AGL:SF/MAT 5

WASTES DISPOSAL AND WATER SUPPLY

MALTA

THE SOILS OF MALTA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

AGL:SF/MAT 5

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WASTES DISPOSAL AND WATER SUPPLY

M A L T A

The Soils of Malta

Report prepared for
World Health Organization (WHO)
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as subcontractor to WHO
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prepared by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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THE SOILS OF MALTA

1. Introduction

1.1 Scope of the Report

This report is based on field observations, laboratory work, literature review and discussions with agriculturists, geologists, hydrologists and sanitary engineers. It seeks to evaluate the soil resources of Malta in perspective with the problems of land scarcity, dry summer, inadequate rainfall, scarce water supply, water salinity, topographic limitations, and the prospects of an industrious, hardworking people, and favourable sunshine and temperature for crops.

1.2 Terms of Reference and Background to the Study.

The present writer's mission to Malta was a member of a study team appointed by the Food and Agriculture Organization under a subcontract with the World Health Organization, within the scope of WHO Special Fund Project on Wastes Disposal and Water Supply, MAT 5. The writer was the Soil Scientist on the team. The other members of the team were:

Dr. Arnold Paulsen - Team Leader and Agricultural Economist

Dr. K. S. Dodds - Agronomist

Dr. Amos Ronn - Irrigation Engineer

Mr. Dieter Link - Agricultural Economist

The present writer arrived in Malta on October 29, 1969 but Dr. Paulsen, Dr. Dodds and Dr. Ronn were able to arrive only in late January and spent a month in Malta. Accordingly, in order to ensure overlap, the present writer's mission was extended in Malta till February 25, 1970. His terms of reference were as follows:

In close cooperation with the other members of the FAO consultant mission:

- collect all available data on the soil resources of the project area;
- make recommendations for additional field work as required;
- study the nature of the soils in prospective irrigation areas and their capacity to support sewage farming;
- determine the locations and extent of the lands which can best be considered for development under sewage farming.

In addition, he undertook the following:

- determine the location and extent of the lands of Malta which from an engineering standpoint can best be considered for development under sewage farming,
- estimate the water requirements and water quality needs of the various crops to be grown in the project area, in order to arrive at quantity and quality of purified sewage which can be profitably used.

In view of his extended stay in Malta and since an Agricultural Survey of Malta was being planned, it was proposed in February that he should prepare, in addition to his initial assignment, a general report on the soils of Malta suitable for future use in an agricultural development study. This report has been written since his departure from Malta from notes gathered during the assignment.

1.3 Acknowledgements

The writer wishes to express his appreciation to Mr. Mordechai Karmon, Project Manager, Wastes Disposal and Water Supply (MAT 5) for providing office, field and laboratory support for undertaking the soil studies to determine feasibility of using sewage effluent in irrigation, to Mr. A. Scicluna-Spiteri, Chief, Land and Wate Use Division who was kind enough to find time to accompany him and show him the many aspects of Maltese soils and agriculture, and to Mr. G. E. Yates, UNDP Resident Representative for his consistent support and guidance which enabled completion of the study with the team as a whole of the problems of using sewage effluent for irrigation.

2. Conclusions and Recommendations

(a) All areas of soils that could be economically developed if good quality irrigation water were provided have been demarcated on a topographic base map (figure 2). Three levels of suitability identified as classes 1, 2 and 3 have been used on the basis of depth of soil, productivity of soil, size of fields, frequency and depth of terracing, frequency of stonewalls and potential salinity and alkalinity hazard (see table 8). Class 1 lands total 419 hectares, class 2 lands total 850 hectares and class 3 lands total 2420 hectares.

(b) Other areas of land that could be developed for irrigation because of a reasonably satisfactory slope configuration or soil depth are listed in class 4. They can be used only for very limited crops or under very special circumstances, as listed in section 5.3, if water is available.

(c) The Ta Qali Airport area of levelled land is suited only for the installation of greenhouses for growing crops in troughs or pots but not for the growth of crops in the natural soil of the ground. Water of sufficiently low conductivity can be obtained from Ta Qali pumping station or by collecting rain water. Sustained, profitable greenhouse production is possible only with water of very low conductivity.

(d) The areas under intensive cultivation with irrigation in summer exhibit a trend towards alkalinity and salinity in the lower layers. This should be arrested early. Reclaiming saline or alkali soils is easier in the early stages. Use of unnecessarily excessive amounts of water particularly of high conductivity should be avoided.

(e) Alkalinity and salinity hazard can be eliminated by adopting crop rotations involving leguminous green manure crops. The build up of soil nitrogen and soil organic matter increases concentration of bicarbonate ions which helps to maintain a dominance of calcium ions over sodium ions in the soil solution and exchange complex of calcareous soils.

(f) Water for irrigation should have conductivity less than 2 000 micromhos per cm., if the relative land class suitability ratings are to be applied.

(g) Ways to improve the quality of groundwater in the structural valleys and depositional valleys be regulating all extraction of groundwater in the area must be developed early if the present productivity of these soils is to be maintained, not to mention improving them.

(h) If sewage effluent of sufficiently low conductivity becomes available, pilot units must be established on 10 to 20 hectare areas in the different regions proposed to be later serviced, to test and develop procedures for soil, crop and water management applicable for larger scale projects. They should be operated for at least three to five years to obtain valid conclusions.

(i) If sewage effluent of sufficiently low conductivity can be actually produced, concurrently with the development and operation of pilot units in different regions that would be serviced by the effluent, very detailed surveys for soil depth and permeability should be undertaken to demarcate the entire service areas suited for irrigation with sewage effluent.

