

## **Development of a Soil Information System of the Maltese Islands.**

In the absence of a national institution responsible for soil survey activities, mapping and monitoring, soil information has until the present day received little attention and has remained a relatively undeveloped agricultural field in Malta. A national soil database is completely lacking, and inevitably the knowledge on Maltese soils is scanty and unharmonised. The existing soil map has never been digitised because it is regarded as outdated and consequently of little use for land management and planning purposes. As a result, soil information is non-existent in agricultural, environmental and planning geographical information systems. Soil information is very fragmented and linked to specific surveys and studies carried out by University departments, and to environmental impact assessments for project location, and development purposes. The Agricultural Research & Development Centre is responsible for soil fertility and salinity monitoring in relation to commercial fertiliser plans. The collection of soil data is restricted because of insufficient facilities for soil characterisation (field survey and laboratory analysis), and lack of expertise in soil science and soil Geographic Information Systems.

Since the date of issue of the national soil map produced by Lang (1960), considerable translocation of topsoil, subsoil and regolith has occurred, together with occasional mixing of soil with other material. The soil descriptive and analytical data in this survey are older than 40 years and do not correspond to the field anymore. This is especially true in areas having strong human-influence (carting, manuring, reclamation etc.). Locally, man is considered as the most influential factor affecting the soil environment. The Soil Preservation Act prohibiting the covering of soil by building construction and imposing on the builder to completely remove the soil on his ground and to dump it elsewhere was a very wise step in the conservation of Maltese soils, but it has undoubtedly greatly contributed to the confused nature of local soils. Updating of the existing soils map is urgently required in view of the extensive translocation of soil and the urbanisation of significant tracts of former soil-covered land.

There is little existing information on soil erosion in the Maltese Islands, beyond a few specific case studies. There is no systematic erosion status/erosion susceptibility database, and consequently, no corresponding map of erosion risk for the Maltese Islands. In order to assess soil erosion in the Maltese Islands, a national team is currently undertaking preparatory works for a Soil Erosion/Desertification Assessment and Mapping activity scheduled to start in January 2000. This project is part of the CAMP Malta with particular emphasis on the Northwest area of the Island, and the responsible institutions are PAP/RAC, FAO/AGL, ERS/RAC and the Environment Protection Department of Malta. One of the objectives of this study is to introduce and apply the FAO/PAP consolidated mapping methodology and apply relevant prevention/rehabilitation techniques. The implementation of the project is based on the principle of sustainable development presented in Agenda 21; principles of the Guidelines on Integrated Coastal Area Management (ICAM) developed by PAP-UNEP and of Guidelines for Erosion Mapping and Measurement (PAP/RAC in collaboration with FAO). The expected project outputs will include basic digitized maps of erosion status and dynamics, supply of GIS and mapping equipment, photo catalogues and improved land use plans.

The final product of this project will be the physical assessment of erosion-prone areas and documentation of this in a cartographic database. This would be used in the identification of areas with a high priority for curative and remedial measures. This project is in line with the implementation of the United Nations Convention to Combat Desertification. Through the ratification of this Convention, the Government of Malta has taken the first measures towards

soil conservation. In a recent assessment of the state of the environment in the Maltese Islands (Axiaq et al., 1999), the need to survey the soil resources, and to estimate their erosion susceptibility, was identified as one of the most urgent priorities which the government should encourage and fund.

In view of Malta's application for EU accession, an increased interest in soil information has been demonstrated, especially in relation to compliance with EU Directives of the Environmental Acquis. The obligations in the Nitrate Directive, particularly the establishment of a code of good agricultural practice and the development of mandatory action programmes for the prevention of nitrate pollution of groundwater are heavily dependent on soil information. In Malta, nitrate is the principal pollutant of groundwater, but there is insufficient data to assess the nitrate leaching hazard and to restrict the use of fertilisers and organic manures by legal provisions. Similarly, the Directive regulating the use of sludge on agricultural land makes provisions for the application of sludge according to the background levels of heavy metals in the soils.

The existing national legislation and policies are inadequate to provide a legal framework for the protection and conservation of soils. Provisions to protect soil against activities contributing to soil erosion (e.g. reclamation of watercourses, reclamation of land that is exposed and/or steeply sloping, deforestation and/or clearing of wild vegetation) are absent and need to be added. Current legislation is primarily directed towards regulating activities leading to soil disturbance in large quantities, and there is no definition and consequently no legislation to preserve the soil's health, quality and fertility status. In view of the need to revise the existing acts and policies and to draft a comprehensive legislative framework for the protection of soils, soil information is essential as baseline data to promote the most sustainable options of soil management and to prohibit activities that could result in the deterioration and degradation of soil, and loss of soil quality.

Presently, the Environment Management Unit of the Planning Authority is co-operating with the Department of Agriculture to develop a system for the classification of agricultural land. This classification is to be based on a matrix of selected criteria and should allow evaluation of arable land for development applications in Outside Development Zones (ODZ). Soil information would constitute one of the criteria for the assigning a value to agricultural land, especially in relation to soil attributes (shallow soils, poor drainage, sodic soils) that constitute limitations for agricultural production. Although the primary aim of this exercise is to provide decision makers with a tool when dealing with development applications, the established criteria, including soil properties, are intended for use in agricultural land mapping.

### ***Direct outputs:***

#### (1) Soil Information System

This georeferenced soil database would serve as a basis for decision making, policy regulation, planning and development at the national and regional levels.

#### (2) National soil map (1:25,000)

#### (3) Detailed soil maps (1:5,000 to 1:1,000)

In view of the very small size of the Maltese Islands (combined area of the three islands is 316 km<sup>2</sup>), a national soil survey should be carried out at a detailed (2<sup>nd</sup> order) scale 1:12,000-1:32,000, to produce a general soil map of the entire country. Detailed map sheets for site planning purposes, would require intensive 1<sup>st</sup> order soil surveys typically at a scale of 1:1,000-1:5,000, since management decisions are often taken at the level of the individual field.

### ***Other outputs:***

#### (1) National Soil Unit

Unlike most European countries, Malta does not have a tradition of soil survey and cartography, and this originates from the absence of a dominant institution responsible for soil studies. It is generally agreed that national soil institutions should be responsible for collecting soil information and for monitoring of spatial and temporal changes in soil variables. International efforts for co-operation should be directed towards establishing and strengthening of such bodies, so that local knowledge and experience is nourished. In the absence of a single organisation whether state-owned or private, which is responsible for soil information and soil monitoring in Malta, it is recommended that a soil office be established within the Agricultural Research Centre of the Department of Agriculture. The Agricultural Chemistry Laboratory carries out monitoring of elementary soil characteristics through repetitive measurements (commercial soil fertility and salinity monitoring), therefore it is recommended to strengthen the existing structure. This unit would serve as the central co-ordinating agency for soil-related activities and would also be responsible for the management, maintenance and ownership of soil data.

