dayegamiye, and Cote (1993) and Six, Elliot, and Paustian (2000), intensive cultivation, especially tillage, can rapidly reduce topsoil OM by enhancing decomposition through increased carbon dioxide emissions. Additionally, topography and erosion exacerbate the loss of organic matter, particularly in highly exposed soils lacking protective cover (Jones et al., 2004). Thus, local soil management practices and environmental factors seem to have a more pronounced impact on OM levels than texture alone.

Conclusion

5. Conclusion

The findings show that the studied soils' salt levels varied significantly, with an average of 3772 µS/cm. Of the various soils that were examined, 104 were found to have an electrical conductivity(e) of less than 4,000 µS/cm, making them non-saline. Other parameters, including texture, carbonate content, OM, pH, metal concentration, and SAR, were examined in addition to salinity; however, no clear correlations or significant dependences were found to directly affect salinity concentrations.

The results of this study demonstrate that the developed general models can reliably estimate the electrical conductivity of the soil saturation extract (ECe) from measurements of electrical conductivity at soil:water suspension ratios of 1:1, 1:2, and 1:5 for the calcareous soils of Malta. While all soil:water ratios provide a reasonable degree of accuracy, statistical indicators such as the regression coefficient, Root Mean Square Error (RMSE), and Nash-Sutcliffe Efficiency (NSE) suggest that the 1:2 soil:water ratio offers the most precise estimation of ECe.

The models are effective across soils of medium and fine texture, as differences between their regression equations were not statistically significant. However, when applied to soils with high sand content, the models tend to underestimate ECe. Such sandy soils are uncommon in the Maltese Islands, primarily confined to a small, cultivated region on the island of Gozo. The majority of soils in the main islands belong to loam, clay loam, and clay textural classes, for which the models are well suited. Furthermore, the study found that variations in carbonate and organic matter (OM) content exert minimal influence on the models, given that parameter-specific equations closely resemble the general models. This indicates that the developed models can be broadly applied across soils with varying carbonate and OM levels.

To provide a more comprehensive understanding of soil salinity and sodicity, this study also incorporated the Sodium Adsorption Ratio (SAR) and metal content analyses. In particular, the developed general model can estimate the concentrations of key metal ions Na^{+}, Ca^{2+}, Mg^{2+}, and K^{+} in the soil saturation extract (ECe) using measurements from soil:water suspensions at ratios of 1:1, 1:2, and 1:5. Including SAR data allowed for better assessment of sodicity risks, while metal ion concentration estimates provided valuable insight into soil chemistry and potential salinity-related impacts. Together, these complementary parameters enhance the robustness of the models and offer a more holistic evaluation of soil quality in Maltese calcareous soils.

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Appendices

7.0 Appendices

7.1 Appendix: 1 Methods

Preparing samples for particle size analysis (Hydrometer Method).

Principle:

Separation of the mineral part of the soil into various size fractions and determination of the proportion of these fractions. The analysis comprises all material, i.e. including gravel and coarser material but the procedure below is applied to the fine earth (< 2mm) only.

Of paramount importance in this analysis is the pretreatment of the sample aimed at complete dispersion of the primary particles. Therefore, cementing materials (usually of secondary origin) such as organic matter and calcium carbonate may have to be removed. It may be argued, however, that for agricultural purposes it is often not relevant or fundamentally wrong to remove these components. Thus, depending on the aim of the study, all pretreatments are to be considered optional. For soil characterization purposes, in the ISRIC laboratory removal of organic matter by H202 and of carbonates by HCI is routinely carried out.

After shaking with a dispersing agent, sand is separated from clay and silt with a 50 μm sieve. The sand is fractioned by dry sieving, the clay and silt fractions are determined by the pipette method or, alternatively, by the hydrometer method.

Apparatus

Equipment required to prepare the samples:

- Water bath (glass container)
- Hot plate
- End over end shaking machine
- Set of sieves, including bottom (diameter 20cm) on stand
- Heavy brass funnel (diameter approx. 23cm) on stand
- Small 50 μm sieve (diameter 8cm)

- Glass sedimentation cylinders, marked at 1 litre
- Drying oven
- Moisture tins
- Stopwatch

Reagents

Hydrogen peroxide, 30%

Dispersing agent: Sodium hexametaphosphate 4% and soda 1% solution ("Calgon" type). Dissolve 40.0g (NaPO3)6 and 10.0g Na2CO3 in water in a 1 litre volumetric flask and make to volume. Both chemicals should be dried overnight at 105 °C prior to use (therefore, hydrated soda qualities may be used).

Calcium chloride solution, 1 M (=mol/l) Dissolve 147g CaCI2.2H2O in 1 litre water.

Procedure

Oxidation of Organic Matter

1. Weigh out approx. 30g fine earth into a 1 litre beaker (at carbonate contents exceeding 10% and carbonate is to be removed, weigh out proportionally more soil).

2. Add 15 ml water and 15 ml H202, 30%. Cover beaker with watch glass. In case of strong frothing place beaker in basin with cold water. In addition, frothing can be tempered by adding a few drops of ethanol.

3. Let stand overnight.

4. The next day, place beaker on water bath (80 °C) and regularly add 5 to 10 ml increments of H202 30% until decomposition of organic matter is completed (usually the supernatant is clear then).

5. Add water to a volume of about 300ml.

6. Place on hot plate and carefully boil for 1 hour to remove any remaining H202.

7. Remove beaker from hot place and allow to cool.

8. Centrifuge and decant or, alternatively, allow material to settle in the beaker and siphon off.

9. If EC supernatant solution is higher than 0.4mS/cm, add about 250ml water, cap centrifuge tube and shake in end over end shaker for one hour (or stir from time to time for one hour) and repeat steps 8 and 9 until EC of supernatant solution < 0.4mS/cm.

Removal of carbonate

Reagent

Hydrochloric acid, 1 M Add 36 ml conc. HCI to 900 ml water and make to 1 l with water (use fume cupboard).

Procedure

1. After removal of organic matter, add 25ml HCI 1 M plus 4 ml of the same for each percent of carbonate in the soil (if about 20 g of sample was used). If proportionally more soil was used, calculate weight of carbonate in sample and add 25 ml HCI 1 M plus 1 ml of the same for each 50 mg of carbonate. If carbonate is less than 2% then only an initial 25 ml of the acid is required (if in this case flocculation is not adequate, add 20 ml 1 M CaCI2 solution). Make up to about 250 ml with water.

2. Place suspension on water bath at approx. 80 °C for about 15 min., stirring from time to time.

3. Remove suspension from water bath and leave to stand overnight.

4. If the soil flocculates to leave a perfectly clear supernatant, then this can be siphoned off or decanted, otherwise centrifugation will be necessary.

5. Repeat washing with water and siphoning off or decantation until EC of supernatant < 0.4 mS/cm.

Dispersion

1. Transfer suspension quantitively to a 1 l polythene bottle (if no pretreatment is given, weigh out approx. 20 g fine earth into this bottle).

2. Add 20.00ml dispersing agent, make the volume to about 400 ml with water and cap the bottle.

3. Shake overnight (16 hrs) on an end over end shaker at a speed of about 30 rpm.

Separation of fractions

1. Pass the suspension through a 50 μm sieve which is placed in a funnel positioned above a sedimentation cylinder with a stand and clamp. Use a wide (3cm) rubber policeman.

2. Make to 1 litre mark with water.

3. Wash the sand fraction remaining on the sieve quantitively into a porcelain dish, evaporate on water bath and dry at 105 °C for at least an hour.

Walkley and Black Titration Method

Source: Head K. H. Manual of Soil Laboratory Testing. Vol. 1 ELE International Ltd 1984

Dichromate Oxidation Method (BS 1377:1975, Test 8)

This method was first introduced by Walkley and Black in 1935. It has been found to give reproducible results.

Apparatus

- Balance accurate to 0.001g.
- Two 1 litre volumetric flasks.
- Two 25 ml burettes, graduated to 0.1 ml, and stands.
- 10 ml pipette with rubber teat.
- 1 ml pipette with rubber teat.
- 5 500 ml conical flasks.
- Graduated measuring cylinders, 200 ml and 20 ml.
- Glass weighing bottle.
- Sieves, 10 mm, and 0.425 mm.
- Pestle and mortar.
- Wash bottle with distilled water.
- Drying oven 105 to 110 ℃ and desiccator.
- Riffle box, small (300 cm3).

Reagents

1. Potassium dichromate, 1N solution. Dissolve 49.035g potassium dichromate in distilled water to make 1 litre of solution.

2. Sulphuric acid, 0.5N solution. Add 14 ml of concentrated sulphuric acid to distilled water to make 1 litre of solution.

3. Sulphuric acid concentrated (SG 1.84).

4. Ferrous sulphate, approximately 0.5 N solution.
Dissolve 140 g of ferrous sulphate in 0.5 N sulphuric acid to make 1 litre of solution. This solution is unstable in air and should be kept tightly stoppered. It should be standardised against dichromate solution weekly.
5. Orthophosphoric acid, 85% (sg 1.70 – 1.75).

6. Indicator solution. Dissolve 0.25 g of sodium diphenylamine sulphonate in 100 ml distilled water.

Procedure

A. Standardisation of ferrous sulphate solution

1. Run 10 ml of the 1N potassium dichromate solution from the burette into a 500 ml conical flask.
2. Very carefully add 20 m concentrated sulphuric acid. This will generate heat. Swirl the mixture and allow to cool, standing on a heat insulating surface or pad. Protect from droughts.
3. Add 200 ml of distilled water.
4. Add 10 ml of orthophosphoric acid and 1 ml of indicator and mix thoroughly.
5. Add ferrous sulphate from the burette in increments of 0.5 ml, swirling the flask, until the colour changes from blue to green.
6. Add a further 0.5 ml of potassium dichromate, changing the colour black to blue.
7. Add ferrous sulphate drop by drop, with continued swirling, until the colour changes from blue to green after the addition of a single drop. Record the total volume of ferrous sulphate used, x, to the nearest 0.05 ml.

B. Preparation of Sample

This part has been modified to suit the nature of the soil as described before.

1. The bulk sample is oven dried at 105-110 ℃ cooled in a desiccator and weighed to an accuracy of 0.1% (m1).

2. Sieve on a 10 mm sieve and crush all particles, other than stones, to pass the sieve.

3. Weigh the mass passing to an accuracy of 0.1% (m2). Take great care not to lose any fines.

4. Reduce the sample by successive riffling to a sample of about 100g.

5. To eliminate sulphides, add dilute sulphuric acid (2N) until no further evolution of hydrogen sulphate occurs, then wash with water. Oven dry before proceeding further.

6. To remove chlorides, wash the soil with distilled water until no turbidity is observed when a drop of the wash water is tested with silver nitrate. Oven dry before proceeding further.

7. Pulverise the sample before with pestle and mortar so that it passes the 425 μm sieve.

8. Subdivide further until a sample weight of about 5 g is obtained. Mix thoroughly and avoid segregation.

9. Place the sample in a glass weighing bottle and dry in an oven set at 105 – 120 ℃.

10. Cool in a desiccator, and weigh to 0.001 g (m5).

11. Transfer a small quantity for the test to a clean dry conical flask, without losing any fines. The quantity to be transferred will range from about 5 g for a soil low in organic matter to as little as 0.2 g for very peaty soils.

12. Weigh the weighing bottle again (m_6), and calculate the mass of sample transferred (m_3) by difference:

$$m_3 = m_5 – m_6$$

The above method has been altered in the following way:

1. Another sieve, 2 mm, was also used.

2. Gravel greater than 2 mm was not pulverised.

3. Aggregate fraction and gravel fraction in each sieve was weighed.

4. A 500 μm sieve was used instead of a 425μm sieve as the latter was not available.

5. The final pulverised quantity used for analysis was greater than 5 g, as five replicas were used for the test.

A more detailed account is given under materials and methods.