(j) Basic studies and collection of data on runoff should be undertaken for diverse conditions like sea cliffs, karst plateau, Blue Clay slopes, depositional and structural valleys and the undulating Globigerina plains.

(k) Evapotranspiration measurements initiated by the Durham group must be revived and undertaken for several different environmental conditions as for runoff.

(l) Basic soil studies on the chemical, physical, mineralogical and micro-biological properties of the different soils like Tas Sigra, Tal Barrani, Alcol, San Biagio, San Lawrenz and Fiddien Soils should be undertaken.

(m) Research and planning for effecting wise land use from a long-term, national view must be undertaken and a comprehensive system for allocation of the scarce land resource for different competing uses like agriculture, dwellings, industry, tourism and service facilities must be established.

(n) Basic studies on irrigation agronomy to find the most economic and sustained agricultural production under the conditions of scarce land and water resources must be undertaken.

(o) A systematic plan of soil and water conservation, taking into account the existing system of embankments and stone walls, must be undertaken to rationalise field size and shape for more efficient, mechanised and/or irrigated farming.

(p) Greenhouse cultivation in troughs and pots must be widely developed on every available flat land to ensure the most efficient use of the scarce soil material of good productivity and the scarce supply of good quality water. Out of season and exotic vegetables, flowers, strawberries, seeds and cuttings can be produced for export markets as well as for the domestic and tourist demands.

(q) The Land and Water Use Division and the Horticulture Division of the Ministry of Agriculture, Trade and Industry should be strengthened by the appointment of staff to carry out the additional work involved in irrigation agronomy, greenhouse culture, land use planning, basic soil research and soil and water conservation programme.

(r) Short-term consultants in the various fields, preferably drawn from countries with a similar environment where such problems have been well studied and solved, should be appointed to work with the Maltese officers.

3. Physical Characteristics

3.1 Location, Area and Population

The Maltese Islands, consist of Malta itself, and Gozo, Comino and some small islets like Comminetto and Filfla. They are located in the Mediterranean Sea roughly 97 kilometres south of Sicily and 288 kilometres north of Tunisia. The total area of the islands is 301.10 square kilometres. Malta has an area of 246.05 sq. km., Gozo an area of 51.80 sq. km. and Comino of 3.24 sq. km.

According to the statistical data for 1959 and 1960, the total population was 327,030, made up of 299,000 on Malta, 28,000 on Gozo and 30 on Comino. The natural annual increase of population reaches 1.09 percent in Malta and 0.4 percent in Gozo.

The density of population on the main island was 1,216 per sq. km. and on Gozo was 540.5 per sq. km.

On the main island about 30 percent of the population is classified as rural while in Gozo, the population as a whole is considered rural.

Malta has very few natural resources. Limestone and salt are the commercially important minerals. But a high proportion of the salt requirement is imported.

Tourism, small scale industries and dockyard facilities are the new developments that have been undertaken to strengthen its economy. Agriculture, however, continues to be an important base of its economic structure and will need to be revitalized to provide higher living standards and to produce more import-substitution human food and animal feeds and also for export like strawberries, out-of-season vegetables, flowers and specialized products like seed and cuttings.

3.2 Climate

The climate of Maltese islands is Mediterranean with a mild, wet winter and a long hot and dry summer.

3.2.1 Rainfall

Very detailed information is available on rainfall and it has been extensively reviewed (Bowen-Jones et al, 1961). For a given station there is a great range of variation not only in the total annual rainfall from year to year but also in the intensity of fall, the frequency of fall by the hour within a day, and the pattern of distribution in a month. In addition there is a great range of regional variation within each of the islands of Malta and Gozo.

Depending on the period of years selected, the rainfall isoheyt maps vary in the details (Verhoeven, 1969; Bulmer and Stormonth, 1960). But in general the central part of Malta (around Rabat-Mdina and Naxxar-Gharghur areas) has the highest rainfall of about 650 mm. The rainfall decreases gradually towards the south-eastern parts to about 475 mm. To the north of Victoria Lines also the rainfall is low, being less than 600 mm. This regional pattern of rainfall and the variations in the distribution with time at a site are due to the influence of the marine convective north-westerly and north-easterly winds and land convective winds superposed on the prevailing north-westerly winds, and the orographic effect especially on the latter winds.

The average rainfall for Malta may be taken as 587 mm. (Martin, 1969). Precipitation is almost exclusively (i.e., more than 99% of total) in the form of rain and falls almost invariably within the six months from October to March. Amounts recorded only as traces less than 0.1 mm. fall as dew occasionally during any time of the year and particularly in the months from November to May.

For about 25 percent of the years the annual rainfall is less than 400 mm. and this aggravates the scarcity of water for agriculture. A disturbing characteristic of the annual variation is the frequent occurrence of two or more consecutive years with rainfall totals much below the average. Cumulative deficits below average and totalling as high as 550 mm. for a consecutive period of 4 years have been recorded. These can be very critical to the vital groundwater supply (which is entirely dependent on the rain falling on the individual island itself) as well as to development of irrigated agriculture (which will be dependent on adequate amount of water for irrigation and leaching).

The greater part of the rain falls as heavy rainstorms or in showers over a period of a few consecutive days followed by longer intervals of little or no rain. Such a rainfall pattern normally gives rise to excessive runoff. In Malta and Gozo, however, the well structured though thin soil cover and the underlying rocks are very rapidly permeable, and runoff is retarded by stone walls, embanked terraces, and infiltration dams. Hence, this rainfall pattern is conducive to high percolation since runoff is minimised. Some of the stone walls and enbanked terraces in the barren and in the marginally agricultural areas around the periphery of the two islands are in a state of disrepair and probably about 3 percent of the total rain falling on the islands is lost as runoff. But it is uncertain if it is economically feasible to maintain them even though they are vital for soil and water conservation.