#### (2) Soil Committee

An advisory technical and scientific committee for soil quality and management should be established. The committee would be composed of experts in different fields, and representing institutions already involved, or intending to become users of soil information (Planning Authority, Institute of Agriculture, University of Malta (Department of Biology and Chemistry), Roads Department, Department of Environment) to enable a multidisciplinary and collaborative approach to soil-related issues. This committee should be responsible for strengthening the Soil Office, planning and policies, and standardisation of methodologies for the surveying and monitoring of soils in Malta.

#### (3) Transfer of knowledge

An important element of this project is a transfer of knowledge. This should be achieved through an intensive programme of training of Maltese staff, both on-the-job and in the UK, in order that once established the Soil Information System can be continually updated and modified.

**Summary of expected benefits:**

Applications of MALSIS	National Requirements
Description of the state of the environment	Detailed updating of the existing soils map was identified as an urgent priority by the expert panel in the State of the Environment Report (Axiag et al., 1999).
Impact assessment	As established in the Environment Protection Act (1991), an impact assessment shall identify and assess the direct and indirect effects on the soil.
Risk assessment	Soil erosion risk maps could be used with hydrological data to model infiltration processes of unsaturated land zones.
Ecological rehabilitation of polluted sites	A soil database would provide a tool for drawing up policies for the protection of sites of scientific and ecological importance.
The base for research development, for new standard elaboration and for land use planning on appropriate level	A major problem in transferring technology and research to Maltese agriculture lies in the absence of detailed soil information.
Monitoring of the impact of natural factors and anthropogenic activities on soils The control of soil processes (degradation, development)	Extensive urbanisation, mixing and disturbance of topsoil is the major man-induced impact on soil which is not monitored.
Providing information for sustainable agriculture and rural development	Identification and protection of good grade agricultural land to ensure continued viability at present does not include soil quality criteria.
Providing information for the elaboration of soil and environment protection strategies	Soil information is a pre-requisite in elaboration of a Soil Code (the Code of Good Agricultural Practice for the Protection of Soil) which compliments guidelines and recommendations given the Water and Air Codes. At present there is no Soil Code for the Maltese Islands.
Providing information for the strategy and decisions on the control of soil fertility	The control of soil fertility is entirely absent from existing regulations and need to be included. This is especially important in view of the need to adopt sustainable nutrient management plans which have minimum impact on the environment.

Evaluation of soil protection measures and farm management practices	In the absence of a Code for the Protection of Soil, soil protection measures are not adopted by the farmers. Soil information would provide the basis for recommending farm management practices which aim at reversing trends in deteriorating soil quality.
Providing data for predictive models	In the absence of data on soils, predictive models cannot be applied. This is especially an important issue in the application of models for designating nitrate vulnerability of groundwater resources.
Serving as a basis of sound land use policy	In the absence of updated soil information, site inspections for evaluating applications for development permits reveal a large number of would-be coincidences wherein the interested sites are degraded beforehand.
Legal measures for soil protection (enforcement, penalisation, stimulation)	Provisions to protect soil against activities contributing to soil erosion are absent and need to be added to the national legislation.

### **Background Information**

The following information on the *geology*, *geomorphology* and *hydrology* of the Maltese Islands is taken from: HUGHES, K.J. 1999. 'Persistent features from a paleo-landscape: the ancient tracks of the Maltese Islands', *The Geographical Journal*, 165:1, 62(1).

"The Maltese archipelago, which includes Malta, Gozo and Comino, lies centrally in the Mediterranean Basin some 250 km from mainland Europe, 290 km from North Africa and 96 km from the island of Sicily. The islands are small: Malta, the largest has a surface area of only 245.7 sq. km, Gozo 67.1 sq. km. and Comino 2.8 sq. km. Boundary configurations, topography and their island status are the outcome of tectonic activity associated with active plate convergence, coupled with post-Quaternary sea-level changes. Like much of the Mediterranean, these islands are dominated by limestone; unlike neighbouring islands (Sicily and Pantelleria), igneous outcrops are entirely absent.

The islands are dominated by Mid-Tertiary, Oligo-Miocene carbonate rocks originating as sediments which accumulated in a shallow shelf environment. The relatively simple succession of limestone strata, interstratified by a calcareous clay facies, are generally only moderately flexured but are characterised by extensive faulting. The juxtaposition of strata of varying composition and thickness, displaced by Miocene and post-Miocene faulting, gives rise to a distinctive topography. The more competent beds of Coralline Limestone generally form upland plateau and ridges (horsts) while the less competent Globigerina Limestone,

extensive in Gozo and eastern Malta, is associated with a more undulating topography; the limited outcrops of Blue Clay form highly distinctive, unstable slopes in western Malta and Gozo. Surficial deposits of Plio-Quaternary age are limited to a few locations particularly around the coast, in fissure fillings and caves. The overall geometry of Malta has been determined by tilting and subsidence giving rise to a generally submerged northern boundary associated with shallow bays and coastal lowlands, in contrast to the pronounced elevation of the southern boundary characterised by dramatic, fault-controlled coastal cliffs.

The structural geology of the Maltese Islands is controlled by two distinct, superimposed fault systems which determine the topography. The uplift of the marine sediments and their subsequent warping, tilting and fracturing is associated with the position of the islands close to the leading edge of the African plate. Different tectonic stress regimes, accompanying crustal extensional processes, have produced a conjugate fault pattern with major, first generation faults generally striking east-north-east, responsible for the classic horst and graben topography, and a later system trending north-west; the islands are considered to be still experiencing neotectonic activity although the frequency and magnitude of earthquake activity is low.

Karstic phenomena, associated with the islands' structural and lithological inheritance, are common and sometimes remarkable. These include extensive small-scale lapies or karren solution features, terrestrial and submerged cave systems, and numerous, large-scale solution subsidence structures.

Geomorphological processes, intensified and accelerated by the juxtaposition of competent and incompetent sedimentary strata, Mediterranean climatic conditions, and most probably, superficial tectonic activity, are responsible for slope collapse. High magnitude mass wastage has been a persistent process in the landscape, testifying to the continuing instability of the islands and demonstrated by the ubiquitous masses of relict and contemporary block debris which clothe the steep slopes of the interior and the coastal cliffs.

In common with other Mediterranean islands, coastal bathymetry indicates that the surface area of each island has been considerably reduced by a transgressing sea. During periods of minimum sea level in the recent geological past, the islands were most probably connected to Sicily as the depth of the intervening sea is generally shallow, less than 90 metres and never deeper than around 200 metres. Remnants of raised beaches, submerged marine platforms and karstic phenomena indicate complex tectonic and eustatic changes which continue to affect the islands.

Surface water is generally transient in these islands; springs, at the Blue Clay - Upper Coralline Limestone junction are associated with semipermanent pools; the valleys, or wadiens of Pleistocene origin remain dry for much of the year but experience, irregular, flash-flooding after storms. The permeable limestones act as aquifers above (perched) and below the Blue Clay. While caves are numerous, only the Ghar Harq Hamiem cave in south-east Malta is known to contain freshwater at the present time. Although it is probable that the geology of the islands would have precluded the existence of surface water in the prehistoric period, the effects of climate change, sea-level changes and possibly geological perturbations are unknown."