C. Testing for Organic Matter

1. Run 10 ml of 1 N potassium dichromate into the conical flask from the burette.

2. Very carefully add 20 ml of concentrated sulphuric acid from a measuring cylinder.

3. Swirl the mixture for one minute and stand it on an asbestos or the organic matter to proceed. Protect the flask from draught.

4. Add 200 ml of distilled water.

5. Add 10 ml of orthophosphoric acid and 1 ml of indicator and shake thoroughly. If the indicator is absorbed by the soil add a further 1 ml of indicator and shake.

6. Add ferrous sulphate from the bottle in increments of 0.5 ml, and swirl the flask, until the colour of the solution changes from blue to green.

7. Add a further 0.5 ml of potassium dichromate, changing the colour back to blue.

8. Add ferrous sulphate drop by drop from a burette, with continued swirling, until the colour changes from blue to green after the addition of a single drop. Record the total volume of the ferrous sulphate used, *y*, to the nearest 0.05 ml. This volume will be between 5 ml and 8 ml if the correct quantity of material was taken for the test.

D. Calculation

Calculate the total volume, V ml of potassium dichromate used to oxidise the organic matter from the equation:

$$V = 10.5\ x\ (1 - y/x)$$

y = Total volume of ferrous sulphate used
x = Total volume used in standardisation

E. Results

1. Report the results as percentage organic matter content, determined by dichromate oxidation method, to the nearest 0.1 % of the original mass of oven dry soil.

7.2 Appendix: 2 Raw Data

Raw data metals concentration (Ca, K, Mg and Na).

Ca concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20RBT1	53.0	21.8	23.0	22.5
M20MST1	158.3	69.8	60.1	33.2
M20MST2	313.7	218.0	153.1	56.9
G20SLW1	516.3	392.2	168.5	86.8
G20SLW2	229.7	97.4	65.3	30.8
G20SLW3	507.0	314.2	272.5	103.5
G20SLW4	127.7	37.6	23.8	25.3
M20BRM2	87.3	27.0	31.7	16.1
M20QRM2	261.3	135.6	77.2	42.4
M20ZJT1	84.3	49.2	31.6	27.9
M20QRM3	213.7	99.6	74.5	25.3
M20QRM4	167.0	98.4	77.4	32.1
M20QRM5	1640.7	728.2	380.5	138.5
M20QRM6	68.0	33.0	29.2	26.1
M20MLL2	76.0	24.4	19.7	24.2
M20RBT3	58.7	48.8	36.9	22.2
M20RBT4	54.3	40.4	30.5	16.2
M20BRM1	63.7	36.8	42.1	19.4
M20QRM7	132.0	52.4	38.4	21.6
M20QRM9	202.3	104.6	91.8	44.7
M20QRM10	763.7	284.6	174.0	67.7
M20QRM11	266.3	86.8	58.6	26.9
M20QRM12	246.7	118.8	84.3	39.3
M20QRM13	1619.7	707.4	352.7	132.9
G20RML1	125.0	46.0	31.7	17.6
G20RML2	115.3	22.2	16.7	12.6
G20RML3	33.3	9.2	11.1	12.9
G20RML4	175.7	128.2	93.3	30.7

Ca concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
G20RML5	78.7	31.4	24.1	15.6
G20RML6	194.3	95.6	48.7	29.8
M20MLL3	61.3	27.8	20.6	15.7
M20MLL4	381.0	77.8	50.6	29.7
M20MLL5	218.7	57.2	49.3	21.1
M20DGL1	351.3	189.8	146.5	51.1
M20MLL6	86.0	34.2	29.5	15.7
M20QRM15	1619.7	828.2	444.3	149.9
M20QRM16	523.7	191.8	119.7	53.7
M20QRM17	750.7	516.6	377.9	157.1
G20RBT3	89.3	30.8	44.1	24.4
M21MST1	76.7	40.2	32.4	22.1
M21MST2	1724.3	975.8	500.7	177.9
M21MST4	138.7	74.2	50.3	36.2
M21MST5	113.0	52.8	43.1	30.3
M21SPB1	119.3	68.8	54.9	29.9
M21QRM1	232.0	97.8	72.4	37.9
M21QRM2	158.7	85.8	62.3	36.5
M21WRD1	372.7	296.4	182.0	86.1
M21MST6	32.3	14.0	16.5	18.1
M21MST7	92.7	44.6	32.0	19.9
M21RBT1	127.0	79.0	59.9	30.7
M21GDJ1	159.3	52.0	36.1	29.5
M21HFR1	178.7	58.2	38.8	26.7
M21BBG1	112.3	35.2	27.3	17.5
M21MRX1	247.3	72.4	51.9	41.0
M21MRX3	88.7	34.4	27.2	23.0
M21GXQ1	387.0	148.8	103.7	43.9
M21MRC1	1920.7	627.4	336.2	116.9
M21ZBR1	549.7	129.6	81.3	40.3
M21XJR1	221.3	74.8	50.6	27.1
M21HMR1	444.0	103.8	58.1	34.6
M21ZJT1	83.3	25.2	21.5	18.3

Ca concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21ZBR3	397.7	140.6	103.5	42.0
G21QLA2	240.0	66.6	46.7	29.5
G21NDR1	270.0	75.4	58.8	29.5
G21NDR2	168.0	70.0	49.5	39.9
G21XGR1	386.0	120.8	77.8	36.5
G21MRS1	371.7	104.2	70.0	36.8
G21GRB2	151.7	63.8	55.1	26.4
G21GSR1	307.3	83.2	59.6	36.5
G21GRB3	528.0	181.6	130.0	55.6
G21SLW1	150.7	41.4	34.2	25.2
G21MNX1	216.3	61.0	42.8	32.4
G21XLN1	682.7	179.6	96.2	39.1
M21IMG1	112.3	40.0	29.0	29.5
M21IMG2	90.0	39.4	28.4	19.5
M21MST8	190.0	71.4	41.0	24.7
M21STL1	234.7	98.8	57.3	25.3
M21SFI1	224.0	79.8	43.3	26.8
M21ZRQ1	161.0	64.4	28.3	24.6
M21ZRQ3	179.7	62.2	37.0	23.5
M21ZRQ4	274.0	84.2	68.1	44.1
M21MQB1	218.3	90.4	50.7	30.9
M21GRG1	149.7	57.4	36.6	24.3
M21KLN1	121.0	61.6	38.5	24.7
M21QRM4	583.7	159.6	82.5	35.3
M21PLA1	168.0	62.8	37.6	31.2
M21SGW1	249.7	68.0	42.9	27.0
M21QRN1	177.3	48.8	33.3	33.3
M21ZBJ1	186.3	48.6	29.5	29.5
M21RBT2	144.3	57.2	36.4	30.3
M21BSK1	214.3	67.6	43.1	32.1
M21DGL1	120.7	40.6	26.0	18.8
M21MTR1	150.0	44.0	44.7	22.1
M21RBT3	335.3	86.6	54.1	33.9

Ca concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21RBT4	215.0	90.8	53.6	26.5
M21BHR1	192.0	74.6	40.9	27.8
M21BNG1	135.3	61.8	40.3	25.3
M21SPB2	165.3	64.0	44.4	21.9
M21SPB3	123.0	47.0	37.3	24.7
M21SPB4	957.3	381.0	212.4	90.0
M21MLL1	264.7	76.8	62.2	29.0
M21MLL2	184.0	71.0	52.1	27.8
M21MLL3	214.3	49.6	46.5	37.4
M21MLL4	184.3	79.2	62.6	30.1
G21SNT1	130.7	66.0	51.1	29.2
G21RBT1	428.0	148.2	130.9	47.7
G21RBT2	203.7	65.0	47.7	29.5
G21RML2	276.7	37.2	38.4	23.5
G21RML3	172.0	42.4	38.8	19.8
G21RML5	177.0	47.2	39.8	26.7
G21XWK1	89.0	35.8	35.3	34.0
M20RBT2	985.3	509.6	287.0	78.1
M20QRM8	918.0	451.4	253.5	112.5
M21SGW2	162.0	53.0	29.5	22.9
M20QRM1	763.7	284.6	174.0	67.7
M20BRM1	63.7	36.8	42.1	19.4
M20TFF1	186.7	61.2	42.4	27.1
M20MLL1	606.0	230.8	139.3	61.1
M20QRM14	1726.3	909.2	497.5	172.9
M21MST3	63.7	35.6	32.4	30.8
M21MRX2	135.7	48.0	39.5	27.5
M21ZBR2	435.0	112.8	74.9	32.1
G21QLA1	196.3	68.2	54.4	33.7
G21QLA3	127.0	50.8	35.3	20.1
G21RML1	418.7	98.8	69.8	38.0
G21KRC1	164.0	44.8	33.6	30.3
G21GJN1	280.3	141.8	71.9	34.6

Ca concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21IMG3	140.0	56.8	37.3	23.5
M21ZRQ2	192.0	79.4	45.8	27.5
M21PMR1	195.7	62.6	47.6	28.4
M21QRM3	246.7	56.2	54.0	41.7
M21SGW3	189.3	91.0	50.7	31.5
M21RBT5	346.3	127.0	69.0	46.0
G21RML4	199.3	48.0	44.3	22.2

Na concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20RBT1	51.3	14.6	5.6	6.7
M20MST1	29.0	9.0	4.1	3.7
M20MST2	88.0	50.0	21.3	11.1
G20SLW1	475.7	233.0	108.2	49.1
G20SLW2	221.7	138.4	69.8	42.7
G20SLW3	103.0	41.4	20.9	10.4
G20SLW4	323.0	68.8	33.2	17.7
M20BRM2	84.3	39.0	28.8	16.3
M20QRM2	125.3	71.0	36.4	20.5
M20ZJT1	75.7	37.0	20.2	16.9
M20QRM3	143.0	73.2	42.2	20.8
M20QRM4	130.3	13.2	5.3	4.5
M20QRM5	3091.3	1360.2	671.1	287.4
M20QRM6	48.7	15.4	7.0	5.1
M20MLL2	152.7	60.0	31.3	17.2
M20RBT3	70.7	44.2	23.2	15.3
M20RBT4	60.0	27.6	16.3	10.3
M20BRM1	28.3	15.6	3.0	7.1
M20QRM7	126.7	64.2	36.9	20.1
M20QRM9	160.0	41.6	29.9	15.1
M20QRM10	151.7	57.0	27.9	13.7

Na concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20QRM11	116.0	49.8	26.2	13.9
M20QRM12	110.3	46.6	20.9	13.5
M20QRM13	270.3	119.2	54.0	28.9
G20RML1	164.3	72.2	38.0	19.7
G20RML2	1635.3	375.2	191.3	82.3
G20RML3	169.3	53.2	21.2	12.7
G20RML4	62.0	23.2	4.9	5.1
G20RML5	58.7	18.6	8.3	5.7
G20RML6	342.3	168.0	76.4	34.8
M20MLL3	175.3	74.6	47.3	27.1
M20MLL4	522.3	144.6	70.8	34.7
M20MLL5	303.0	114.8	85.6	41.6
M20DGL1	107.3	47.6	22.0	12.5
M20MLL6	135.0	87.2	51.8	30.5
M20QRM15	2429.3	1072.2	558.3	225.5
M20QRM16	151.3	72.0	31.6	18.5
M20QRM17	757.0	414.0	226.6	108.4
G20RBT3	98.3	34.5	33.5	21.0
M21MST1	55.3	24.4	12.7	10.9
M21MST2	3531.0	1952.2	990.6	55.7
M21MST4	230.3	137.0	74.6	47.7
M21MST5	173.0	86.8	49.3	25.1
M21SPB1	100.3	52.2	32.0	48.3
M21QRM1	41.3	14.8	4.8	4.7
M21QRM2	115.0	64.2	34.9	20.9
M21WRD1	83.0	38.0	16.0	10.4
M21MST6	71.3	26.2	13.5	10.1
M21MST7	92.3	53.0	26.0	15.3
M21RBT1	58.3	38.6	22.8	12.9
M21GDJ1	106.0	60.4	29.5	17.2
M21HFR1	101.3	64.0	33.3	18.9
M21BBG1	40.7	29.2	13.7	10.9
M21MRX1	207.0	128.6	64.2	33.4