3.2.2 Temperature

The mean monthly temperature is very high in the summer months (26.3°C in August) but not sufficiently low in winter (12.3°C in January and February) to inhibit the growth of all plants. Evaporation is low owing to the low winter temperatures. Hence deep percolation is enhanced. Thus the winter rainfall is very effective in recharging the groundwater supply.

3.2.3 Winds

Although the average wind speed is low, it is composed of long periods of calms and of speeds less than 4 knots and short periods of high speeds (see table 1). The frequency of strong winds is highest in winter and spring. It is lowest in summer especially during night and early morning. The winds blow from all directions but the north-westerly winds are dominant.

3.2.4 Sunshine

The average sunshine hours vary from 5.37 hours in December to 12.34 hours in July in an annual cycle like mean monthly temperature (see graph). The many hours of sunshine in the summer months would be an asset for plant production if moisture were not limiting.

3.2.5 Humidity

The mean relative humidity is fairly high, the value at 15.00 hours GMT varying from 53 percent in June to 74 percent in December. In the winter months, the lowest humidity occurs in the morning while in the summer months, it is in the afternoon.

Table 1. Frequencies of wind speeds in percentages (Luga, 1958 to 1962)

Wind speed (knots)	Spring (Mar. to May)	Summer (June to August)	Autumn (September to November)	Winter (December to February)
Less than 4	22.5	38.9	26.5	16.3
4 to 10	38.4	42.4	43.2	40.5
11 to 21	33.8	17.6	27.4	36.7
22 to 33	5.3	1.1	2.8	6.5
More than 33	nil	nil	0.1	nil

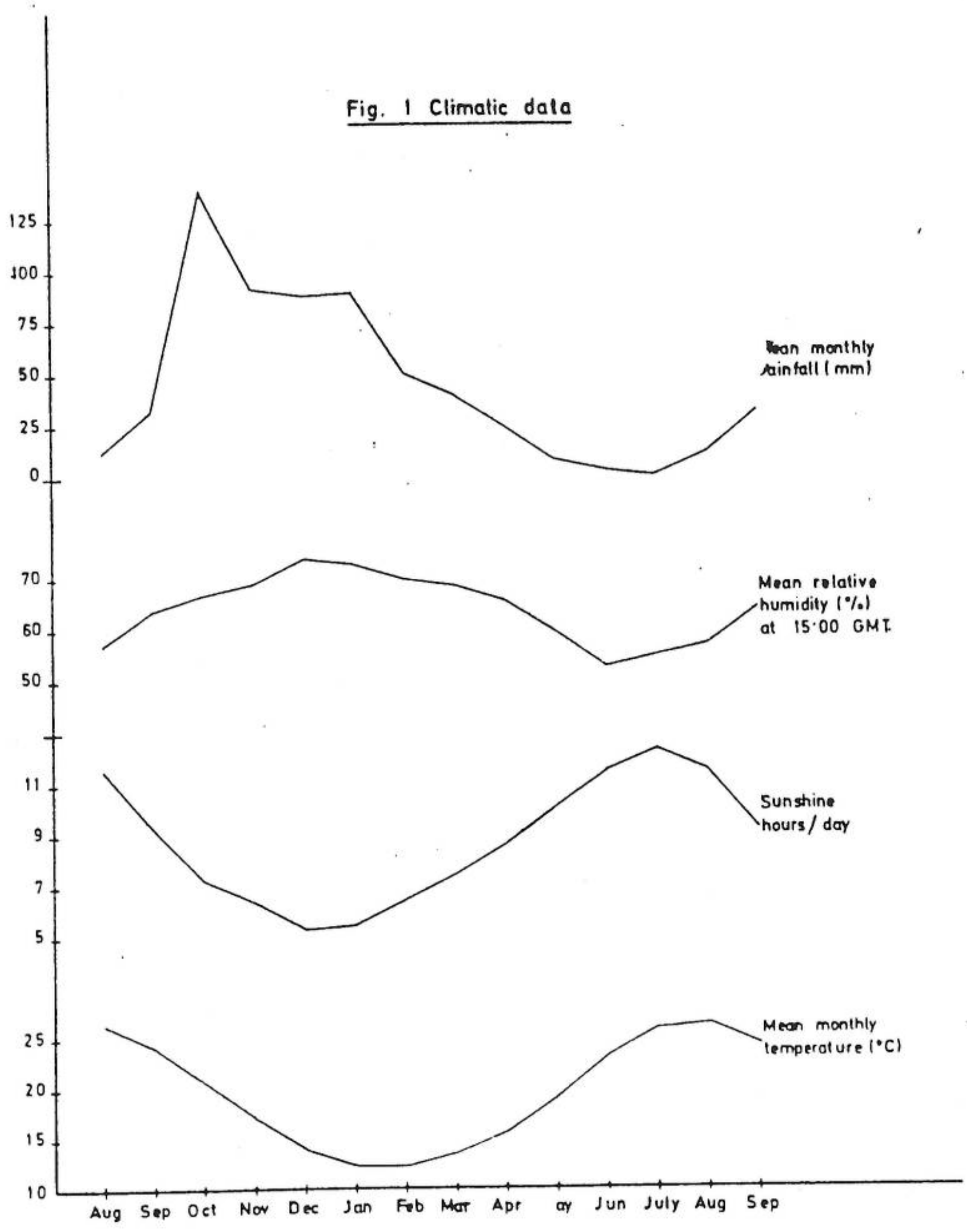

Fig. 1 Climatic data
125
100
75
50
25
0
Mean monthly rainfall (mm)
70
60
50
Mean relative humidity (%) at 15·00 GMT
11
9
7
5
Sunshine hours / day
25
20
15
10
Mean monthly temperature (°C)
Aug Sep Oct Nov Dec Jan Feb Mar Apr ay Jun July Aug Sep

3.3 Geology and Physiography

The Maltese Islands are the remaining parts of a sunken land bridge which connected Italy and North Africa during parts of the later Tertiary and Pleistocene. They are almost entirely composed of limestones and layers of marl and calcareous clays of Miocene age. In the valleys and some slopes, Pleistocene and Recent conglomerates, coastal breccias and valley deposits occur.