#### ***Climate:***

Due to the geographical locations of the Maltese Islands exhibit a typical Mediterranean climate: hot, dry summers and mild, humid winters. The rain season falls between September

and March, with the last rainfall occurring in April. The average annual rainfall is 524mm and the temperature varies between 7°C and 15°C in January, to between 25°C and 35°C in August.

#### ***Land Use:***

Malta's agricultural potential is limited by its small size, its predominantly shallow soil cover and the major environmental constraint of insufficient and seasonal rainfall. Except where water is available for irrigation, cultivation is restricted to rain-fed, dry farming. Less than five per cent of the cultivated area is irrigated. Many dry-farmed fields have been abandoned and for economic and sociological reasons, this trend is unlikely to be reversed.

An analysis of land use changes in the past four decades shows a 42% decrease in agricultural land from 20,433 to 11,902 ha. Fragmentation is a dominant feature, and in fact, the number of holdings is still comparable to that in 1956 in spite of the shrinkage in total arable land.

#### ***Soil Information***

Soil forming factors as identified by Jenny (1941) include: parent material, relief, vegetation, climate and human influence. Of these Lang (1961) identifies three as being fundamental in the genesis of Maltese soils: parent material, climate and time.

##### *Parent material:*

The soils of the Maltese islands differ primarily due to the differences in chemical composition (carbonate content, clay content and other impurities), and the physical constitution of the rock.

##### *Time:*

Soils of Malta and Gozo are rather young or immature soils. This is due to the fact that pedological processes are slow in calcareous soils.

##### *Climate:*

The uniformity of the arid climate is cited as a determining factor in the restricted range of soils found in Malta and Gozo.

##### *Topography:*

Identifying soils is possible through the study of the topography, as soils associated with various rock strata have characteristic topographic features.

D.M. Lang is responsible for the only detailed study of the soils of Malta and Gozo. The soil survey was carried out from 1956-57 and finalised in 1960 with a soil map of the Maltese Islands published. The map was published on a scale of 1:31,680 (2 inches to 1 mile).

Lang's main objective of the soil survey was to provide basic descriptions of the soils and map their distribution as an aid to agricultural planning. In view of this he mapped differences in chemistry, physics, and biology of the soil, as reflected in soil colour, texture, and structure, in conjunction with the landscape type.

The geological and climatic controls have been very distinctive in the genesis of the soils of Malta and Gozo. However, the existing soils are complex and difficult to categorise owing to centuries of intense human activity. To accommodate for this Lang used profiles relatively untouched by man. The principal modes of soil disturbance are: carting, quarrying, manuring and terracing.

In classifying the soils of the Maltese Islands Lang adopted the system developed by Kubiena (1953) (Fig. 1). According to this classification system three sub-types were recognised: carbonate raw soils, xerorendzinas and terra soils.

**Figure 1:** Classification of Maltese soils according to Kubiena (1953)

Division	Class	Type	Sub-type (qualified)	Variety	Locality/Series
A. Sub-aqueous					
B. Semi-terrestrial	BA. Semi-terrestrial raw soils	VI Rambla	12. Chalk Rambla		Ghadira Alcol
	BD. Salt soils				
C. Terrestrial	CA. Terrestrial raw soils	XXIII Syrosem	50. Carbonate raw soil		Fiddien, San Lawrenz, Nadur, Ramla, part S.B.
	CC. Rendzina-like soils	XXV Rendzina	60. Humid Rendzina	(36) Protorendzina Mull rendzina	Malta E. Malta P.
			61. Xerorendzina	Xerorendzina	San Biagio Alcol Tal-Barrani
	CE. Terrae Calxis	XXXIII Terra	74. Terra fusca	(47) Earthy terra fusca	Xaghra, Tas-Sigra
			75. Terra rossa	(48) Siallitic terra rossa	

### **Methodology:**

Lang commenced the survey of Maltese soils with the following methodology:

1. preliminary reconnaissance accompanied by the digging of occasional profile pits to gain general impression of soil characteristics and identify 'typical soils'
2. use of small pits and auger borings to delineate extent of 'typical soils' and range of characteristics of these soils.

However, largely as a result of the intensive use of the land Lang noted that:

- the soils change very rapidly over short distances, especially in strongly terraced areas.
- pedological horizons are nearly impossible to distinguish - although this was not limited to cultivated areas. Pedological processes are slow on calcareous parent materials under the Maltese climate.

As a result it was necessary to map much of the islands as complexes of series.

A strong correlation between geology, and the natural and cultural landscapes made it possible to do some of the mapping from aerial photographs, using landscape boundaries as the boundaries of some series and complexes. This provided the basis for the method finally adopted by Lang, which involved:

1. *traversing across the 'grain' of the country examining profiles and locating boundaries*
2. *extending and adding new landscape boundaries from aerial photographs.*

The observations were recorded on 6 inch maps. These maps were edited and reduced to the 2 inch scale, resulting in some loss of detail. Information detailing the number of observations made is lacking, although it is noted that just 10 sq. miles in two areas were mapped in detail using borings. While the remaining 112 sq. miles were mapped mainly by the use of aerial photographs and checking traverses.

During the survey a number of profiles were dug, described in some detail, and sampled: Malta (23) and Gozo (17). These profiles were chosen as representative of each series, described in some detail, and sampled. The following table lists the parameters described and the chemical analysis carried out:

<b>SITE CHARACTERISTICS:</b>	
<i>altitude; aspect; crop or natural vegetation; depth of water-table; drainage; irrigation; anthropogenic, features (e.g. terracing, soil dumping, manuring); geomorphological locations</i>	given were appropriate to aid interpretation of topographic location
<i>mesoclimate description</i>	details describing areas where local modifications of climate could be expected (e.g. insolation variations with aspect)
<i>topographic amplitude</i>	height from valley bottom to ridge crest and the height of lesser topographic features in the landscape (e.g. river terraces)
<i>personel description</i>	where possible a local inhabitant was asked his opinion
<i>site or profile photographed</i>	
<b>HORIZON DESCRIPTIONS:</b>	
<i>soil colour</i>	Munsell Soil Colour Charts were used
<i>soil texture</i>	use of definitions given in the Soil Survey Handbook (USDA, 1956)
<i>consistence</i>	use of definitions given in the Soil Survey Handbook (USDA, 1956)
<i>structure</i>	use of definitions given in the Soil Survey Handbook (USDA, 1956)

<b>CHEMICAL ANALYSIS:</b>	
pH; organic matter content; C:N ratio; phosphorus as P <sub>2</sub> O <sub>5</sub> , total and available; the exchangeable cations; calcium carbonate, total and active; water soluble salts	

**Classification:**

The carbonate raw soils and xerorendzinas are immature soils of similar genesis, both having developing from weathering of the Globigerina Limestone. These fine textured limestones impede the percolation of rainfall, which accounts for the raw nature and high calcium carbonate levels of these soils.

The xerorendzinas are the most common soils found on the Maltese Islands. They are ash grey in colour and have a humus content of 2-5 per cent.