Na concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21MRX3	119.3	89.2	50.2	28.3
M21GXQ1	155.7	108.0	54.4	27.4
M21MRC1	3633.3	1615.4	838.6	353.3
M21ZBR1	784.3	346.6	186.4	104.1
M21XJR1	186.0	99.6	54.5	30.4
M21HMR1	143.0	55.6	21.6	14.6
M21ZJT1	78.3	42.4	21.5	15.7
M21ZBR3	140.3	73.8	39.6	21.9
G21QLA2	91.7	43.2	21.2	13.7
G21NDR1	114.3	51.0	26.7	16.9
G21NDR2	52.3	24.0	9.0	6.9
G21XGR1	36.0	21.6	9.2	7.5
G21MRS1	454.7	250.4	131.1	67.9
G21GRB2	86.0	57.2	33.8	18.9
G21GSR1	258.0	146.0	79.8	42.5
G21GRB3	182.0	101.6	54.7	28.7
G21SLW1	124.0	68.2	37.4	25.2
G21MNX1	154.3	87.6	48.4	29.7
G21XLN1	731.7	338.2	187.4	93.7
M21IMG1	90.3	51.6	28.0	19.1
M21IMG2	68.7	48.2	29.1	18.1
M21MST8	85.0	55.2	28.5	21.1
M21STL1	61.3	35.8	18.0	10.5
M21SFI1	111.7	65.2	33.8	19.7
M21ZRQ1	91.0	61.3	24.1	73.9
M21ZRQ3	76.7	41.6	21.0	34.2
M21ZRQ4	113.7	86.0	50.4	30.2
M21MQB1	95.3	64.2	28.4	78.5
M21GRG1	52.3	36.6	16.1	12.2
M21KLN1	77.7	63.0	30.9	21.5
M21QRM4	899.3	440.0	240.7	124.7
M21PLA1	78.3	59.2	24.6	18.5
M21SGW1	78.7	34.8	16.3	10.1

Na concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21QRN1	72.3	35.6	17.8	13.0
M21ZBJ1	98.3	48.6	20.4	15.3
M21RBT2	83.0	61.0	31.2	77.9
M21BSK1	61.3	30.2	13.1	8.8
M21DGL1	81.7	60.4	31.6	20.9
M21MTR1	34.3	20.4	12.4	7.1
M21RBT3	289.3	129.2	63.3	30.2
M21RBT4	157.0	99.4	49.7	26.7
M21BHR1	147.7	100.8	47.3	72.5
M21BNG1	39.0	31.8	10.3	7.4
M21SPB2	97.0	59.0	33.8	20.3
M21SPB3	71.3	45.4	32.4	17.6
M21SPB4	970.7	781.6	362.6	162.7
M21MLL1	181.3	110.2	62.6	41.8
M21MLL2	71.7	55.0	21.9	14.1
M21MLL3	237.7	102.6	57.3	28.5
M21MLL4	72.3	79.4	36.2	30.4
G21SNT1	82.7	72.2	34.2	24.1
G21RBT1	310.3	214.2	123.4	66.9
G21RBT2	235.7	50.2	23.5	16.7
G21RML2	181.0	26.4	11.8	8.5
G21RML3	52.3	31.8	7.7	7.2
G21RML5	83.3	34.0	14.4	9.5
G21XWK1	31.0	21.0	9.8	8.6
M20RBT2	296.7	156.6	83.1	41.1
M20QRM8	395.7	158.6	96.1	50.2
M21SGW2	63.7	36.8	19.8	13.3
M20QRM1	151.7	57.0	27.9	13.7
M20BRM1	28.3	15.6	3.0	7.1
M20TFF1	117.0	49.2	25.3	29.5
M20MLL1	343.3	152.0	79.7	37.2
M20QRM14	1543.7	712.0	374.5	174.0
M21MST3	83.0	27.8	14.2	9.0

Na concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21MRX2	61.0	39.2	20.6	12.5
M21ZBR2	368.7	187.6	96.4	50.9
G21QLA1	155.3	91.2	51.7	28.4
G21QLA3	119.3	75.4	39.9	24.9
G21RML1	58.3	29.2	10.9	6.9
G21KRC1	120.3	67.2	34.6	19.9
G21GJN1	651.3	476.0	265.1	132.6
M21IMG3	71.3	38.4	22.7	18.1
M21ZRQ2	148.0	89.4	46.6	25.1
M21PMR1	228.7	151.4	81.9	45.7
M21QRM3	176.0	103.8	57.0	29.6
M21SGW3	65.0	38.2	18.6	12.1
M21RBT5	89.7	60.8	25.8	16.9
G21RML4	77.3	28.2	12.2	7.3

Mg concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20RBT1	5.3	3.6	0.1	1.7
M20MST1	24.7	13.2	0.2	4.3
M20MST2	66.3	52.4	0.7	10.3
G20SLW1	153.0	121.4	1.2	23.0
G20SLW2	56.7	39.6	0.5	8.2
G20SLW3	74.3	45.8	0.8	13.5
G20SLW4	72.7	11.2	0.1	2.4
M20BRM2	13.7	5.8	0.1	2.7
M20QRM2	38.7	25.8	0.3	6.6
M20ZJT1	16.7	14.0	0.2	17.5
M20QRM3	50.0	28.2	0.4	5.6
M20QRM4	60.7	20.8	0.3	4.4
M20QRM5	602.7	267.8	3.0	51.3
M20QRM6	7.0	4.6	0.1	1.5

Mg concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20MLL2	7.3	4.8	0.1	2.6
M20RBT3	15.0	15.4	0.2	3.2
M20RBT4	14.7	10.8	0.2	3.1
M20BRM1	9.0	4.8	0.1	1.8
M20QRM7	21.7	11.6	0.2	3.3
M20QRM9	71.0	32.8	0.6	9.7
M20QRM10	101.3	43.0	0.6	9.1
M20QRM11	44.0	19.2	0.3	4.7
M20QRM12	45.3	24.2	0.4	6.3
M20QRM13	386.7	192.2	2.1	36.2
G20RML1	36.3	17.0	0.2	4.3
G20RML2	159.0	34.6	0.5	8.5
G20RML3	12.0	4.6	0.1	2.3
G20RML4	53.7	45.0	0.6	7.7
G20RML5	17.0	9.0	0.1	2.7
G20RML6	72.7	46.0	0.4	6.3
M20MLL3	17.7	9.8	0.1	3.2
M20MLL4	137.3	36.4	0.5	7.5
M20MLL5	29.3	9.6	0.2	2.8
M20DGL1	111.7	69.6	1.1	16.5
M20MLL6	13.7	6.6	0.1	2.5
M20QRM15	452.7	212.4	2.6	42.1
M20QRM16	125.3	51.2	0.7	12.6
M20QRM17	188.0	131.4	1.9	36.2
G20RBT3	29.3	10.8	0.3	6.6
M21MST1	6.7	0.1	0.1	1.1
M21MST2	564.3	5.6	3.7	60.1
M21MST4	48.0	0.5	0.4	6.6
M21MST5	25.7	0.2	0.2	4.3
M21SPB1	12.7	0.1	0.1	2.7
M21QRM1	11.7	0.1	0.1	1.8
M21QRM2	17.7	0.2	0.2	3.5
M21WRD1	29.0	0.4	0.3	6.0

Mg concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21MST6	1.3	0.0	0.0	1.2
M21MST7	12.7	0.1	0.1	2.4
M21RBT1	20.3	0.2	0.2	4.8
M21GDJ1	10.7	0.1	0.1	1.7
M21HFR1	13.7	0.1	0.1	2.4
M21BBG1	9.0	0.1	0.1	1.8
M21MRX1	34.7	0.3	0.2	4.7
M21MRX3	6.0	0.1	0.1	1.7
M21GXQ1	48.7	0.5	0.4	7.0
M21MRC1	527.0	3.2	2.1	32.4
M21ZBR1	114.7	0.7	0.5	9.9
M21XJR1	18.3	0.2	0.1	2.8
M21HMR1	25.7	0.2	0.1	2.7
M21ZJT1	11.3	0.1	0.1	2.5
M21ZBR3	34.0	0.3	0.3	4.8
G21QLA2	32.3	0.2	0.2	4.0
G21NDR1	36.7	0.3	0.3	4.7
G21NDR2	33.0	0.3	0.2	4.8
G21XGR1	45.7	0.4	0.3	4.9
G21MRS1	93.3	0.7	0.5	9.9
G21GRB2	31.7	0.3	0.4	5.9
G21GSR1	78.3	0.6	0.5	9.1
G21GRB3	113.0	1.0	0.8	13.7
G21SLW1	21.0	0.1	0.2	3.9
G21MNX1	28.7	0.2	0.2	4.3
G21XLN1	175.3	0.9	0.8	11.9
M21IMG1	17.3	0.1	0.1	3.0
M21IMG2	11.0	0.1	0.1	2.3
M21MST8	14.0	0.1	0.1	2.1
M21STL1	35.0	0.3	0.3	4.3
M21SFI1	36.0	0.2	0.2	4.3
M21ZRQ1	12.3	0.1	0.1	2.1
M21ZRQ3	10.3	0.1	0.1	1.6

Mg concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21ZRQ4	26.7	0.2	0.2	4.9
M21MQB1	23.0	0.2	0.2	3.2
M21GRG1	12.3	0.1	0.1	2.7
M21KLN1	17.7	0.2	0.2	4.3
M21QRM4	68.7	0.3	0.3	4.1
M21PLA1	18.7	0.1	0.1	3.1
M21SGW1	20.7	0.1	0.1	2.0
M21QRN1	18.3	0.1	0.1	6.3
M21ZBJ1	12.3	0.1	0.1	1.7
M21RBT2	15.0	0.1	0.1	2.5
M21BSK1	16.0	0.1	0.1	2.3
M21DGL1	9.7	0.1	0.1	5.3
M21MTR1	10.3	0.0	0.1	1.9
M21RBT3	37.3	0.2	0.2	4.3
M21RBT4	30.3	0.3	0.2	4.3
M21BHR1	28.3	0.2	0.2	4.3
M21BNG1	12.0	0.1	0.1	2.5
M21SPB2	17.0	0.1	0.2	2.5
M21SPB3	9.3	0.1	0.1	3.5
M21SPB4	121.7	1.1	0.7	12.1
M21MLL1	22.7	0.1	0.1	5.3
M21MLL2	13.0	0.1	0.1	2.5
M21MLL3	47.0	0.2	0.2	5.1
M21MLL4	13.0	0.2	0.2	5.0
G21SNT1	10.7	0.1	0.1	2.7
G21RBT1	100.0	0.9	0.7	11.5
G21RBT2	46.7	0.1	0.1	4.5
G21RML2	23.7	0.1	0.1	3.3
G21RML3	21.7	0.1	0.1	3.1
G21RML5	22.3	0.1	0.1	2.3
G21XWK1	10.3	0.1	0.1	3.0
M20RBT2	242.3	148.8	1.7	21.9
M20QRM8	349.7	186.6	2.3	45.5