These layers have an undulating regional dip to the southeast in Malta and North-east and to the east in Gozo and the islands are cut by a system of normal faults striking east of north-east.

3.3.1 Stratigraphy

The succession of the Miocene rocks on the islands is as follows:-

Upper Coralline Limestone	at least 475 metres thick
Greensand	0 to 45 metres thick
Blue Clay	0 to 205 metres thick
Globigerina Limestone	67 to 610 metres thick
Lower Coralline Limestone	at least 560 metres thick

These geological formations are very distinctive lithologically and the differences in their physical properties are reflected in the characteristic topography associated with each stratum.

1) Lower Coralline Limestone: The Lower Coralline Limestone is a dense, semi-crystalline, massive to moderately bedded limestone. It is occasionally silicified and ranges in colour from pure white to buff. It is made up of calcareous algae especially Lithothamnium and common Foraminifera.

It is separated from the overlying Globigerina in many places by a characterstic band, a few feet thick, containing numerous fossils of Scutella and other echinoids.

The Lower Coralline Limestone formation forms the characteristic vertical cliffs around most of Malta south of Fomm-ir-Rih, and around St. Paul's Bay and also in Western Gozo. Inland, the rock gives rise to a barren, grey, karstic limestone surface.

2) Globigerina Limestone: The Globigerina Limestone is a fine grained, white to buff calcarenite completely formed by calcareous tests of globigerinids, anomalinids and other small foraminiferans. The formation shows marked thickness variations. The bed contains several thin layers of black to dark brown, collophanic, phosphatic nodules. Two of these extend throughout the islands and are used to separate the formation into Upper, Middle and Lower. All the three layers increase in thickness southwards in Malta and westwards in Gozo but to varying degrees.

The Lower Globigerina Limestone is a yellow, fine-grained, usually unbedded limestone, called "franka." It is the most important building stone in the country. This layer is separated from the overlying Middle Globigerina Limestone by a phosphatic nodule layer which is found everywhere though varying in thickness from a few inches to about three feet in thickness. Other layers of phosphatic nodules occur within the franka but are of limited extents only.

The Middle Globigerina Limestone is made up of white marly limestones readily distinguishable from the underlying franka or Lower Globigerina Limestone. The Middle Globigerina Limestone contains scattered layers of phosphatic nodules and cherts. This layer is separated from the overlying Upper Globigerina Limestone by a phosphatic nodule layer.

The Upper Globigerina Limestone is made up of yellow, fine-grained limestone like the franka or Lower Globigerina Limestone; a light blue marly and argillaceous division may be found in the middle of this formation separating the yellow, fine-grained limestone in an upper and a lower layer.

3) Blue Clay: The Blue Clay lies conformably on the Globigerina limestone and, in good exposures, is readily distinguishable from the latter. It is formed of layers of blue and yellow clays and marls containing selenite. It extends up to 205 metres in thickness but in places it thins out completely. It is of considerable significance as it forms a seal to the aquifer in the Upper Coralline Limestone and Greensand.

4) Greensand: The Greensand is a coarse, thick bedded, detrital, slightly glauconitic limestone; it is greenish when unweathered and orange-brown when weathered. This layer is of variable thickness and in some places it is absent. The boundary with the Blue Clay below is very abrupt. The upper boundary is more difficult to define.

5) Upper Coralline Limestone: The Upper Coralline Limestone is the youngest of the Tertiary Miocene formations in the islands. It caps the highest plateaus, but especially in northern Malta, faults bring it down to sea level. The rock varies considerably. Compact and usually poorly bedded limestone predominates but in places it is dense and crystalline. It is frequently separated by thin marly layers; elsehwere thick marly seams rich in fossils occur.

The Pleistocene and Recent Deposits

Two kinds of deposits are observed:- valley deposits and coastal conglomerates and breccias.

The valley deposits are poorly sorted, stratified loams and gravel. They occur in the Pwales Valley, Bur Marrad or Wied il-Ghasel Valley, Il Hofra Valley and Mistra Valley.

Conglomerates and coastal breccias of Pleistocene age occur in small patches round the Marfa Ridge, St. Paul's Bay, Mellieha Bay, Ghar Lapsi and St. Thomas Bay. They are usually composed of local material and are moderately cemented.

3.3.2 Physical and Chemical Nature

The Globigerina Limestone is very porous but the pores are very fine. Hence permeability is low. The Upper and Lower Coralline Limestones, on the other hand, may not be inherently much more porous but many large interconnecting solution channels have developed in the rather heterogenous, but generally compact or dense mass. The porosity and permeability of the Maltese rocks as reported by Hyde (1955) are as follows:-

Kind of rock	Percent porosity	Permeability (cm/hr)
Upper Coralline Limestone	38.5	151.0
Blue Clay	nil	nil
Globigerina	30.2	nil to 3.0
Lower Coralline Limestone	27.4	29.1

Water would be expected to flow faster through the Coralline Limestones than through Globigerina. The actual porosity of the rocks would be even higher than the figures given due to solution channels; which are developed to a higher degree in Coralline Limestones than in Globigerina.