The carbonate raw soils are distinctively light in colour, becoming white when dry. This reflects the very high calcium carbonate content and very low content (< 2 per cent) of organic matter. They exhibit very little profile differentiation.

Soils within the class *Terrae Calxis* were also identified. This group is comprised of relict soils developed from weathering processes active during the Pleistocene when the regional climate was warm and markedly wetter than it is now. These paleosols are a distinctive dark brown or red colour and possess a humus content of approximately 5 per cent and are composed of less than 15 per cent of calcium carbonate. These soils are the most agriculturally valuable of Malta's soils and are located on both the Globigerina and Coralline outcrops wherever karstic processes, with the associated percolation and solutioning, has facilitated decalcification. It is noted that this process of decalcification would have been slow, even with the favourable pedogenic forces of the Pleistocene. Houston (1964) estimates that 400m of limestone would have to be decalcified in order to yield 1m of soil. This explains their predominately shallow nature.

Lang differentiates between two sub-types: *terra rossa* and *terra fusca*. He regards the series' that comprise the Terra soils as being predominately earthy *terra fuscas*, with transitions to siallitic *terra rossa*. These soils are the most agriculturally valuable of Malta's soils.

Lang further subdivided the subtypes into a 'series' of soils named after the localities where Lang had originally encountered them:

**Carbonate raw soil** - a very young, raw soil, low in humus and with an (A)C profile, formed on calcareous parent material.

- **Ramla Series:** a deep, brown, loose sand, low in humus, of very limited extent. They occur locally on the northern coastal slopes either alone as in Ramla valley in Gozo or in a complex with Tas-Sigra soils as in Marfa Ridge in Malta. These soils are formed on calcareous stratified sands of contemporary or Quaternary dune beds, through natural physical disintegration or through quarrying. Chemical weathering of these soils is minimal, accounting for their raw state and lack of horizon differentiation.

- *Nadur Series*: a shallow, reddish brown to yellow, light textured, loose soil, limited mainly to a narrow strip of strongly terraced land along the upper part of the slopes of the main scarps. These soils are formed either *in situ* by physical weathering or by man from Greensand and Upper Corraline Limestone, or from poorly sorted colluvium derived from such soft limestone.
- *Fiddien Series, heavy type*: olive coloured, shallow to moderately deep, heavy, plastic, sticky clay with a prismatic structure breaking down to medium subangular blocky. It is frequently alkaline and, in addition, sometimes saline. The soil has formed in place from the Blue Clay with very little chemical weathering, apart from oxidation of newly exposed clay and occurs on the upper slopes of scarps, remnant hillocks and flat valleys of the Blue Clay lying above the Globigerina dissected plateau.
- *Fiddien Series, light type*: a moderately deep, grey brown, gritty clay loam with a fine granular structure in the surface horizon. Exhibits similar structure to heavy type and occurs on the upper slopes of scarps, remnant hillocks and flat valleys of the Blue Clay lying above the Globigerina dissected plateau. Also occurs on the lower slopes, formed on locally transported colluvial Blue Clay. These soils frequently exhibit an overwash of Nadur or Terra material.
- *San Lawrenz Series*: a moderately deep, light olive brown, medium to heavy textured soil with a moderate granular structure. These soils occur as a thin belt at the foot of the scarp of the Blue Clay and on the upper edge of the Globigerina, below the Fiddien soils and above the San Biagio soils. The soil has formed from a mixture of alluvium and colluvium from the Blue Clay and the soft Upper Globigerina.

*Xerorendzinas* - a "rendzina, ash grey in colour, usually very loose, when dry in general very powdery, with extremely high chalk content often also of water soluble salts, particularly gypsum; occurring in dry regions" (Kubienna, 1953).

- *San Biagio Series*: a shallow to moderately deep, whitish, medium textured soil, with a weak medium subangular blocky structure, with a crust that develops in the early summer season. They are slightly decalcified, slightly humus-enriched with an A C R profile developed on Globigerina soft limestones and marls. The soils are found principally at the foot of the main scarps, where they are strongly terraced, and in the dissected low plateau below the scarps. No natural soil can be found. The whole area of these soils, the most extensive soil in agricultural use, has been reworked.
- *Alcol Series*: very deep, brown, fine sandy clay loams and silty clay loams with a moderate, medium, granular surface layer. They are moderately decalcified, with a humus-enriched surface layer and an AC profile. The series is found developed in the broader flat valleys bottoms and is formed from the valley loams, composed of alluvial and colluvial material eroded from the terra, rendzina and carbonate raw soils. These soils are well suited to intensive irrigated mechanised agriculture.
- *Tal Barrani Series*: a broad range of shallow to moderately deep, reddish brown to brown, medium to heavy textured soils with a fine granular layer under a thin surface crust. The artificial nature of these soils partly accounts for this variability. They are moderately decalcified, with a humus-enriched surface layer and have an A C D profile. These soils occur on the broad, low hills, strongly dissected with rounded shoulders and smooth slopes, found mainly in south Malta. They have formed, it is believed, on massive, fine textured Globigerina limestone similar to and including Franka.

## ***Terra Soils***

- *Xaghra Series*: very shallow to very deep, red, heavy textured (clay and clay loam), decalcified soils with a strong subangular or angular blocky structure, occurring intermittently among hard limestone bedrock outcrops of Upper Coralline, Franka and Lower Coralline, on the karst landscape, little altered by man. The soils are strongly decalcified, with a humus-enriched surface layer and an A C D profile, on an almost completely decalcified B horizon soil material of a relic soil.
- *Tas-Sigra Series*: moderately deep to very deep, red, heavy textured (clay and clay loam) soils with a strong granular or subangular blocky surface horizon. They are strongly decalcified, with a humus-enriched surface layer and an AC profile which is believed to have formed on strongly decalcified B horizon of a relic soil. The series are found on nearly level land. They occur on deep alluvial deposits, in valleys and dolines of the main karst area and in weakly karstic Franka limestone where rock outcrops are absent.

In addition, Lang mapped one association and three complexes:

- *Rdum sequence*: a lithosequence on scarp slopes
- *Armeir complex*: a natural complex due to mixed parent materials
- *L'Inglin complex*: a man-made complex due to terracing on the steep slopes
- *Tad Dawl complex*: a man-made complex in quarries

## ***Soil Moisture Regime***

According to a source at the National Soil Survey Center (NSSC) of the United States Department of Agriculture (USDA) Malta has a *xeric moisture regime*:

“The xeric (Gr. *xeros*, dry) moisture regime is the typical moisture regime in areas of Mediterranean climates, where winters are moist and cool and summers are warm and dry. The moisture, which falls during the winter, when potential evapotranspiration is at a minimum, is particularly effective for leaching. In areas of a xeric moisture regime, the soil moisture control section, in normal years, is dry in all parts for 45 or more consecutive days in the 4 months following the summer solstice and moist in all parts for 45 consecutive days in the 4 months following the winter solstice. Also, in normal years, the moisture control section is moist in some part for more than half of the cumulative days per year when the soil temperature at a depth of 50 cm from the soil surface is higher than 6°C or for 90 days or more consecutive days when the soil temperature at a depth of 50 cm is higher than 8°C. The mean annual soil temperature is lower than 22°C, and the mean summer and mean winter soil temperatures differ by 6°C or more either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact if shallower.”