Mg concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21SGW2	9.7	0.1	0.1	1.7
M20QRM1	101.3	43.0	0.6	9.1
M20BRM1	9.0	4.8	0.1	1.8
M20TFF1	42.3	18.4	0.2	5.0
M20MLL1	133.0	64.6	0.8	13.5
M20QRM14	450.3	221.4	2.8	52.6
M21MST3	9.7	0.1	0.1	2.3
M21MRX2	12.3	0.1	0.1	2.5
M21ZBR2	44.3	0.3	0.2	3.7
G21QLA1	24.7	0.3	0.2	4.3
G21QLA3	22.7	0.3	0.2	3.9
G21RML1	30.7	0.2	0.2	3.1
G21KRC1	29.3	0.2	0.2	3.8
G21GJN1	66.0	0.6	0.5	7.3
M21IMG3	25.3	0.2	0.2	3.9
M21ZRQ2	25.0	0.2	0.2	3.3
M21PMR1	20.3	0.2	0.2	3.3
M21QRM3	40.7	0.2	0.3	6.5
M21SGW3	25.3	0.2	0.2	4.9
M21RBT5	20.0	0.1	0.1	2.9
G21RML4	26.7	0.1	0.1	2.9

K concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20RBT1	5.3	10.8	166.3	0.0
M20MST1	39.3	28.4	47.7	12.4
M20MST2	58.0	51.8	154.4	18.2
G20SLW1	119.0	92.0	53.7	29.2
G20SLW2	53.7	57.0	37.9	28.7
G20SLW3	123.3	92.8	71.3	43.1
G20SLW4	37.0	6.4	7.9	4.6
M20BRM2	0.0	0.0	0.0	0.0

K concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M20QRM2	13.0	13.6	13.4	11.9
M20ZJT1	89.0	72.2	52.9	62.3
M20QRM3	165.3	143.4	337.7	72.8
M20QRM4	65.7	53.0	44.7	30.9
M20QRM5	383.0	226.0	124.9	82.5
M20QRM6	4.0	0.0	5.3	2.7
M20MLL2	0.0	0.0	4.0	5.4
M20RBT3	22.7	36.6	252.7	23.7
M20RBT4	12.0	11.6	17.4	14.7
M20BRM1	0.0	0.0	256.4	0.9
M20QRM7	0.0	0.0	4.6	3.3
M20QRM9	259.0	145.0	118.8	89.9
M20QRM10	169.0	76.2	57.4	41.3
M20QRM11	19.0	8.0	13.7	11.7
M20QRM12	44.3	32.0	55.1	23.3
M20QRM13	423.7	287.6	200.9	140.3
G20RML1	46.3	29.2	27.5	22.3
G20RML2	57.3	7.0	11.2	5.9
G20RML3	2.7	0.0	24.3	0.0
G20RML4	137.0	94.0	306.5	41.0
G20RML5	13.7	3.0	12.8	8.7
G20RML6	218.7	159.0	86.2	64.9
M20MLL3	5.7	0.0	0.0	0.0
M20MLL4	189.7	86.8	58.1	46.2
M20MLL5	0.0	0.0	0.0	0.0
M20DGL1	15.3	6.4	56.3	10.3
M20MLL6	0.0	0.0	244.9	0.8
M20QRM15	31.7	8.4	12.7	8.7
M20QRM16	302.7	227.8	171.0	133.5
M20QRM17	545.7	518.8	565.0	254.5
G20RBT3	27.3	10.5	26.1	26.5
M21MST1	4.7	12.2	4.2	7.5
M21MST2	640.0	673.4	377.6	294.7

K concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21MST4	183.0	214.6	143.6	119.9
M21MST5	30.3	42.2	32.5	27.4
M21SPB1	0.7	8.2	4.6	7.5
M21QRM1	0.0	4.0	0.0	0.7
M21QRM2	0.0	4.8	1.0	4.3
M21WRD1	21.0	38.4	18.7	18.3
M21MST6	0.0	4.4	4.5	5.3
M21MST7	0.0	1.8	0.1	2.1
M21RBT1	5.7	15.6	16.5	11.4
M21GDJ1	82.0	0.0	0.0	0.0
M21HFR1	45.7	5.6	3.1	4.7
M21BBG1	12.3	0.0	0.0	0.0
M21MRX1	32.0	18.4	10.8	12.5
M21MRX3	0.0	0.0	0.0	0.0
M21GXQ1	49.7	49.8	27.2	31.1
M21MRC1	236.3	123.0	64.2	62.1
M21ZBR1	86.3	53.4	22.1	28.3
M21XJR1	7.3	8.8	4.8	6.3
M21HMR1	8.0	10.4	3.0	5.1
M21ZJT1	0.0	2.6	3.3	5.3
M21ZBR3	7.0	16.2	11.2	25.3
G21QLA2	96.7	89.4	48.5	56.9
G21NDR1	17.7	27.8	17.8	20.1
G21NDR2	34.7	42.8	23.0	29.5
G21XGR1	17.0	36.0	21.2	26.7
G21MRS1	13.0	21.6	12.3	15.9
G21GRB2	2.3	17.4	13.7	16.9
G21GSR1	92.7	96.0	53.8	61.3
G21GRB3	98.7	91.0	53.2	55.2
G21SLW1	0.0	0.0	0.0	1.3
G21MNX1	60.0	54.4	32.4	40.9
G21XLN1	20.7	21.8	9.4	11.6
M21IMG1	0.0	0.0	0.0	0.4

K concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
M21IMG2	0.0	0.0	0.0	1.0
M21MST8	0.0	0.0	0.0	0.0
M21STL1	74.3	62.2	40.6	45.1
M21SFI1	109.3	79.8	52.1	59.4
M21ZRQ1	0.0	38.8	0.0	1.0
M21ZRQ3	0.7	0.0	0.0	0.0
M21ZRQ4	0.0	0.0	0.7	4.4
M21MQB1	29.7	28.6	23.2	32.1
M21GRG1	0.0	0.0	0.0	3.7
M21KLN1	19.3	24.6	21.3	34.7
M21QRM4	0.0	0.0	0.0	1.7
M21PLA1	0.0	0.0	1.4	5.4
M21SGW1	34.7	21.0	17.6	20.0
M21QRN1	0.0	0.0	4.9	16.2
M21ZBJ1	2.0	0.0	0.0	0.1
M21RBT2	4.7	17.2	17.2	28.9
M21BSK1	0.0	0.0	0.1	2.9
M21DGL1	0.0	4.0	0.0	16.5
M21MTR1	0.0	0.0	0.0	0.0
M21RBT3	18.0	16.0	17.5	16.7
M21RBT4	0.0	7.8	10.4	13.9
M21BHR1	0.0	0.0	6.0	13.0
M21BNG1	0.0	0.0	6.3	9.6
M21SPB2	0.0	0.0	6.3	8.6
M21SPB3	0.0	0.0	0.0	4.3
M21SPB4	389.0	392.0	165.2	147.1
M21MLL1	6.7	3.4	20.9	24.1
M21MLL2	0.0	0.0	10.3	5.7
M21MLL3	18.0	12.2	25.7	17.7
M21MLL4	0.0	0.0	14.1	14.9
G21SNT1	0.0	0.0	2.5	0.0
G21RBT1	1.7	12.2	23.4	18.3
G21RBT2	16.3	3.8	16.7	14.1

K concentration ppm in soil samples				
Code	**Soil Paste**	**1:1**	**1:2**	**1:5**
G21RML2	0.3	1.2	13.7	8.7
G21RML3	0.0	0.0	10.7	5.3
G21RML5	12.0	6.2	15.6	10.3
G21XWK1	0.0	0.0	7.0	4.9
M20RBT2	97.7	84.8	56.7	45.2
M20QRM8	1202.0	698.4	431.7	304.3
M21SGW2	0.0	0.0	0.0	0.0
M20QRM1	169.0	76.2	57.4	41.3
M20BRM1	0.0	0.0	256.4	0.9
M20TFF1	9.7	3.8	9.0	10.9
M20MLL1	97.3	74.6	50.0	41.4
M20QRM14	412.3	326.0	208.3	161.9
M21MST3	17.0	19.6	13.7	12.2
M21MRX2	0.0	0.0	0.0	0.0
M21ZBR2	106.3	94.8	45.2	47.1
G21QLA1	9.0	23.4	16.5	16.5
G21QLA3	8.7	25.4	14.5	18.3
G21RML1	6.3	18.6	11.5	12.5
G21KRC1	10.7	16.4	11.5	15.3
G21GJN1	710.7	565.2	291.2	264.1
M21IMG3	14.7	22.8	22.1	24.5
M21ZRQ2	0.0	0.0	4.5	6.8
M21PMR1	23.0	0.0	0.7	3.8
M21QRM3	77.3	36.4	42.4	49.3
M21SGW3	20.0	27.4	22.4	23.5
M21RBT5	0.7	8.2	8.9	14.1
G21RML4	11.0	4.0	13.8	9.1

Raw data water percentage in soil sample.

Code	g	- g	-g of tin	Actual Weight	WATER	CONTROL	% of water
M20RBT1	30	30.99	2.5	28.49	**1.51**	30	5.03
M20MST1	30	30.23	2.5	27.73	**2.27**	30	7.57
M20MST2	30	29.29	2.5	26.79	**3.21**	30	10.70
G20SLW1	30	29.26	2.5	26.76	**3.24**	30	10.80
G20SLW2	30	30.72	2.5	28.22	**1.78**	30	5.93
G20SLW3	30	30.95	2.5	28.45	**1.55**	30	5.17
G20SLW4	30	30.63	2.5	28.13	**1.87**	30	6.23
M20BRM2	30	29.31	2.5	26.81	**3.19**	30	10.63
M20QRM2	30	29.2	2.5	26.7	**3.3**	30	11.00
M20ZJT1	30	29.82	2.5	27.32	**2.68**	30	8.93
M20QRM3	30	30.42	2.5	27.92	**2.08**	30	6.93
M20QRM4	30	30.6	2.5	28.1	**1.9**	30	6.33
M20QRM5	30	29.56	2.5	27.06	**2.94**	30	9.80
M20QRM6	30	31.33	2.5	28.83	**1.17**	30	3.90
M20MLL2	30	30.28	2.5	27.78	**2.22**	30	7.40
M20RBT3	30	29.56	2.5	27.06	**2.94**	30	9.80
M20RBT4	30	29.21	2.5	26.71	**3.29**	30	10.97
M20BRM1	30	30.33	2.5	27.83	**2.17**	30	7.23
M20QRM7	30	30.45	2.5	27.95	**2.05**	30	6.83
M20QRM9	30	29.19	2.5	26.69	**3.31**	30	11.03
M20QRM10	30	30.03	2.5	27.53	**2.47**	30	8.23
M20QRM11	30	30.6	2.5	28.1	**1.9**	30	6.33
M20QRM12	30	29.05	2.5	26.55	**3.45**	30	11.50
M20QRM13	30	28.8	2.5	26.3	**3.7**	30	12.33
G20RML1	30	30.35	2.5	27.85	**2.15**	30	7.17
G20RML2	30	31.84	2.5	29.34	**0.66**	30	2.20
G20RML3	30	32.28	2.5	29.78	**0.22**	30	0.73
G20RML4	30	30.95	2.5	28.45	**1.55**	30	5.17
G20RML5	30	31.77	2.5	29.27	**0.73**	30	2.43
G20RML6	30	30.27	2.5	27.77	**2.23**	30	7.43
M20MLL3	30	27.19	2.5	24.69	**5.31**	30	17.70
M20MLL4	30	31.23	2.5	28.73	**1.27**	30	4.23
M20MLL5	30	29.46	2.5	26.96	**3.04**	30	10.13
M20DGL1	30	27.46	2.5	24.96	**5.04**	30	16.80
M20MLL6	30	28.85	2.5	26.35	**3.65**	30	12.17
M20QRM15	30	29.56	2.5	27.06	**2.94**	30	9.80
M20QRM16	30	30.01	2.5	27.51	**2.49**	30	8.30