The calcium and magnesium carbonate composition of the Coralline Limestones and Globigerina is generally in excess of 80 to 95 percent. The balance is made up of calcium suphate, iron and aluminium oxides, silica and phosphates.

The Blue Clay has only 2 to 67 percent calcium carbonate, 4 to 30 percent calcium sulphate, 28 to 68 percent alumina and silica and 4 to 10 percent iron oxide. Hence Blue Clay varies from a very calcareous material to a slightly calcareous clay.

3.3.3 Structure

The limestones deposits of Malta form a gently undulating system with a N-S axis. The anticline runs from Salina Bay to Ghar Lapsi. The surfacing of the Lower Coralline Limestone near Naxxar - Mosta and near Attard is largely due to the anticlinal effect. East of this anticline, there is a broad synclinal basin around Valletta and east-central Malta. The Upper Coralline Limestone which outcrops in east Gozo, Comino and north and west Malta may be interpreted as the original elongate N.S. synclinal basin that has since deposition been much faulted transversely and uplifted as a whole. The faults and the gentle folds have been imposed on strata with a regional dip to the east and north-east in Gozo and to the south-east in Malta.

Gozo is structurally a tilted block dipping to the north-east. Normal faults and fault complexes characterise the southern half giving rise to picturesque bays.

Northern Malta is dominated by large normal faults striking east of north-east. They divide the region into horst and rift blocks which are reflected topographically in ridges and valleys. These areas are dominated by the Upper Coralline Limestone except for the area east of Wied il Ghasel. They are bounded to the south by the Great Fault or Victoria Lines Fault, with a down throw of the north side between 270 and 540 metres and giving rise to the most striking topographic feature of the islands.

In Central and Southern Malta, south of the Victoria Lines Fault, the most important structures are large-scale gentle folds.

The position of the water-bearing limestone strata and water-sealing stratum of Blue Clay in relation to sea level and location of faults are of great importance to the hydrology of the islands. (see section 3.4)

3.3.4 Physiography

The Maltese Islands show great diversity in relief and landform and can be divided into many easily identifiable physiographic elements. Twenty-one such elements have been recognized in Malta by House, Dunham and Wigglesworth (Bowen-Jones et al, 1962). These are grouped below into five classes. (The Roman numeral used to designate the unit in the report by Bowen-Jones et al, (1962) is given in parenthesis).

a) Coralline Limestone Plateaux which form high areas bounded by well-marked escarpments:

- Marfa Peninsula (I)
- Mellieha Ridge (III)
- Bajda Ridge (V)
- Wardija Upland (VII)
- Bingemma Plateau (XIII)
- Rabat-Dingli Plateau (XIV)

b) Blue Clay Slopes and valleys:

- Fiddien Valley (XV)
- Slopes of Bingemma Plateau (XIII)
- Slopes of Rabat-Dingli Plateau (XIV)

c) Coastal cliffs where the Coralline Limestone Plateaux meet the sea:

- complex of Wied l'Imtahleb and Rdum lands (XII)

d) Flat-floored basins due to faulting and downwarping or erosion but now filled by colluvial and alluvial deposition:

- Mellieha Isthmus (II)
- Mizieb Depression (IV)
- Pwales Valley (VI)
- Bingemma Basin (XI)
- Bur Marrad Valley (IX)

e) Globigerina hills and plains - large areas of gently sloping land which take the form of a series of low ridges and shallow valleys:

- Ghallis Hills (X)
- Qawra Peninsula (XIII)
- Tal 'Isperanza Valley (XVI)
- Gharghur-Naxxar Hills (XVII)
- Central undulating ridges and valleys (XVIII)
- Southern undulating ridges and valleys (XIX)
- Eastern undulating ridges and valleys (XX)
- Sliema-Valletta-Cospicua (XXI)

In Gozo, also, the physiographic elements are characteristic and they can be grouped into the following four classes.

a) Coralline Limestone Plateaux which form extensive, high areas bounded by well marked escarpments (north and east Gozo)

b) Blue clay slopes and valleys surrounding these highland summits

c) Coastal cliffs and slopes (north and north-east coasts)

d) Undulating plains on Globigerina limestone with Blue Clay slopes leading up to mesas on Upper Coralline Limestone (north-west Gozo)

e) Accidented hills and valleys due to fault scarps and complex faults (south-west and south Gozo)

f) Blue Clay Slopes (east-central and west-central Gozo)

These physiographic units associated with specific kinds of bedrock and slopes are therefore highly correlated with particular combinations of soil kinds. (see table 3). The additional characteristics that determine land use potential like overall slope, slope on terrace, intensity of human modification by mixing, carting etc., depth of soil, and frequency, thickness and height of stone walls are also related to the geology and physiography of the area.

3.3.5 Drainage System

A striking feature of the drainage system of Malta is that the watershed "divides" are aligned in such a way that about 80 percent of the catchment area is composed of watersheds or basins that are separated by "divides" to almost enclose the watershed as an inland basin. One is, in fact, an inland basin and the others have only narrow outlets for the outflowing river. The remaining 20 percent of the area is composed of cliffs and long slopes leading directly to the sea.

Nevertheless total runoff losses are probably low since the fields are all terraced and diked by stone embankments and stone walls, and since the land is provided with diversion drains into quarries and cisterns, and since the river valleys are provided with a series of barrier dams to impound the water which can then percolate slowly. But the very low rate of 2 percent runoff was experimentally observed for the large watershed of Wied-is-Dewda and Wied-il-Kbir with a narrow outlet preceded by an extensive, very flat land at Marsa. This is not applicable to Malta as a whole. The rates are bound to be much higher for the smaller watershed and for watersheds with less narrow outlets or more sloping terrain and rivers. The runoff will be very much higher for the sea cliffs, marginal coastal slopes where the terraces are not being properly maintained and the coastal built-up areas. Also much of the storm water finds it way into the sewer system. Since the sewer tunnels are limited in size, are porous, and are open to the surface at intervals, much of the water either seeps into bedrock or overflows and spreads on the surface. The loss into the sea may not be very great.