## ***Soil Temperature Regime***

According to the same source, Malta experiences a *thermic temperature regime*:

“The mean annual soil temperature is 15°C or higher but lower than 22°C, and the difference between mean summer and mean winter soil temperatures is more than 6°C either at a depth of 50 cm from the soil surface or at a densic, lithic or paralithic contact, whichever is shallower.”

With regard to both the soil moisture regime and the soil temperature regime, they are based on assumption rather than fact. Hence, they need confirmation through further studies.

In the early 1970's, and FAO consultant mission prepared a report on the soils Malta within the scope of a WHO special Fund Project on Wastes Disposal and Water Supply to study the nature of the soils in prospective irrigation areas and to assess their suitability for irrigation with sewage effluent. On the basis of this study, areas of soils were demarcated on a topographic base map according to defined irrigation suitability classes. The same study provides a tentative classification of Maltese soils into families in the USDA Revised System and according to the FAO system (key to soil units for the soil map of the world).

***Classification of Maltese soils according to USDA revised system:***

Ramla	sandy, carbonatic, calcareous, Typic Ustorthent
Nadur	coarse loamy, carbonatic, calcareous, Typic Ustorthent
Fiddien	fine clayey, mixed calcareous Typic Ustorthent
San Lawrenz	fine loamy, carbonatic, calcareous Typic Ustorthent
San Biagio	fine loamy, carbonatic, calcareous Lithic Typic Ustorthent
Alcol	fine loamy, carbonatic, calcareous, Rnedollic Ustochrept
Tal-Barrani	fine loamy, carbonatic, calcareous, Rnedollic Ustochrept
Xaghra	fine clayey, mixed calcareous Typic Ustochrept
Tas-Sigra	fine clayey, mixed calcareous Typic Ustochrept

(Source: FAO, 1971)

The classification of Maltese soils in accordance with the 7<sup>th</sup> approximation prior to the publication of Soil Taxonomy in 1975, places the carbonate raw soils and the San Biagio series of the xerorendzinas into the Entisol order of Soil Taxonomy.

Torrent (1995) writes: "Entisols are mineral soils with little or no evidence of pedogenetic horizons...arising from a too short pedogenesis period, geomorphic instability or little weatherability of the parent materials."

Five Entisol suborders are recognised: *Aquents* (poorly developed wet soils), *Ardents* (disturbed by man), *Psammments* (sandy), *Fluvents* (alluvial soils with irregular organic matter ditribution in depth), and *Orthents* (other Entisols). Orthents are, by far, the most abundant Entisols in the Mediterranean region and account for the Entisols of the Maltese Islands.

***Order - Entisol***

***Suborder - Orthents:***

"Other Entisols."

***Great Group - Xerorthents:***

"Other Orthents that have a xeric moisture regime."

***Subgroup - Typic Xerorthents:***

“Other Xerorthents.”

*Subgroup - Lithic Typic Xerorthents:*

“Other Xerorthents that have a lithic contact within 50 cm of the mineral soil surface.”

The remaining series within the xerorendzinas: alcol and tal-barrani series; together with the terra soils are classified as *Ustochrepts*, a great group of the order *Inceptisols*: “young, immature soils whose pedogenic features are less outstanding than in mature soils” (Torrent, 1995).

However, the great group is not present in the “Keys to Soil Taxonomy, eighth edition, 1998”. The great group Ustochrepts was deleted from Soil Taxonomy in 1975 and replaced with the great group *Xerochrepts*. The great group Xerochrepts was then deleted from Soil Taxonomy in 1998 and was replaced with the suborder *Xerepts*.

*Order - Inceptisols*

*Suborder - Xerepts:*

“Other Inceptisols that have a xeric soil moisture regime.”

The terra soils were classified as Typic Ustochrepts. With regard to the latest Soil Taxonomy, these are likely to be *Typic Haploxerepts*.

*Great Group - Haploxerepts:*

“Other Xerepts.”

*Subgroup - Typic Haploxerepts:*

“Other Haploxerepts.”

While the Rendollic Ustochrepts (alcol and tal-barrani series) will likely be *Calcixerepts* in either an aridic or typic subgroup.

*Great Group - Calcixerepts:*

“Other Xerepts that *both*:

1. Have a calcic horizon with its upper boundary within 100 cm of the mineral soil surface or a petrocalcic horizon with its upper boundary within 150 cm of the mineral soil surface; *and*
2. Are calcareous in all parts above the calcic or petrocalcic horizon, after the soil between the mineral soil surface and a depth of 18 cm has been mixed.

*Subgroup - Aridic Calcixerepts:*

“Other Calcixerepts that have, when neither irrigated nor fallowed to store moisture, *one* of the following:

1. A frigid temperature regime and a moisture control section that in normal years is dry in all parts for four-tenths or more of the cumulative days per year when the temperature at a depth of 50 cm below the soil surface is higher than 5°C; *or*

2. A mesic or thermic soil temperature regime and a moisture control section that in normal years is dry in some or all parts for six-tenths or more of the cumulative days per year when the temperature at a depth of 50 cm below the soil surface is higher than 5°C; or
3. A hypothermic, isomesic, or warmer *iso* soil temperature regime and a moisture control section that in normal years:
  - a. Is moist in some or all parts for fewer than 90 consecutive days per year when the temperature at a depth of 50 cm below the soil surface is higher than 8°C; and
  - b. Is dry in some or all parts for six-tenths or more of the cumulative days per year when the temperature at a depth of 50 cm below the soil surface is higher than 5°C.

**Subgroup - Typic Calcixerepts:**

“Other Calcixerepts.”

**Classification of Maltese soils according to FAO system:**

Ramla	Calcaric Regosol
Nadur	Calcaric Regosol
Fiddien	Calcaric Regosol (in some places Chromic Vertisol sodic)
San Lawrenz	Calcaric Regosol
San Biagio	Calcic Cambisol lithic
Alcol	Calcic Cambisol
Tal-Barrani	Calcic Cambisol
Xaghra	Chromic Cambisol
Tas-Sigra	Chromic Cambisol

(Source: FAO, 1971)

The FAO report was published in 1971, three year prior to the inception of the Legend of the Soil Map of the World (FAO-UNESCO, 1974). Hence, there is some uncertainty as to how these classifications were realised. Further investigation is required regarding this point.

With reference to the “Key to the FAO Soil Units” as contained in the “Legend of the Soil Map of the World” (1974, UNESCO, Paris) the classifications are defined as follows:

**Regosols:**

“Other soils having no diagnostic horizons or none other than (unless buried by 50 cm or more new material) an *ochric* A horizon.”

**Calcaric Regosols (Rc):**

“Other Regosols which are calcareous at least between 20 and 50 cm from the surface”.