Code	g	- g	-g of tin	Actual Weight	WATER	CONTROL	% of water
M20QRM17	30	29.96	2.5	27.46	**2.54**	30	8.47
G20RBT3	30	30.2	2.5	27.7	**2.3**	30	7.67
M21MST1	30	30.6	2.5	29.8	**0.8**	30.6	2.61
M21MST2	30	31.1	2.5	29.8	**1.3**	31.1	4.18
M21MST4	30	30.6	2.5	29.8	**0.8**	30.6	2.61
M21MST5	30	31.3	2.5	30.5	**0.8**	31.3	2.56
M21SPB1	30	30.1	2.5	29.3	**0.8**	30.1	2.66
M21QRM1	30	31.4	2.5	30.6	**0.8**	31.4	2.55
M21QRM2	30	31.5	2.5	30.2	**1.3**	31.5	4.13
M21WRD1	30	31.2	2.5	30.4	**0.8**	31.2	2.56
M21MST6	30	29.6	2.5	28.8	**0.8**	29.6	2.70
M21MST7	30	31.6	2.5	30.8	**0.8**	31.6	2.53
M21RBT1	30	31.4	2.5	30.1	**1.3**	31.4	4.14
M21GDJ1	30	32.1	2.5	30.8	**1.3**	32.1	4.05
M21HFR1	30	30.7	2.5	29.9	**0.8**	30.7	2.61
M21BBG1	30	30.5	2.5	29.7	**0.8**	30.5	2.62
M21MRX1	30	32	2.5	30.7	**1.3**	32	4.06
M21MRX3	30	30.7	2.5	29.9	**0.8**	30.7	2.61
M21GXQ1	30	30.8	2.5	30	**0.8**	30.8	2.60
M21MRC1	30	31.6	2.5	30.3	**1.3**	31.6	4.11
M21ZBR1	30	32	2.5	30.7	**1.3**	32	4.06
M21XJR1	30	32.1	2.5	30.8	**1.3**	32.1	4.05
M21HMR1	30	30.2	2.5	28.9	**1.3**	30.2	4.30
M21ZJT1	30	31.6	2.5	30.3	**1.3**	31.6	4.11
M21ZBR3	30	31.9	2.5	30.6	**1.3**	31.9	4.08
G21QLA2	30	31.9	2.5	30.6	**1.3**	31.9	4.08
G21NDR1	30	31.9	2.5	30.6	**1.3**	31.9	4.08
G21NDR2	30	32.1	2.5	30.8	**1.3**	32.1	4.05
G21XGR1	30	30.9	2.5	30.1	**0.8**	30.9	2.59
G21MRS1	30	30.9	2.5	30.1	**0.8**	30.9	2.59
G21GRB2	30	30.3	2.5	29.5	**0.8**	30.3	2.64
G21GSR1	30	30.8	2.5	30	**0.8**	30.8	2.60
G21GRB3	30	30.9	2.5	30.1	**0.8**	30.9	2.59
G21SLW1	30	32.1	2.5	30.8	**1.3**	32.1	4.05
G21MNX1	30	30.8	2.5	30	**0.8**	30.8	2.60

Code	g	- g	-g of tin	Actual Weight	WATER	CONTROL	% of water
G21XLN1	30	28.7	2.5	27.4	**1.3**	28.7	4.53
M21IMG1	30	30.8	2.5	30	**0.8**	30.8	2.60
M21IMG2	30	30.4	2.5	29.6	**0.8**	30.4	2.63
M21MST8	30	30.5	2.5	29.7	**0.8**	30.5	2.62
M21STL1	30	30.6	2.5	29.8	**0.8**	30.6	2.61
M21SFI1	30	32	2.5	30.7	**1.3**	32	4.06
M21ZRQ1	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21ZRQ3	30	30.6	2.5	29.8	**0.8**	30.6	2.61
M21ZRQ4	30	29.8	2.5	29	**0.8**	29.8	2.68
M21MQB1	30	31.3	2.5	30.5	**0.8**	31.3	2.56
M21GRG1	30	31	2.5	30.2	**0.8**	31	2.58
M21KLN1	30	28.9	2.5	28.1	**0.8**	28.9	2.77
M21QRM4	30	31.7	2.5	30.4	**1.3**	31.7	4.10
M21PLA1	30	30.7	2.5	29.9	**0.8**	30.7	2.61
M21SGW1	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21QRN1	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21ZBJ1	30	31	2.5	30.2	**0.8**	31	2.58
M21RBT2	30	32.1	2.5	30.8	**1.3**	32.1	4.05
M21BSK1	30	32.4	2.5	31.1	**1.3**	32.4	4.01
M21DGL1	30	29.9	2.5	29.1	**0.8**	29.9	2.68
M21MTR1	30	30	2.5	29.2	**0.8**	30	2.67
M21RBT3	30	32.1	2.5	30.8	**1.3**	32.1	4.05
M21RBT4	30	30.5	2.5	29.7	**0.8**	30.5	2.62
M21BHR1	30	30.7	2.5	29.9	**0.8**	30.7	2.61
M21BNG1	30	30.4	2.5	29.6	**0.8**	30.4	2.63
M21SPB2	30	30.4	2.5	29.6	**0.8**	30.4	2.63
M21SPB3	30	30.4	2.5	29.6	**0.8**	30.4	2.63
M21SPB4	30	30.9	2.5	29.6	**1.3**	30.9	4.21
M21MLL1	30	31.6	2.5	30.3	**1.3**	31.6	4.11
M21MLL2	30	31.8	2.5	30.5	**1.3**	31.8	4.09
M21MLL3	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21MLL4	30	30.3	2.5	29.5	**0.8**	30.3	2.64
G21SNT1	30	30.7	2.5	29.9	**0.8**	30.7	2.61
G21RBT1	30	30.2	2.5	29.4	**0.8**	30.2	2.65
G21RBT2	30	31.8	2.5	30.5	**1.3**	31.8	4.09

Code	g	- g	-g of tin	Actual Weight	WATER	CONTROL	% of water
G21RML2	30	32.4	2.5	31.1	**1.3**	32.4	4.01
G21RML3	30	32.5	2.5	31.2	**1.3**	32.5	4.00
G21RML5	30	33.2	2.5	31.9	**1.3**	33.2	3.92
G21XWK1	30	31.1	2.5	29.8	**1.3**	31.1	4.18
M20RBT2	30	26.69	2.5	24.19	**5.81**	30	19.37
M20QRM8	30	25.73	2.5	23.23	**6.77**	30	22.57
M21SGW2	30	31.7	2.5	30.4	**1.3**	31.7	4.10
M20QRM1	30	29.92	2.5	27.42	**2.58**	30	8.60
M20BRM1	30	29.87	2.5	27.37	**2.63**	30	8.77
M20TFF1	30	30.18	2.5	27.68	**2.32**	30	7.73
M20MLL1	30	28.96	2.5	26.46	**3.54**	30	11.80
M20QRM14	30	29.4	2.5	26.9	**3.1**	30	10.33
M21MST3	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21MRX2	30	30.9	2.5	30.1	**0.8**	30.9	2.59
M21ZBR2	30	30.5	2.5	29.7	**0.8**	30.5	2.62
G21QLA1	30	31.4	2.5	30.1	**1.3**	31.4	4.14
G21QLA3	30	31.6	2.5	30.3	**1.3**	31.6	4.11
G21RML1	30	31.3	2.5	30.5	**0.8**	31.3	2.56
G21KRC1	30	31	2.5	30.2	**0.8**	31	2.58
G21GJN1	30	30.2	2.5	29.4	**0.8**	30.2	2.65
M21IMG3	30	30.6	2.5	29.8	**0.8**	30.6	2.61
M21ZRQ2	30	31.9	2.5	30.6	**1.3**	31.9	4.08
M21PMR1	30	31.2	2.5	30.4	**0.8**	31.2	2.56
M21QRM3	30	32.2	2.5	30.9	**1.3**	32.2	4.04
M21SGW3	30	31.8	2.5	30.5	**1.3**	31.8	4.09
M21RBT5	30	31	2.5	30.2	**0.8**	31	2.58
G21RML4	30	32.4	2.5	31.1	**1.3**	32.4	4.01
G20RML7	30	30.25	2.5	27.75	**2.25**	30	7.50
G20RBT1	30	30.08	2.5	27.58	**2.42**	30	8.07
G20RBT4	30	30.57	2.5	28.07	**1.93**	30	6.43
M21MRC2	30	32.2	2.5	30.9	**1.3**	32.2	4.04
G21GRB1	30	29.6	2.5	28.8	**0.8**	29.6	2.70
G20RBT2	30	30.21	2.5	27.71	**2.29**	30	7.63

Raw data organic matter in %.