Nevertheless there is a great need to initiate work that could lead to more reliable estimates of the loss by runoff and to more effective control measures to eliminate or minimize runoff losses.

The runoff losses in Gozo are probably even greater since the watersheds are more open. In addition, the proportion of areas directly sloping to the sea is higher. Thirdly, the Blue Clay layers and colluvium from it cover a larger proportion of area and percolation in such clayey material is slow. Terraces and stone walls are in general better maintained. Yet there is a need to have reliable estimates of runoff losses during peak rainfalls and to investigate if any of this runoff could be avoided thereby augmenting groundwater supply.

3.4 Hydrogeology and Water Resources

The groundwater resources of Malta and Gozo are determined by the total porosity of the bedrock due to natural pore space and to fissures, joints, bedding places and faults and finally solution channels that have formed along them. Water is held in these porous rocks above sea level if there is an impermeable layer that prevents the water percolating to the sea level. Hence in areas with Blue Clay stratum above sea level, it provides a perched watertable of the water held in the overlying Corraline Limestone and Green sand, as in the extensive Rabat-Dingli plateau of west Malta and the narrow fault blocks of Marfa, Mellieha, Wardija and Bingemma.

When the Blue Clay layer is below sea level, the water contained in the overlying limestone is liable to be contaminated by sea water flowing laterally or through solution channels punctured through the Blue Clay. This situation occurs in the sunken valleys of Mellieha, Mizieb and Pwales.

But in the greater part of Malta, which is undulating terrain on Globigerina and lies to the south of Victoria Lines and east of the Rabat-Dingli Plateau, the percolating fresh water rests on the sea water which is denser than fresh water by about 2.5 percent. This is the most important source of water, providing 95 percent of the island's requirements. The water bearing rock is the rock at sea level. In most places it is Lower Coralline Limestone though in some parts of south central Malta, it is Globigerina. Ideally, assuming there is no zone of mixing to give brackish water, the fresh water forms a thin lens on the sea water, every metre of water above sea level being supported by 40 metres of fresh water that has pushed the salt water below sea level. The maximum recorded height of watertable of this floating groundwater is only 6.9 metres but extraction in galleries is usually skimming the water as low as 1.4 metres above sea level. Unless the ground water built up over sea level can be augmented, total supply is necessarily small. On a small island with a large circumference - area ratio, and large solution channels, fissures and fault zones traversing the aquifer - the watertable will tend to flatten out fast.

Secondly, extraction of fresh water tends to bring salt water close to suction inlet due to upconing. The numerous fissures connecting directly to sea level made this even faster. Hence a rapid rate of extraction of the fresh water from boreholes is undesirable. The ingenious system of a horizontal network of water galleries radiating from a central point from which water is pumped up eliminates sharp upconing. Yet contamination by sea water through solution channels and fissures is widespread. Measures to minimize this by blocking out or raising the water level in gallery segments prone to salt water infiltration have been undertaken.

Thirdly, uniform rates of pumping will minimize infiltration of salt water. Intermittent and hence rapid rates of pumping tend to produce fluctuation of the zone of brackish water separating the fresh water and salt water. Frequent and wide fluctuation of this zone will give rise to a thickening of the zone of brackish water and hence to an increase of its salt content. A zone of brackish water is inevitable but as it gets thicker, the layer of fresh water maintained by a given height of watertable above sea level gets less and less.

The groundwater floating on sea water has now a conductivity ranging from 800 to 3,000 micromhos and usually of 2,000 micromhos. Reduced and steady rates of extraction only could improve the water quality. Other measures like minimizing loss of lateral flow of groundwater to sea by grouting and extracting water along the periphery of the water lens and above points of high lateral flow into the sea have also been recommended.

The average conductivity of 2,000 micromhos may be regarded as the value of the dynamic equilibrium of additions from above by annual rainfall, with very minor additions by seepage from leaking domestic water supply systems (which incidentally has been estimated to be even as high as 40 to 50 percent of total intake), seepage from sewers and from domestic and other uses, and from below the water lens by salt water intrusion. Any deliberate, large scale addition of water at the surface for direct recharge of groundwater or indirectly as leaching requirement in large scale irrigation can affect the salinity of the underlying watertable, since locally it can form a significant proportion of the total additions received by aquifer below. Hence any attempts to re-use water must first ensure that the average conductivity of the groundwater is sufficiently low that it can absorb the salts carried by the added water without any adverse effect. Alternately the added water must be as nearly as possible similar to rainwater so that it does not increase salt content of underlying groundwater.

The high level groundwater perched on the Blue Clay in Rabat-Dingli Plateau and other plateaus supplies about 5 percent of the island's annual production. This water has a much lower content of soluble salts and a lower proportion of sodium to calcium and magnesium. Hence the water has a low sodium adsorption ratio, $(Na) / \sqrt{(Ca) + (Mg) / 2}$, and a low sodium percentage, $Na \times 100 / (Ca + Mg + K + Na)$. The supply is limited and possibilities of tapping the lateral seepage before it is lost to the sea or the adjoining lowland can augment supplies for domestic use and irrigation.

Water is a very scarce resource even though a high proportion (estimated to be as high as 40-50 percent) is yet lost through leaks in the domestic water supply system. Concurrently with measures to locate and remedy the leaks, additional sources of water and possibilities of reusing water are being investigated.