**Vertisols (V):**

“Other soils which, after the upper 20 cm are mixed, have 30 per cent or more clay in all horizons to at least 50 cm from the surface; at some period in most years have

cracks at least 1 cm wide at a depth of 50 cm, unless irrigated, and have one or more of the following characteristics: gilgai microrelief, intersecting slickensides or wedge-shaped or parallelepiped structural aggregates at some depth between 25 and 100 cm from the surface”.

*Chromic Vertisols (Vc):*

“Other Vertisols” than “Vertisols having moist chromas of less than 1.5 dominant in the soil matrix throughout the upper 30 cm”.

*Chromic Vertisol sodic:*

“Other Vertisols” with “an exchangeable sodium percentage (ESP) of more than 15 within 50 cm from the soil surface”.

*Cambisols (B):*

“Other soils having a *cambic* B horizon or an *umbric* A horizon which is more than 25 cm thick.”

*Calcic Cambisols (Bk):*

“Other Cambisols showing one or more of the following: a *calcic* horizon or a *gypsic* horizon or concentrations of soft powdery lime within 125 cm of the surface when the weighted average textural class is coarse, within 90 cm for medium textures, within 75 cm for fine textures; calcareous at least between 20 and 50 cm from the surface.”

*Calcic Cambisol lithic:*

As above, with a “continuous hard rock within 10 cm from the soil surface”.

*Chromic Cambisols (Bc):*

“Other Cambisols which have a strong brown to red B horizon (rubbed soil has a hue of 7.5YR and a chroma of more than 4, or a hue redder than 7.5 YR).”

Torrent (1995) produced a useful table comparing the classifications, according to FAO and USDA, of the soils most evident in the Mediterranean region. A copy of this table follows, with minor alterations were necessary.

Order <sup>(a)</sup>	Suborder <sup>(a)</sup>	Group <sup>(a)</sup>	FAO Soil Grouping <sup>(b)</sup>
Entisols	Orthents	Xerorthents	Leptosols, Regosols
	Fluvents	Xerofluvents	Fluvisols
	Psamments	Quartzipsamments, Xeropsamments	Arenosols
Inceptisols	Xerepts <sup>(c)</sup>	Haploxerepts	Cambisols,

		Cacixerepts Durixerepts Fragixerepts Dystoxerepts	Calcisols
Vertisols	Umbrepts	Xerumbrepts	Cambisols
	Xererts	Calcixererts	Vertisols
		Haploxererts	Vertisols
Alfisols	Xeralfs	Rhodoxeralfs	Luvisols
		Palexeralfs	Luvisols
		Haploxeralfs	Luvisols
		Natrixeralfs	Luvisols
Mollisols	Xerolls	Calcixerolls	Kastanozems
		Haploxerolls	Phaeozems
Ultisols	Xerults	Palexerults	Acrisols
		Haploxerults	Acrisols
Aridisols	Orthids	Salorthids	Solonchaks

<sup>(a)</sup> According to Soil Survey Staff (1992)

(Source: Torrent, 1995)

<sup>(b)</sup> Where the group is partly or totally included

<sup>(c)</sup> According to Soil Survey Staff (1998)

### **Soil Regions of Europe**

A detailed study of the Maltese soils by D.M. Lang in 1956-57 resulted in their classification, following the system established by Kubiena (1953). Later, a tentative reclassification was made by FAO (1971), in order to allow representation of the soils of the Maltese Islands in the Soil Regions Map of Europe at scale 1:5,000,000. Of a total of 172 soil regions, created as combinations of 75 different soil associations and 14 different parent material associations the following soil region was determined to be relevant:

No.	Soil Region and Dominant Soils	Dominant Parent Material	Climatic Data	Altitude and Major Landform
<b>62.</b>	<b>Cambisols - Vertisols - Luvisol Regions</b>			
62.2	Cambisol-, Luvisol-Region, with Leptosols, Andosols and Vertisols, of Sicilia (Italy) (CMv, Cme, LVx, LPk, ANh, VRk)	tertiary, partly cretaceous and jurassic clayey deposits, calcareous rocks, flysch	mean annual temp: 16.4 - 18.6°C mean annual precip: 500 - 850mm months of highest precip: Dec-Jan months of drought: May-Sept months with temps below zero: --	0-1900 m sloping to steep land

This is comparable to Malta and Gozo, as follows:

Dominant Soils	Dominant Parent Material	Climatic Data	Altitude and Major Landform
----------------	--------------------------	---------------	-----------------------------

Cambisols - Vertisols - Regosols	marine sedimentary rocks, mainly limestones of Oligo-Miocene age. Minor Quaternary deposits of terrestrial origin.	mean annual temp: 18.6oC  mean annual precip: 529.6mm  Months of highest precip: Nov - Jan months of drought: June - Aug months with temps below zero: - -	0 - 253m  plains and shallow depressions seperated by low hills
--	--	--	---

### Dominant Soil Types

The information detailing which soils dominate the Maltese Islands are derived from a report prepared by a FAO consultant mission during the early 1970s. The report provides a tentative reclassification of the soils, from Lang (1960), according to the FAO system. The tentative nature of the classification should be noted.

### Parent Material Association

Hughes (1999) described the Maltese Islands as being 'dominated by Mid-Tertiary, Oligo-Miocene carbonate rocks originating as sediments which accumulated in a shallow shelf environment'.

### Climatic Area

With regard to the established climate classifications (e.g. FAO, 1993), four major climates can be related to Europe. Of these Malta demonstrates a **Mediterranean climate**, characterised by:

*Winter rain and droughts in summer, and the high evaporation entails a water deficit. There is hardly any frost risk and accordingly agriculture produces frost-sensitive crops like citrus fruit, olives or grapes. The natural vegetation consists of e.g. evergreen oaks or laurel and coniferous woods with pine, cypress or juniper. Corresponding to the climate, the soil-forming processes are influenced by rainfall and drought and these cause on the one hand migration and accumulation of clay or calcium carbonate (Luvisols, Vertisols, Calcisols) and, in areas with an intense relief, on the other hand erosion (Leptosols).*

Further subdivision of the major climates can be obtained by adding the seasonal and daily equability of humidity and temperature. That, in relation to the Maltese Islands, fits best into the description of a **oceanic or maritime type**:

*Typical are the low daily and annual variations of air temperature (the mean monthly temperatures, calculated for one year, vary less than seven degrees), day and night and summer and winter are very equable. In general, the mean annual precipitation falls as rain and is higher than in continental climate.*

Combinations of the major climates with climatic type are related to areas with different climatic conditions, characterised by precipitation, temperatures and in some cases by the vegetation period. With regard to Europe, nineteen such areas have been defined.