Code	g of Soil	X-Value	Y-Value 1	Y-Value 2	Y-Value 3	Y-Value 4	Y-Value 5	Average	V value	%
M20RBT1	1.6	22.5	21.5	21	18	21	19.5	20.20	1.073333	**0.45**
M20MST1	1.6	22.5	13	13	13.5	13	12.5	13.00	4.433333	**1.86**
M20MST2	1.6	22.5	12.5	13	13	13	13.5	13.00	4.433333	**1.86**
G20SLW1	1.6	22.5	11	11	11	10	9.5	10.50	5.6	**2.35**
G20SLW2	1.6	22.5	15.5	15	15.5	15	14.5	15.10	3.453333	**1.45**
G20SLW3	1.6	22.5	6.5	6.5	6.5	6	5.5	6.20	7.606667	**3.19**
G20SLW4	1.8	22.5	19	18.5	18	19	17.5	18.40	1.913333	**0.71**
M20BRM2	1.6	21.5	14.5	15	14.5	15	15	14.80	3.272093	**1.37**
M20QRM2	1.6	21.5	8.5	7.5	8	7.5	7	7.70	6.739535	**2.82**
M20ZJT1	1.6	21.5	9.5	7.5	8	7.5	6.5	7.80	6.690698	**2.80**
M20QRM3	1.6	21.5	2.5	2	2.5	3	2.5	2.50	9.27907	**3.89**
M20QRM4	1.6	21	3.5	2	2.5	2	2.5	2.50	9.25	**3.87**
M20QRM5	1.6	21	15	15.5	15	15.5	15	15.20	2.9	**1.21**
M20QRM6	1.6	21	18	17.5	18	17.5	17	17.60	1.7	**0.71**
M20MLL2	1.6	21	18.5	18.5	18.5	18	18.5	18.40	1.3	**0.54**
M20RBT3	1.6	21	16.5	16	16.5	16	16	16.20	2.4	**1.01**
M20RBT4	1.6	21	15	15	15	15.5	15	15.10	2.95	**1.24**
M20BRM1	1.6	21	17	17.5	16.5	17	17.5	17.10	1.95	**0.82**
M20QRM7	1.6	22.5	20	21.5	20.5	21	21.5	20.90	0.746667	**0.31**
M20QRM9	1.6	21	10	11	10.5	11	10.5	10.60	5.2	**2.18**
M20QRM10	1.6	21	10	10.5	11.5	11	10	10.60	5.2	**2.18**
M20QRM11	1.6	21	8	8.5	9.5	9	8.5	8.70	6.15	**2.58**
M20QRM12	1.6	21	10.5	10	9.5	10	10	10.00	5.5	**2.30**
M20QRM13	1.6	21	2.5	3	2	2	2	2.30	9.35	**3.92**
G20RML1	0.9	23	19	20	19	19	20	19.40	1.643478	**1.22**
G20RML2	1.4	23	23	22	22.5	23	22	22.50	0.228261	**0.11**
G20RML3	1.6	21	21	21	20.5	21	21	20.90	0.05	**0.02**
G20RML4	1.6	21	15.5	15	15.5	15.5	16	15.50	2.75	**1.15**
G20RML5	1.6	21	16	15.5	15	15	16.5	15.60	2.7	**1.13**
G20RML6	1.6	21	13.5	14.5	15	14	14.5	14.30	3.35	**1.40**
M20MLL3	1.6	21	11	10	10.5	10	10	10.30	5.35	**2.24**
M20MLL4	1.6	21	11.5	12	11.5	12	12.5	11.90	4.55	**1.91**
M20MLL5	1.6	21	15.5	13.5	14	13.5	14	14.10	3.45	**1.44**
M20DGL1	1.6	21	4.5	4	3.5	4.5	5	4.30	8.35	**3.50**
M20MLL6	1.6	21	12.5	12	11.5	11	11.5	11.70	4.65	**1.95**
M20QRM15	0.8	23	16	21	20	18	19	18.80	1.917391	**1.61**
M20QRM16	0.8	23	11	11.5	12.5	12.5	12.5	12.00	5.021739	**4.21**
M20QRM17	1.6	21	1.5	2	2.5	1.5	2	1.90	9.55	**4.00**
G20RBT3	1.6	21	19	19.5	19	19.5	19.5	19.30	0.85	**0.36**
M21MST1	1.6	22	10	12	12.5	11	11.5	11.40	5.059091	**2.12**
M21MST2	1.6	22	2	2.5	2	1.5	2	2.00	9.545455	**4.00**
M21MST4	1.6	22	5	5.5	5	5	5.5	5.20	8.018182	**3.36**
M21MST5	1.6	22	13	13	13.5	12.5	13	13.00	4.295455	**1.80**
M21SPB1	1.6	22.5	12	10	11	10	11	10.80	5.46	**2.29**
M21QRM1	1.6	22.5	7.5	7	7.5	7	6	7.00	7.233333	**3.03**
M21QRM2	1.6	22.5	8.5	8	8.5	8	9	8.40	6.58	**2.76**
M21WRD1	1.6	22.5	2.5	2	2.5	2.5	2	2.30	9.426667	**3.95**
M21MST6	1.6	22.5	19.5	19.5	19	18	18.5	18.90	1.68	**0.70**
M21MST7	1.6	22.5	10	10.5	11	11	10.5	10.60	5.553333	**2.33**
M21RBT1	1.6	22.5	3	3.5	4	4	4.5	3.80	8.726667	**3.65**
M21GDJ1	1.6	22.5	11	12	11.5	12	11.5	11.60	5.086667	**2.13**
M21HFR1	1.6	22.5	10	9	10.5	11	10	10.10	5.786667	**2.42**
M21BBG1	1.6	22.5	10	11.5	12	13	12	11.70	5.04	**2.11**
M21MRX1	1.6	22	6	6.5	6	5.5	6.5	6.10	7.588636	**3.18**
M21MRX3	1.6	22	14	13	13.5	14	13.5	13.60	4.009091	**1.68**

Code	g of Soil	X-Value	Y-Value 1	Y-Value 2	Y-Value 3	Y-Value 4	Y-Value 5	Average	V value	%
M21GXQ1	1.6	22	7.5	7	7.5	7	7.5	7.30	7.015909	**2.94**
M21MRC1	1.6	22	12.5	13	12	12.5	13	12.60	4.486364	**1.88**
M21ZBR1	1.6	22	10	9.5	10.5	10	10	10.00	5.727273	**2.40**
M21XJR1	1.6	22	9	8	8.5	9	9	8.70	6.347727	**2.66**
M21HMR1	1.6	22	11	10	8	10	9	9.60	5.918182	**2.48**
M21ZJT1	1.6	22	7	8	8	7	7.5	7.50	6.920455	**2.90**
M21ZBR3	1.6	22	6.5	6	6.5	7	6.5	6.50	7.397727	**3.10**
G21QLA2	1.6	22	3	3.5	3	3.5	3.5	3.30	8.925	**3.74**
G21NDR1	1.6	22	7.5	8	8	9	8.5	8.20	6.586364	**2.76**
G21NDR2	1.6	22	8	7.5	7.5	7.5	8	7.70	6.825	**2.86**
G21XGR1	1.6	22	2	2.5	2	2	2.5	2.20	9.45	**3.96**
G21MRS1	1.6	22	15	14.5	15	15	14.5	14.80	3.436364	**1.44**
G21GRB2	1.6	22	18.5	18	17.5	18	17.5	17.90	1.956818	**0.82**
G21GSR1	1.6	22	15	13.5	14	13	13.5	13.80	3.913636	**1.64**
G21GRB3	1.6	22	17	18.5	17	16.5	17	17.20	2.290909	**0.96**
G21SLW1	1.6	22	16	14.5	13.5	14	14.5	14.50	3.579545	**1.50**
G21MNX1	1.6	22	8.5	8.5	9	8.5	9	8.70	6.347727	**2.66**
G21XLN1	1.6	22	11	11.5	12	12	11.5	11.60	4.963636	**2.08**
M21IMG1	1.6	22	16.5	16.5	16	16.5	16	16.30	2.720455	**1.14**
M21IMG2	1.6	22	13	12.5	13.5	13	12.5	12.90	4.343182	**1.82**
M21MST8	1.6	22	5	5.5	6	5	6	5.50	7.875	**3.30**
M21STL1	1.6	22	4.5	5	5	4.5	4.5	4.70	8.256818	**3.46**
M21SFI1	1.6	22	5	5.5	5	4.5	5	5.00	8.113636	**3.40**
M21ZRQ1	1.6	22	9	9.5	10	9.5	10	9.60	5.918182	**2.48**
M21ZRQ3	1.6	22	16	15.5	15	14.5	15	15.20	3.245455	**1.36**
M21ZRQ4	1.6	22	4	3	3	3.5	4	3.50	8.829545	**3.70**
M21MQB1	1.6	22	6	6	6.5	6.5	6	6.20	7.540909	**3.16**
M21GRG1	1.6	22	1.5	1.5	2	2	1.5	1.70	9.688636	**4.06**
M21KLN1	1.6	22	1	1.5	2	1.5	2	1.60	9.736364	**4.08**
M21QRM4	1.6	22	11	12	11.5	11	12	11.50	5.011364	**2.10**
M21PLA1	1.6	22	8.5	7.5	8	7.5	7.5	7.80	6.777273	**2.84**
M21SGW1	1.6	22	15	15	15.5	16	16	15.50	3.102273	**1.30**
M21QRN1	1.6	22	11	11.5	12	10.5	11	11.20	5.154545	**2.16**
M21ZBJ1	1.6	22	13	14	12.5	13.5	13	13.20	4.2	**1.76**
M21RBT2	1.6	22	8	8.5	9	9	8	8.50	6.443182	**2.70**
M21BSK1	1.6	22	17	20	17.5	17.5	18	18.00	1.909091	**0.80**
M21DGL1	1.6	22	10.5	12	11.5	11	11.5	11.30	5.106818	**2.14**
M21MTR1	1.6	22	16	15	14.5	14.5	15	15.00	3.340909	**1.40**
M21RBT3	1.6	22	13.5	14	14.5	14	13.5	13.90	3.865909	**1.62**
M21RBT4	1.6	22	15	14.5	14	14.5	15	14.60	3.531818	**1.48**
M21BHR1	1.6	22	10.5	10	11	10	10.5	10.40	5.536364	**2.32**
M21BNG1	1.6	22	11	10.5	10.5	11	10.5	10.70	5.393182	**2.26**
M21SPB2	1.6	22	5.5	6	5.5	6.5	6	5.90	7.684091	**3.22**
M21SPB3	1.6	22	8.5	10	9.5	9	8.5	9.10	6.156818	**2.58**
M21SPB4	1.6	22	4.5	4.5	5	4.5	5	4.70	8.256818	**3.46**
M21MLL1	1.6	22	8	8.5	9	9	8.5	8.60	6.395455	**2.68**
M21MLL2	1.6	22	4.5	5	5.5	4.5	5	4.90	8.161364	**3.42**
M21MLL3	1.6	22	8.5	8.5	9	9	8.5	8.70	6.347727	**2.66**
M21MLL4	1.6	22	10.5	11	10	11	11.5	10.80	5.345455	**2.24**
G21SNT1	1.6	22	6	7	8	7.5	6.5	7.00	7.159091	**3.00**
G21RBT1	1.6	22	13.5	14	14.5	14	14	14.00	3.818182	**1.60**
G21RBT2	1.6	22	14	13.5	15	14.5	15	14.40	3.627273	**1.52**
G21RML2	1.6	22	18.5	19	18	17.5	18	18.20	1.813636	**0.76**
G21RML3	1.6	22	16	14.5	14.5	15	14.5	14.90	3.388636	**1.42**
G21RML5	1.6	22	17	16	15.5	16	16.5	16.20	2.768182	**1.16**
G21XWK1	1.6	22	12	13	12.5	12	12.5	12.40	4.581818	**1.92**
M20RBT2	1.6	22.5	6	6	6	6	5.5	5.90	7.746667	**3.24**
M20QRM8	1.6	21	2.5	2	2.5	3	3.5	2.70	9.15	**3.83**

Code	g of Soil	X-Value	Y-Value 1	Y-Value 2	Y-Value 3	Y-Value 4	Y-Value 5	Average	V value	%
M21SGW2	1.6	22	14.5	15	14	14.5	15	14.60	3.531818	**1.48**
M20QRM1	1.6	22.5	8.5	9.5	8.5	9	10	9.10	6.253333	**2.62**
M20BRM1	1.6	22.5	15	15	15.5	15.5	15	15.20	3.406667	**1.43**
M20TFF1	1.6	21.5	12	12	12	11	11.5	11.70	4.786047	**2.00**
M20MLL1	1.6	21.5	12	12	12	11.5	11	11.70	4.786047	**2.00**
M20QRM14	0.8	23	5	3	4	6	3	4.20	8.582609	**7.19**
M21MST3	1.6	22	14	13.5	13	13	13	13.30	4.152273	**1.74**
M21MRX2	1.6	22	9.5	10	9	9.5	10	9.60	5.918182	**2.48**
M21ZBR2	1.6	22	6	6.5	6	6	6.5	6.20	7.540909	**3.16**
G21QLA1	1.6	22	4	3.5	4	3.5	3.5	3.70	8.734091	**3.66**
G21QLA3	1.6	22	13.5	13	12.5	13	12.5	12.90	4.343182	**1.82**
G21RML1	1.6	22	14	14.5	13.5	14	13	13.80	3.913636	**1.64**
G21KRC1	1.6	22	16	16.5	16	15.5	16	16.00	2.863636	**1.20**
G21GJN1	1.6	22	2	2.5	2	2	2.5	2.20	9.45	**3.96**
M21IMG3	1.6	22	8	9	8.5	9	8.5	8.60	6.395455	**2.68**
M21ZRQ2	1.6	22	7.5	8	7.5	8	8	7.80	6.777273	**2.84**
M21PMR1	1.6	22	12.5	13	12	12	12.5	12.40	4.581818	**1.92**
M21QRM3	1.6	22	4.5	6	5	4.5	5	5.00	8.113636	**3.40**
M21SGW3	1.6	22	16.5	15.5	16	16	15.5	15.90	2.911364	**1.22**
M21RBT5	1.6	22	1.5	2	2	1.5	1.5	1.70	9.688636	**4.06**
G21RML4	1.6	22	14.5	15.5	15.5	14.5	15	15.00	3.340909	**1.40**
G20RML7	1.6	21	16	15.5	15	15	15.5	15.40	2.8	**1.17**
G20RBT1	0.9	23	11	10	9	9	10	9.80	6.026087	**4.49**
G20RBT4	1.6	21	21	20	21	20.5	21	20.70	0.15	**0.06**
M21MRC2	1.6	22	16.5	16	16.5	16	16	16.20	2.768182	**1.16**
G21GRB1	1.6	22	20	20	19.5	20	19	19.70	1.097727	**0.46**
G20RBT2	1.6	21	21	20.5	21	20.5	20	20.60	0.2	**0.08**

Raw data conductivity workings in µS/cm .