Agriculture is a prime and prior user of groundwater. But it faces competition from the increasing domestic and industrial needs. While it is true that physically, chemically and biologically impure water such as muddy water is used in irrigation systems often with advantage due to the contained clay and nutrients, certain limits on the chemical and biological impurities are inevitable for successful agriculture with no restriction on crops and free from health hazards to the agriculturist and his environment.

According to Martin (1969), the total groundwater extracted in 1967-68 was 22 323 000 m^3 of which 6 328 000 m^3 was obtained by private pumping mostly for irrigation. He has estimated the total aquifer recharge as 26 126 000 m^3. If the artificial recharge of 3 765 000 m^3 from water leaks is excluded, the natural recharge from the infiltration is only 22 361 000 m^3. This is obtained as the difference between surface additions of 129 353 000 m^3 by precipitation and inflow from slopes outside the area considered, and runoff and evapotranspiration losses of 106 992 000 m^3. This is based on several assumptions, calculations and extrapolation and not substantiated by any measurement. If the method of calculating percolation takes into account the actual rainfall pattern day by day and the moisture available for evapotranspiration loss, the annual infiltration as a percentage of the annual rainfall will be found to be much higher, about 75 percent higher. But using his conservative estimate for recharge, the surplus of recharge over consumption is only 3 803 000 m^3. Other factors like groundwater flow due to leaks through large solution channels and frequent upconing cannot be quantitatively estimated. Nevertheless if the runoff and evapotranspiration losses are low, the safe yield can be higher. The recommended figure of 15 500 000 m^3 for total extraction is at least a working guide. It could be modified by actually monitoring the salinity as various rates of extraction are employed to meet the island's demand. Evapotranspiration measurements under the different physiographic situations in Malta should be initiated to make more reliable forecasts on water balance. Desalinated sea water is used to supplement the groundwater supply and this will increase as the island's requirements increase.

Desalinated water costs about 6 to 9 times more than groundwater. Hence the tendency of the Water Works Department will be to extract as much groundwater as possible in order to minimize total cost.

If methods to avoid the corrosive effect of desalinated water on pipes are developed without deliberate addition of salts, there may be a possibility to continue to extract groundwater of higher conductivity and yet keep the final mixed water within acceptable limits.

3.5 Agriculture and Land Use

Every cultivatable piece of land with soil has been terraced and was used to grow some crop at some time or other. Only land unsuited or marginal for cultivation is left for rough grazing or as waste land.

The most important crops are wheat, barley, sulla, potatoes, onions, tomatoes, marrows, beans, peas, vetches, vines, apples, peaches, lemons and olives.

An excellent description of the land use distribution under the various crops is given by Bowen-Jones (1961).

Land for the production of all the requirements of the islands for human food and animal feeds is scarce.

Table 2. Agricultural Land Distribution in Malta and Gozo

MALTA (Total Area: 27 626 ha.)	1960 Tmien*	1961 Tmien*	1963 Tmien*	1964 Tmien*	1965 Tmien*
Agricultural Land					
Dry	107 980	105 543	100 687	99 613	96 750
Irrigated	5 528	5 470	5 585	5 287	5 048
Waste	19 511	18 860	18 064	17 712	16 627
Total	133 019	129 873	124 336	122 612	118 425
GOZO (Total Area: 7 467 ha.)					
Agricultural Land					
Dry	29 121	27 866	27 642	26 626	25 781
Irrigated	741	689	624	560	533
Waste	1 845	1 757	1 953	2 037	1 821
Total	31 707	30 321	30 219	29 223	28 135
Total Malta and Gozo	164 726	160 194	154 556	151 835	146 560

* One Tmien is equal to 0.1125 hectare

From the Annual Report of the Ministry of Trade, Industry and Agriculture, 1966. p.81

The Maltese economy was, until recently, based chiefly on services generated by the military establishments and the naval base facilities and, to a lesser degree, on trade. The change, almost overnight, to a market economy has been remarkably smooth and fairly successful. Expansion of tourism, development of food and other small industries, and dockyard facilities has promoted an unprecedented flush of new buildings all over Malta and even Gozo for residences, hotels and offices. This has certainly buoyed up the economy and will be asset as long as tourism and other industries maintain a sustained growth.

From a long term point of view, however, the allocation of large tracts of agricultural land, (large in terms of Malta's size) for urban and industrial development must be considered in the broader national context. Many of these lands taken out of agriculture have productive, permeable soils with favourable slope, absence of stoniness and sufficient depth of soil (and hence favourable field size as controlled by these factors) and a potential for improved management or irrigation development. The conversion of a pleasant, rural or agricultural landscape into asphalt and concrete suburbia may be self-defeating even for the tourism industry. The question is, can the Maltese islands allow the agricultural base of its economy to be shrunk further by competing users of the land? Could not the other users of the land develop areas that are very unsuitable for agriculture even though such land may not be the best choice for the other uses? An overall land use allocation policy based on the soil and land information available on the 25 inches to a mile, and 6 inches to a mile maps should be the basis for all urban, industrial and agricultural development.

4. Soils

4.1 General Features

4.1.1 Composition

The most striking features of the soils of Malta and Gozo is the high content of calcium and magnesium carbonates in the whole profile. The carbonate content (as determined by solubility in dilute hydrochloric acid) was found to be as high as 50 to 80 percent in the surface layers of the pale brown (Xerorendzina) soils and the white (Carbonate Raw) soils. In the red (Terra Rossa) soils, the carbonate content was 25 to 60 percent, the higher values being due to incorporation of wind-borne calcite dust and of rock flour and gravel during terrace construction. The carbonate content increases with depth in the pale brown (Xerorendzina) and white (Carbonate Raw soils), while in the red (Terra Rossa) soils it decreases with depth. (see Table 4 for chemical data).