The Maltese Islands; defined by a Mediterranean climate, of oceanic or maritime type, accords with climatic type:

**42 - mediterranean-oceanic to mediterranean-suboceanic climate, partly mountainous climate**

*medium to high precipitation in autumn, winter and springtime, regional only a short dry period in summer.*

However, here the logic of the system breaks down, as climatic type 42 does not accurately describe the climate as of the Maltese Islands. Rather, the climate is most aptly defined by climate type:

**43 - mediterranean-subcontinental to mediterranean-continental climate**

*medium to very low precipitation in springtime, autumn and winter, long dry period in summer, partly arid, cold winter and hot summer.*

It should therefore be inferred that the Maltese Islands exhibit a Mediterranean climate of subcontinental type. This refers to a transitional type with relation to a Continental type climate as that of Continental type is highly inappropriate.

*Altitudes and Major Landforms*

According to the first level of the SOTER program the following major landforms describe the most general features of the morphology of a landscape: level land, sloping land, steep land and land with composite landforms. As some soil regions exhibit more than one type of morphology, combinations of these four major landforms were also used. This is the case of the soil region applicable to the Maltese Islands, described as: sloping to steep land.

A general description of the morphology of Malta and Gozo is given by Chetcuti et al. (1992). In order to describe the general features of the morphology of the landscape according to the 2<sup>nd</sup> level in SOTER (1993) it is necessary to obtain more detailed data - gradient and relief intensity. This information may be obtainable from the Planning Authority.

**APPENDIX A**  
**Cartographic Data**

Type of map	Organization	Area covered	Date	Scale	Remarks
Topographical maps	Public Works Department	Malta & Gozo	1968	1:2500	Available in print form
Topographical maps	Planning Authority	Malta & Gozo	1990	1:25000	Available in print and digital form
Topographical maps	Planning Authority	Malta & Gozo	1990	1:25000	Available in print and digital form
Geological maps	Department of Information	Malta & Gozo		1:25000	
Soil map	Department of Agriculture	Malta & Gozo	1960	1:31680	
Land registration (tenancy)	Department of Agriculture	Malta & Gozo	N/A		outdated
Land use (agriculture)	Department of Agriculture	Malta north (pilot area)			
Habitat data (rural)	Environmental Management Unit, Planning Authority	Selected areas			Circulation restricted

## APPENDIX B

### Soil Data

LANG, D.M. 1960. *Soils of Malta and Gozo: Colonial Research Studies No. 29*, Colonial Office, London: HMSO. (in: Lang.xls)

<i>Table 1:</i>	Summary of analyses of normal soils
<i>Table 2:</i>	General chemical analyses
<i>Table 3:</i>	Exchangeable cations
<i>Table 4:</i>	Selected samples analysed for total CaCO <sub>3</sub> , and soluble salts
<i>Table 5:</i>	pH measurements at different dilutions

SIVARAJASINGHAM, S. 1971. *Wastes Disposal and Water Supply, Malta: The Soils of Malta*, AGL:SF/MAT 5, Rome: FAO. (in: FAO(1971).xls)

<i>Table 1:</i>	Summary of LANG (1960)
<i>Table 2:</i>	Analytical data of soils - pH values
<i>Table 3:</i>	Analytical data of soils - soluble salts

Table 5

Ph measured at various dilutions of the soil solution

Series	Profile No.	Depth (cm)	soil : water ratio				
			1 : 1	1 : 2.5	1 : 5	1 : 10	1 : 25
CARBONATE RAW SOILS							
ramla	gozo N	5-15	7.91	7.80	8.20	8.51	8.91
nadur	gozo R	0-15	7.99	8.59	8.50	8.60	8.79
fiddien	gozo I	8-18	8.15	7.73	8.43	8.50	8.83
san lawrenz	gozo A	10-20	8.21	8.55	8.72	8.78	9.27
XERORENDZINAS							
san biagio	gozo B	topsoil	7.69	8.49	8.29	8.80	9.10
alcol	malta K	43-53	8.40	8.95	8.81	9.10	9.30
alcol	malta X	5-15	8.12	8.75	8.70	8.97	8.58
TERRA SOILS							
carted	gozo Q	13-23	7.80	8.37	8.17	8.38	8.42

Table 3

## ANALYTICAL DATA OF SOILS - SOLUBLE SALTS

Lab. No.	Series	Location, pit No.	Depth (cm)	Total CaCO <sub>3</sub> (%)	pH 0.01M CaCl <sub>2</sub>	Condy. paste (micromho/cm)	Condy. (micromho/cm)	1.5 Soil Water Extract										
								Solub. salt (%)	Ca <sup>++</sup> (mg/l)	Mg <sup>++</sup> (mg/l)	Na <sup>+</sup> (mg/l)	K <sup>+</sup> (mg/l)	CO <sub>3</sub> <sup>-</sup> (mg/l)	HCO <sub>3</sub> <sup>-</sup> (mg/l)	Cl <sup>-</sup> (mg/l)	SO <sub>4</sub> <sup>-</sup> (mg/l)		
1	san biagio	Ta Qali, 1	0-23	60	7.7	310	225	0.70	20.0	3.6	41.4	4.3					(28.4)	0.0
2			23-109	68	8.1	330	268	0.04	16	4.8	55.2	2.0					(28.4)	62.4
3			109-203	73	8.1	450	237	0.02	20.0	2.4	43.7	1.6					(28.4)	52.8
4			203-282	75	8.1	620	306	0.06	22	3.6	50.6	1.6	3	85.4			(28.4)	57.6
5			282-381	79	8.1	950	300	0.10	24	2.4	48.3	2.0	6	79.3			(28.4)	62.4
6			381-406	86	8.2	670	237	0.03	16	9.6	48.3	1.6	3	54.9			(28.4)	62.4
7	san biagio	Ta Qali, 2	0-15	66	7.7	460	300	0.05	32	2.4	36.8	2.3	6	103.7			(28.4)	62.4
8	san biagio	Ta Qali, 3	0-15	49	7.8	1045	202	0.11	34	3.6	23.0	2.7	18	97.6			14.9	24.0
9			15-53	60	8.0	538	202	0.15	28	2.4	25.3	0.8	12	97.6			14.9	24.0
10			53-69	80	8.1	759	165	0.09	16	7.2	32.2	1.2	0	79.3			14.9	14.4
11	san biagio	Ta Qali, 4	0-13	57	7.8	482	200	0.19	36	7.2	16.1	1.6	6	134.2			12.1	48.0
12			20-30	58	8.1	398	170	0.20	20.0	7.2	23.0	1.2	6	85.4			18.1	43.2
13	san biagio	Ta Qali, 5	0-13	49	7.9	1330	207	0.45	32	3.6	23.0	1.2	6	122.0			14.9	38.4
14			20-30	50	8.3	1645	218	0.30	22	8.4	39.1	1.2	3	103.7			27.0	48.0
15			30-41	71	7.9	1957	236	0.19	22	7.2	39.1	1.6	0	85.4			33.0	67.2
16	san biagio	Ta Qali, 6	0-13	51	7.6	1142	219	0.10	26	7.2	29.9	1.6	6	109.8			20.9	67.2
17			18-28	73	7.9	802	191	0.14	18	3.6	32.2	1.2	0	73.2			14.9	24.0
18	san biagio	Ta Qali, 7	0-15	50	7.4	1110	274	0.14	36	4.8	36.8	2.3	6	115.9			17.8	57.6
19			30-46	52	7.9	1730	160	0.10	14	3.6	32.2	1.2	0	67.1			10.7	48.0
20	san biagio	Qormi, 8	0-36	78	7.9	1360	214	0.19	22	1.2	39.1	1.6	3	85.4			39.1	43.2
21			36-69	72	7.7	1685	293	0.19	38	3.6	36.8	1.2	3	85.4			28.4	72.0
22			69-117	67	8.0	686	175	0.07	20.0	1.2	25.3	1.2	0	67.1			17.8	62.4
23			117-137	77	8.0	512	166	0.06	20.0	0.0	27.6	1.2	0	61.0			10.7	19.2
24	san biagio	Qormi, 9	0-18	72	7.9	748	193	0.17	20.0	1.2	32.2	1.6	3	85.4			14.2	0.0
25			18-33	79	8.0	610	188	0.17	14	1.2	39.1	1.6	0	97.6			17.8	4.8
26			33-36	77	7.5	1060	218	0.13	24	4.8	32.2	1.2	0	91.5			28.4	38.4
27			61-94	74	7.5	1098	248	0.14	20.0	2.4	29.9	1.2	0	91.5			28.4	9.6
28			94-154	76	7.6	915	218	0.09	22	4.8	36.8	1.2	3	67.1			24.9	38.4
29	san biagio	Qormi, 10	0-23	76	7.7	552	183	0.16	22	2.4	32.2	1.6	6	103.7			28.4	19.2
30			23-41	76	7.7	678	180	0.08	24	2.4	29.9	1.2	6	97.6			24.9	43.2
34			41-48	77	7.7	650	171	0.09	22	7.2	23.0	2.0	6	79.3			21.3	48.0
32			71-112	75	7.7	707	177	0.09	22	1.2	27.6	0.8	3	67.1			17.8	48.0
33			112-130	73	7.7	590	183	0.08	18	3.6	27.6	0.8	0	67.1			17.8	43.2
37	tas sigra	Ghaxaq, 11	0-15	50		494	196	0.09					3	115.9			24.9	
36			15-41	45	7.6	585	165	0.06	20.0	3.6	25.3	2.3	6	85.4			14.2	24.0
35			41-61	56	7.7	507	167	0.06	18	2.4	34.5	0.8	6	48.8			14.2	19.2