Code	1:1	1:1	1:1	**Average**	1:2	1:2	1:2	**Average**	1:5	1:5	1:5	**Average**	SP 200g	SP 200g	SP 200g	**Average**	H2O in	H2O out	% H20 out
M20RBT1	365	425	361	**384**	238	231	247	**239**	142	138	144	**141**	783	741	658	**727**	70	12	17
M20MST1	1159	1044	1101	**1101**	635	641	700	**659**	456	337	320	**371**	2330	2281	2148	**2253**	60	15	25
M20MST2	2875	2505	2637	**2672**	1467	1567	1668	**1567**	751	673	615	**680**	4270	4140	3850	**4087**	65	17	26
G20SLW1	5300	4650	4760	**4903**	2364	2520	1904	**2263**	1152	1179	1165	**1165**	6990	7580	7170	**7247**	60	27	45
G20SLW2	1823	1542	1416	**1594**	1142	1157	1063	**1121**	554	541	478	**524**	3380	3430	3420	**3410**	90	13	14
G20SLW3	3100	3030	3060	**3063**	2275	2245	2140	**2220**	1005	1114	983	**1034**	5130	5080	4690	**4967**	60	24	40
G20SLW4	730	713	688	**710**	433	455	466	**451**	220	214	221	**218**	2272	3320	2980	**2857**	50	10	20
M20BRM2	583	567	576	**575**	413	419	440	**424**	201	205	199	**202**	1631	1487	1470	**1529**	70	19	27
M20QRM2	2188	1820	1830	**1946**	1022	982	1002	**1002**	564	547	497	**536**	3640	3520	3350	**3503**	70	26	37
M20ZJT1	961	974	932	**956**	613	616	595	**608**	389	329	360	**359**	2084	1780	2248	**2037**	60	16	27
M20QRM3	2050	2066	2018	**2045**	1205	1190	1200	**1198**	551	520	550	**540**	4210	3520	3660	**3797**	70	17	24
M20QRM4	1493	1463	1518	**1491**	966	942	924	**944**	390	391	401	**394**	2265	3240	3200	**2902**	80	30	38
M20QRM5	10970	11250	10460	**10893**	6460	6250	6290	**6333**	2703	2765	2676	**2715**	24430	25130	22650	**24070**	45	15	33
M20QRM6	548	513	535	**532**	296	315	335	**315**	166	179	152	**166**	1100	1163	1075	**1113**	70	13	19
M20MLL2	550	572	525	**549**	365	402	341	**369**	184	171	190	**182**	1453	1383	1337	**1391**	50	22	44
M20RBT3	942	972	1025	**980**	577	552	554	**561**	297	289	275	**287**	1316	1165	1250	**1244**	75	15	20
M20RBT4	780	840	786	**802**	489	461	487	**479**	267	237	250	**251**	1066	1233	1234	**1178**	55	12	22
M20BRM1	663	620	632	**638**	424	342	415	**394**	218	226	231	**225**	960	919	1005	**961**	65	16	25
M20QRM7	996	975	1023	**998**	594	564	556	**571**	300	289	314	**301**	2039	2064	2167	**2090**	60	19	32
M20QRM9	1807	1841	1813	**1820**	1490	1328	1319	**1379**	665	713	645	**674**	4090	4180	4720	**4330**	50	30	60
M20QRM10	3430	3420	3420	**3423**	1970	1965	1881	**1939**	896	849	834	**860**	8550	8310	8110	**8323**	50	25	50
M20QRM11	1315	1330	1378	**1341**	786	770	830	**795**	371	391	385	**382**	3280	3380	3330	**3330**	50	16	32

Code	1:1	1:1	1:1	**Average**	1:2	1:2	1:2	**Average**	1:5	1:5	1:5	**Average**	SP 200g	SP 200g	SP 200g	**Average**	H2O in	H2O out	% H20 out
M20QRM12	1580	1334	1970	**1628**	969	903	1135	**1002**	480	485	513	**493**	3220	3520	3670	**3470**	50	25	50
M20QRM13	7850	8050	8290	**8063**	4630	4120	4230	**4327**	1888	2009	1933	**1943**	16810	16120	16890	**16607**	50	20	40
G20RML1	1145	1101	1078	**1108**	618	605	620	**614**	304	295	320	**306**	2472	2537	2574	**2528**	50	26	52
G20RML2	2395	1988	2211	**2198**	1166	1328	1433	**1309**	598	558	537	**564**	8860	9060	8390	**8770**	45	36	80
G20RML3	377	383	477	**412**	231	274	245	**250**	122	124	133	**126**	1138	1148	1123	**1136**	50	17	34
G20RML4	1790	1767	1740	**1766**	1068	1094	990	**1051**	450	432	453	**445**	2850	2980	3040	**2957**	50	25	50
G20RML5	477	438	442	**452**	343	325	311	**326**	160	182	149	**164**	1337	1273	1358	**1323**	50	18	36
G20RML6	2421	2389	2413	**2408**	1212	1286	1120	**1206**	532	509	520	**520**	4630	4310	4500	**4480**	55	17.5	32
M20MLL3	677	622	739	**679**	481	450	462	**464**	244	219	246	**236**	1855	1767	1674	**1765**	50	15	30
M20MLL4	2069	1822	1956	**1949**	1006	1082	1096	**1061**	502	519	505	**509**	6430	6320	5520	**6090**	50	15	30
M20MLL5	1196	1092	1256	**1181**	933	810	814	**852**	384	391	405	**393**	3550	3540	3810	**3633**	60	17	28
M20DGL1	2704	2718	2733	**2718**	1653	1649	1768	**1690**	692	714	698	**701**	4420	4850	4550	**4607**	50	19	38
M20MLL6	886	847	881	**871**	512	500	541	**518**	289	324	293	**302**	1675	1890	1753	**1773**	60	20	33
M20QRM15	10430	11400	10410	**10747**	6110	5950	6040	**6033**	2573	2518	2420	**2504**	19550	22710	17380	**19880**	55	21	38
M20QRM16	3610	3750	3320	**3560**	1894	1824	1932	**1883**	865	887	878	**877**	6680	7230	7290	**7067**	65	17	26
M20QRM17	6510	6630	6530	**6557**	4308	3990	4200	**4166**	2155	2069	2212	**2145**	9890	9940	10160	**9997**	90	26	29
G20RBT3	955	838	976	**923**	712	729	744	**728**	414	384	413	**404**	1767	1976	1847	**1863**	100	13	13
M21MST1	632	612	636	**627**	375	377	390	**381**	199	198	197	**198**	1089	1049	1110	**1083**	80	25	31
M21MST2	16070	15620	16410	**16033**	8410	8950	8970	**8777**	4200	4090	3990	**4093**	25570	28210	26400	**26727**	90	25	28
M21MST4	2241	2193	2230	**2221**	1262	1235	1258	**1252**	627	584	598	**603**	3350	3260	3200	**3270**	85	25	29
M21MST5	1136	1094	1112	**1114**	641	634	642	**639**	314	315	311	**313**	2031	2154	2170	**2118**	75	22	29
M21SPB1	1096	1064	1045	**1068**	671	649	664	**661**	303	319	308	**310**	1826	1695	1848	**1790**	80	20	25
M21QRM1	1118	995	1015	**1043**	607	528	656	**597**	304	270	296	**290**	2130	1972	2070	**2057**	70	37	53

Code	1:1	1:1	1:1	Average	1:2	1:2	1:2	Average	1:5	1:5	1:5	Average	SP 200g	SP 200g	SP 200g	Average	H2O in	H2O out	% H20 out
M21QRM2	1179	1185	1210	**1191**	667	660	691	**673**	317	301	320	**313**	2195	2329	2074	**2199**	80	20	25
M21WRD1	2530	2487	2300	**2439**	1382	1482	1214	**1359**	815	776	805	**799**	3320	3220	3330	**3290**	80	24	30
M21MST6	357	353	331	**347**	187	200	207	**198**	122	126	123	**124**	849	887	880	**872**	35	10	29
M21MST7	792	739	855	**795**	476	450	457	**461**	262	226	220	**236**	1606	1466	1620	**1564**	55	13	24
M21RBT1	1205	1150	1158	**1171**	708	669	678	**685**	312	313	313	**313**	1897	1814	1940	**1884**	80	18	23
M21GDJ1	755	790	824	**790**	461	483	451	**465**	175	176	231	**194**	1586	1565	1575	**1575**	70	23	33
M21HFR1	998	1013	993	**1001**	547	560	534	**547**	270	257	264	**264**	1748	1660	1658	**1689**	85	26	31
M21BBG1	561	479	552	**531**	336	321	315	**324**	177	220	229	**209**	1026	997	988	**1004**	80	25	31
M21MRX1	1383	1360	1392	**1378**	761	787	788	**779**	365	341	351	**352**	2664	2581	2598	**2614**	85	25	29
M21MRX3	726	865	717	**769**	441	445	437	**441**	223	216	189	**209**	1209	1148	1154	**1170**	80	21	26
M21GXQ1	2344	2327	2400	**2357**	1310	1379	1387	**1359**	577	578	561	**572**	3260	3190	3270	**3240**	85	21	25
M21MRC1	11530	11210	11390	**11377**	6150	6220	6590	**6320**	2599	2558	2635	**2597**	25270	24690	24980	**24980**	70	22	31
M21ZBR1	2990	3000	3110	**3033**	1693	1665	1675	**1678**	882	823	782	**829**	6910	6570	6070	**6517**	60	15	25
M21XJR1	1437	1390	1435	**1421**	755	735	798	**763**	351	357	355	**354**	2124	2277	2101	**2167**	75	17	23
M21HMR1	1320	1362	1404	**1362**	764	741	784	**763**	382	365	391	**379**	3290	3090	3190	**3190**	50	20	40
M21ZJT1	550	556	539	**548**	325	344	339	**336**	167	176	175	**173**	920	923	943	**929**	75	20	27
M21ZBR3	1840	1750	1785	**1792**	1090	1060	1062	**1071**	513	519	528	**520**	2797	2842	2728	**2789**	75	20	27
G21QLA2	1160	1168	1172	**1167**	619	586	620	**608**	312	304	295	**304**	2185	2241	2317	**2248**	85	24	28
G21NDR1	1296	1205	1231	**1244**	738	744	758	**747**	330	399	366	**365**	2325	2269	2091	**2228**	70	17	24
G21NDR2	915	943	946	**935**	435	433	436	**435**	232	235	205	**224**	2001	1782	1838	**1874**	75	21	28
G21XGR1	1332	1304	1315	**1317**	680	683	689	**684**	353	348	361	**354**	2324	2229	2338	**2297**	85	19	22
G21MRS1	2506	2443	2446	**2465**	1358	1320	1344	**1341**	647	629	684	**653**	4560	4320	4710	**4530**	80	19	24
G21GRB2	1260	1213	1240	**1238**	824	791	811	**809**	361	388	341	**363**	1632	1614	1881	**1709**	80	11	14
G21GSR1	1927	1980	1990	**1966**	1143	1095	1141	**1126**	535	529	557	**540**	3590	3720	3610	**3640**	85	19	22