Table 3

Lab. No.	Series	Location, pit No.	Depth (cm)	Total CaCO <sub>3</sub> (%)	pH 0.01M CaCl <sub>2</sub>	Condy. paste (micromho/cm)	1.5 Soil Water Extract									
							Condy. (micromho/cm)	Solub. salt (%)	Ca <sup>++</sup> (mg/l)	Mg <sup>++</sup> (mg/l)	Na <sup>+</sup> (mg/l)	K <sup>+</sup> (mg/l)	CO <sub>3</sub> <sup>--</sup> (mg/l)	HCO <sub>3</sub> <sup>-</sup> (mg/l)	Cl <sup>-</sup> (mg/l)	SO <sub>4</sub> <sup>--</sup> (mg/l)
95	tas sigra	Pwales, 30	0-33	26			264	0.18	22	6.0	43.7	6.6	0	146.4	24.9	4.8
96			33-66	16			373	0.16	22	1.2	78.2	2.0	3	115.9	53.3	38.4
97			66-130	10			506	0.23	32	6.0	85.1	1.6	3	91.5	88.8	52.8
98			130-152	4			560	0.13	36	4.8	92.0	2.3	3	91.5	117.2	38.4
99			152-160	55			403	0.20	24	13.2	59.8	2.3	6	103.7	78.1	24.0
100	alcol	Pwales, 31	0-15	25			283	0.17	16	14.4	50.6	3.1	3	164.7	28.4	19.2
101			15-30	24			417	0.38	10	2.4	248.4	95.6	0	115.9	67.5	38.4
102			30-69	23			775	0.48	32	4.8	345.0	54.6	0	85.4	170.4	48.0
103			69-107	28			745	0.46	28	3.6	349.6	23.4	0	97.6	163.3	62.4
104			107-140	27			710	0.11	24	2.4	363.4	15.6	0	85.4	156.2	38.4
105	tas sigra	Pwales, 32	0-23	27			200	0.16	14	4.8	119.6	128.7	0	128.1	106.5	14.4
106			23-61	79			252	0.32	16	2.4	156.4	113.1	3	158.6	53.3	0.0
107			61-104	26			407	0.29	12	3.6	257.6	25.4	3	109.8	63.9	33.6
108			104-145	53			462	0.38	22	2.4	243.8	15.6	0	91.5	78.1	43.2
109	tas sigra	Pwales, 33	0-25	51			204	0.13	14	7.2	105.8	273.0	0	128.1	35.5	4.8
110			25-56	50			314	0.34	10	0.0	243.8	378.3	6	189.1	14.2	4.8
111			56-81	59			343	0.31	6	2.4	239.2	89.7	6	158.6	17.8	28.8
112			81-135	29			970	0.57	30	8.4	450.8	50.7	3	61.0	241.4	57.6
113			135-157	37			970	0.62	40	6.0	450.8	31.2	3	103.7	255.6	52.8
114	alcol	Pwales, 34	0-20	39			192	0.12	24	4.8	64.4	119.0	3	115.9	35.5	24.0
115			20-41	35			130	0.09	24	3.6	46.0	50.7	3	97.6	35.5	4.8
116			41-61	33			192	0.15	26	4.8	50.6	11.7	0	103.7	35.5	28.8
117			61-94	34			250	0.19	32	9.6	55.2	13.7	3	97.6	3.6	33.6
118			94-145	42			207	0.12	30	4.8	50.6	13.7	3	91.5	32.0	14.4
119	tas sigra	Ghadira, 35	0-20	26			326	0.11	16	3.6	170.2	170.2	3	146.4	24.9	9.6
120			20-41	21			373	0.44	10	2.4	207.0	148.2	3	140.3	32.0	24.0
121			41-76	15			460	0.38	20.0	2.4	172.5	42.9	3	109.8	46.2	72.0
122			76-127	8			870	0.98	34	26.4	368.0	27.3	3	73.2	203.4	57.6
123	tas sigra	Ghadira, 36	0-15													
124			15-36	22			181	0.33	14	3.6	78.2	46.8	0	109.8	198.8	9.6
125			36-66													
126			66-104	58			289	0.49	6	3.6	119.6	78.0	12	152.5	170.4	0.0
202	alcol	Bur Marrad, 40	84-122				116	0.36	18	2.4	23.0	1.2	3	85.4	10.7	0.0
201			122-150				118	0.74	16	3.6	23.0	1.2	0	85.4	24.9	28.8
205	alcol	Bur Marrad, 41	0-8				138	0.78	26	1.2	48.3	1.2	3	91.5	24.9	0.0
204			8-43				142	0.31	24	2.4	11.5	2.0	3	91.5	32.0	4.8
203			43-81				113	0.73	20.0	7.2	11.5	1.2	0	79.3	24.9	81.6