Code	1:1	1:1	1:1	**Average**	1:2	1:2	1:2	**Average**	1:5	1:5	1:5	**Average**	SP 200g	SP 200g	SP 200g	**Average**	H2O in	H2O out	% H20 out
G21GRB3	2431	2478	2654	**2521**	1499	1428	1468	**1465**	723	687	726	**712**	3880	3960	4170	**4003**	85	18	21
G21SLW1	836	795	820	**817**	454	453	447	**451**	262	231	253	**249**	1529	1690	1615	**1611**	75	23	31
G21MNX1	1412	1462	1483	**1452**	804	807	826	**812**	432	459	448	**446**	2507	2526	2630	**2554**	75	20	27
G21XLN1	3250	3280	3290	**3273**	1830	1827	1860	**1839**	868	834	813	**838**	7490	7730	7680	**7633**	60	25	42
M21IMG1	750	690	710	**717**	405	394	399	**399**	210	202	204	**205**	1330	1229	1342	**1300**	75	18	24
M21IMG2	635	650	621	**635**	416	398	399	**404**	180	188	193	**187**	899	1030	1032	**987**	85	15	18
M21MST8	900	820	890	**870**	501	520	501	**507**	272	240	249	**254**	1474	1540	1603	**1539**	95	31	33
M21STL1	1515	1435	1382	**1444**	836	840	845	**840**	393	382	391	**389**	2216	2147	2416	**2260**	75	23	31
M21SFI1	1308	1236	1231	**1258**	755	731	706	**731**	340	361	355	**352**	2325	2227	2472	**2341**	80	24	30
M21ZRQ1	763	701	725	**730**	448	435	440	**441**	241	240	236	**239**	1441	1571	1455	**1489**	80	25	31
M21ZRQ3	774	699	795	**756**	418	440	424	**427**	218	219	229	**222**	1298	1299	1320	**1306**	75	20	27
M21ZRQ4	1301	1162	1290	**1251**	713	762	680	**718**	357	335	402	**365**	2181	2070	2191	**2147**	100	33	33
M21MQB1	1300	1239	1290	**1276**	696	688	690	**691**	344	359	350	**351**	1858	1992	2017	**1956**	75	21	28
M21GRG1	674	573	713	**653**	375	362	395	**377**	207	208	215	**210**	1207	1195	1251	**1218**	85	22	26
M21KLN1	1039	906	955	**967**	598	585	582	**588**	286	348	320	**318**	1503	1491	1407	**1467**	85	28	33
M21QRM4	3280	3070	3290	**3213**	1807	1784	1803	**1798**	790	800	798	**796**	6920	7240	6920	**7027**	70	22	31
M21PLA1	769	723	771	**754**	411	402	407	**407**	207	208	204	**206**	1362	1512	1371	**1415**	80	18	23
M21SGW1	980	981	1009	**990**	630	593	583	**602**	282	314	286	**294**	2403	2214	2300	**2306**	55	14	25
M21QRN1	635	591	600	**609**	351	347	354	**351**	187	190	189	**189**	1504	1436	1480	**1473**	70	23	33
M21ZBJ1	642	635	637	**638**	328	320	326	**325**	192	183	187	**187**	1463	1446	1450	**1453**	75	30	40
M21RBT2	928	869	739	**845**	505	488	535	**509**	279	285	260	**275**	1276	1399	1534	**1403**	85	11	13
M21BSK1	771	773	778	**774**	462	452	458	**457**	227	234	235	**232**	1618	1623	1606	**1616**	70	24	34
M21DGL1	612	658	629	**633**	405	392	394	**397**	195	201	212	**203**	1175	1243	1265	**1228**	85	27	32
M21MTR1	511	426	484	**474**	393	445	438	**425**	180	169	172	**174**	1199	1093	1231	**1174**	80	20	25

Code	1:1	1:1	1:1	Average	1:2	1:2	1:2	Average	1:5	1:5	1:5	Average	SP 200g	SP 200g	SP 200g	Average	H2O in	H2O out	% H20 out
M21RBT3	1415	1348	1395	**1386**	793	783	779	**785**	352	353	357	**354**	3540	3660	3490	**3563**	55	15	27
M21RBT4	930	1370	1400	**1233**	703	769	762	**745**	361	356	345	**354**	2377	2321	2301	**2333**	85	18	21
M21BHR1	1116	1120	1139	**1125**	631	627	610	**623**	289	299	290	**293**	2085	1969	1988	**2014**	75	19	25
M21BNG1	820	809	829	**819**	458	479	480	**472**	220	224	225	**223**	1281	1224	1153	**1219**	75	21	28
M21SPB2	928	980	1000	**969**	588	528	680	**599**	274	266	274	**271**	1543	1640	1553	**1579**	80	22	28
M21SPB3	608	579	590	**592**	337	325	321	**328**	196	197	185	**193**	1189	1075	1148	**1137**	80	24	30
M21SPB4	9480	9110	9250	**9280**	4700	4690	4750	**4713**	1929	2033	2091	**2018**	12240	12740	11970	**12317**	90	28	31
M21MLL1	1269	1255	1245	**1256**	753	763	749	**755**	345	340	334	**340**	2546	2243	2614	**2468**	85	24	28
M21MLL2	808	821	827	**819**	474	465	471	**470**	230	224	234	**229**	1513	1441	1581	**1512**	85	23	27
M21MLL3	1181	1120	1130	**1144**	617	619	653	**630**	290	293	303	**295**	2538	2586	2845	**2656**	70	26	37
M21MLL4	1121	1145	1170	**1145**	671	637	661	**656**	311	304	305	**307**	1848	1840	1674	**1787**	100	30	30
G21SNT1	954	849	1000	**934**	507	518	498	**508**	237	248	256	**247**	1347	1215	1273	**1278**	85	19	22
G21RBT1	2936	2942	2903	**2927**	1604	1704	1691	**1666**	750	686	740	**725**	4770	4220	4860	**4617**	75	19	25
G21RBT2	927	925	893	**915**	510	496	498	**501**	239	238	242	**240**	1619	1620	1716	**1652**	85	15	18
G21RML2	582	588	576	**582**	339	343	370	**351**	177	161	168	**169**	1749	1723	1619	**1697**	55	30	55
G21RML3	595	569	578	**581**	285	299	289	**291**	139	149	147	**145**	1629	1453	1482	**1521**	55	28	51
G21RML5	690	683	730	**701**	384	393	407	**395**	216	182	193	**197**	1651	1767	1901	**1773**	60	29	48
G21XWK1	570	557	588	**572**	358	341	363	**354**	174	184	173	**177**	937	964	899	**933**	75	16	21
M20RBT2	7130	7010	7880	**7340**	4250	3330	4600	**4060**	2055	2139	2002	**2065**	14730	13570	12650	**13650**	60	26	43
M20QRM8	5900	6210	6010	**6040**	3320	3130	3290	**3247**	1551	1510	1556	**1539**	9840	12130	10700	**10890**	50	22	44
M21SGW2	705	615	635	**652**	355	356	356	**356**	193	188	193	**191**	1371	1335	1338	**1348**	80	22	28
M20QRM1	4580	4459	4670	**4570**	2518	2412	2531	**2487**	1078	1062	1110	**1083**	10680	10320	9830	**10277**	60	22	37
M20BRM1	744	733	724	**734**	534	492	439	**488**	237	254	238	**243**	1945	1774	1511	**1743**	65	17	26
M20TFF1	1138	1156	1076	**1123**	673	613	654	**647**	334	316	306	**319**	2660	3230	2921	**2937**	50	15	30

Code	1:1	1:1	1:1	Average	1:2	1:2	1:2	Average	1:5	1:5	1:5	Average	SP 200g	SP 200g	SP 200g	Average	H2O in	H2O out	% H20 out
M20MLL1	3150	3350	3300	**3267**	1743	1816	1914	**1824**	793	844	876	**838**	7640	7370	8030	**7680**	40	22	55
M20QRM14	10400	10750	9800	**10317**	6370	6550	6400	**6440**	2901	2955	2882	**2913**	20150	20590	20070	**20270**	70	18	26
M21MST3	619	579	568	**589**	346	331	356	**344**	172	156	170	**166**	1291	1213	1275	**1260**	55	14	25
M21MRX2	639	701	714	**685**	401	388	408	**399**	198	221	184	**201**	1264	1130	1224	**1206**	75	20	27
M21ZBR2	2310	2354	2311	**2325**	1285	1260	1280	**1275**	575	591	581	**582**	4660	4810	4650	**4707**	75	19	25
G21QLA1	1337	1338	1310	**1328**	724	727	710	**720**	341	336	358	**345**	2031	2074	2046	**2050**	85	25	29
G21QLA3	1028	1029	1061	**1039**	589	570	610	**590**	295	271	294	**287**	1549	1518	1561	**1543**	100	21	21
G21RML1	1120	1115	1202	**1146**	675	639	653	**656**	324	290	318	**311**	2567	2346	2497	**2470**	65	19	29
G21KRC1	924	927	978	**943**	504	491	496	**497**	249	248	242	**246**	1880	1894	1767	**1847**	70	17	24
G21GJN1	4680	4610	4720	**4670**	2658	2622	2638	**2639**	1230	1191	1168	**1196**	6380	6470	5930	**6260**	100	18	18
M21IMG3	957	933	936	**942**	541	526	530	**532**	267	266	266	**266**	1568	1418	1577	**1521**	70	23	33
M21ZRQ2	1178	1186	1179	**1181**	732	628	688	**683**	316	311	321	**316**	1943	2013	2052	**2003**	70	23	33
M21PMR1	1420	1325	1390	**1378**	803	813	760	**792**	390	370	403	**388**	2157	2190	2188	**2178**	80	25	31
M21QRM3	644	735	1150	**843**	704	690	695	**696**	347	341	346	**345**	2410	2263	2291	**2321**	80	26	33
M21SGW3	1362	1251	1252	**1288**	710	712	727	**716**	372	334	322	**343**	1782	1712	1787	**1760**	80	20	25
M21RBT5	1208	1100	1120	**1143**	653	577	633	**621**	347	337	319	**334**	2309	2342	2221	**2291**	100	32	32
G21RML4	655	660	665	**660**	381	357	361	**366**	183	188	189	**187**	1824	1863	1858	**1848**	60	30	50
G20RML7	8260	8270	8000	**8177**	6540	6080	6450	**6357**	4060	4010	4150	**4073**	2768	2586	2540	**2631**	50	11	22
G20RBT1	1493	1534	1453	**1493**	991	837	937	**922**	386	418	446	**417**	14540	14120	11810	**13490**	100	10	10
G20RBT4	12010	10360	9710	**10693**	7240	7450	7440	**7377**	4910	4990	4270	**4723**	18580	18040	16690	**17770**	110	15	14
M21MRC2	35500	36400	39100	**37000**	20360	19460	19800	**19873**	8400	8170	8700	**8423**	96000	99400	100300	**98567**	50	15	30
G21GRB1	7360	7180	7230	**7257**	5230	5330	5210	**5257**	3760	3600	3720	**3693**	9520	9410	9640	**9523**	110	15	14
G20RBT2	9850	9940	9870	**9887**	7850	7780	7860	**7830**	4530	4680	4660	**4623**	17820	17130	16180	**17043**	110	11	10