In general, the carbonate content imparts a silty or very fine sandy textural feel to the soils. The influence of high amounts of calcium carbonate on plant growth is varied and must be taken into account. The presence of high amounts of carbonates especially in a finely divided form affects uptake of certain nutrients like phosphate and iron. The contribution of the carbonates to water holding capacity is probably very low except when they occur as particles of silt size which can give rise to much pore space in the soil. On the other hand, structural aggregation of the clay minerals and permeability are improved by the high content of calcium in soil solution that will be maintained by the calcium carbonate phase. The high calcium content will also prevent the accumulation of sodium in the exchange complex of the clay minerals. Hence alkalinity hazards as a result of irrigation with water high in sodium is minimized.

4.1.2 Depth

The depth of soil and soil material is very variable. Both are considered together since any distinction between soil and soil material is not always possible nor necessary. As will be seen in subsection 4.1.4 and section 4.3, due to the slow rate of soil formation in a semi-arid climate and due to the widespread carting and mixing of soil caused by man's terrace building activities, the soil horizons formed in place under the past or present climate are similar for all practical purposes to the corresponding soil materials laid down by man.

On the ridges, plateaux and plains (erosion surfaces) formed on hard limestones, the soils are very shallow usually ranging in depth from less than 20 cm. to about 60 cm. Deeper soils occur only in isolated pockets. In addition, in much of the undeveloped areas, bare rock is exposed as an irregular surface.

In the erosional valleys (like Bur Marrad Valley) and structural valleys (like Pwales Valley), the soils have formed on accumulated deposits of material weathered to varying degrees under previous climates on the adjoining uplands. These soils and soil materials are very deep often exceeding 150 cm. But patches of shallow soils especially near the valley edges are very common.

The soils on the scarp slopes and occasional summit surfaces of Blue Clay exposures are for practical purposes considered as deep since the parent material though only slowly permeable is soft and readily disintegrates into soil-like material which is barely distinguishable from the humus-deficient soil itself, which is commonly only about 75 cm. deep.

On the gentler slopes of Globigerina limestone, the soils are moderately deep ranging in depth from 60 to 120 cm. but many patches of shallow soils of varying size occur very commonly. These are not mappable.

4.1.3 Erodibility

The soils, under natural conditions, are easily eroded in a climatic regime of a long dry summer and a wet season in which rain frequently falls in heavy showers. But the actual field situation in Malta gives rise to very little erosion because of stone walls and embankments, as described in section 4.1.4. In some, especially marginal areas, these stone walls are in a state of disrepair and the unrestricted flow from ill-kept fields tends to erode the soils and destroy the stone walls of the fields below. Successful agriculture in areas lying below fields improperly managed is hazardous. The extra effort needed to maintain the conservation measures, when the neighbouring areas are abandoned or mismanaged, has led to progressive deterioration of large areas.

4.1.4 Terracing and other Human Influence

The land surface with a soil cover too shallow, rocky and erodible to be used directly has been literally remodelled by the Maltese farmer over the years in order to conserve and utilize his scarce resource-soil and soil parent material - to the full extent possible. The only areas which have escaped the profound human alteration are the nearly level areas of deep soil in the erosional and structural valleys (like Bur Marrad Valley and Pwales Valley), the areas of deep, soft parent material (as in the long concave slopes of the Blue Clay strata) and the less intensely used, very shallow, very rocky, wind-swept areas (as in the karst plateaus of Mellieha and parts of the Rabat-Dingli plateau).

The highly productive, well-structured, decalcified clay and clay loam soils of the Terra group under natural conditons occur as a shallow soil on an irregular rock surface which frequently outcrops at the surface. Few patches of deep soil fill the solution channels in the bedrock. In such areas on the hard Coralline limestone, man has resculptured the land surface to better utilize the limited soil material on his land. The soil material is carefully removed to a side, the irregular rock surface is hewn to form a terraced, gently sloping surface, the deeper holes are covered with some of the stones, the terrace floor is laid successively with coarser stones and then finer stones and cobbles and finally the soil material is spread back uniformly on the new surface. The terraced levels are protected by embankments built simultaneously by using the large regular shaped stones and these embankments are often extended upwards as stone walls. The stone wall appears to be a convenient way of disposing of the excess stones, in addition to having any possible benefit as a wind break.

In the softer Globigerina limestone areas, sculpturing of the landscape has been even more drastic. The softer rock has permitted more extensive and deeper cuts giving rise to terraces separated by a vertical interval of as much as a metre or two. In addition the scarce soil material has been supplemented by fine rock fragments and rock flour produced in the process of terracing the land, or of building underground cisterns or of quarrying and rock cutting for building stones. Suitable land itself is so scarce that even deep quarry floors themselves are used after layering the floor with stones and soil for growing crops. The deep quarries are believed to afford protection from the wind. Trees are apparently being grown successfully along quarry walls and on the downslope side of high stone walls.

Though it has been reported in the literature that the Maltese farmer periodically dismantles the soil and stone layers to scour the rock surface and thus improve deep percolation and drainage, field examinations of the underlying rock in the soil pits and interviews with farmers and Government agriculturists failed to find confirmation. On the contrary, the stones of the basal man-made layer and the underlying bedrock showed a 2 to 5 mm. thick, weathered, leached porous zone indicating that under the present climate in the terraced, built-up fields, net deep percolation is able to dissolve and leach calcium carbonate. Hence conditions are favourable for downward deep percolation.

Soil material is recognised as a scarce resource that there are even references in the literature to the transport of ship-loads of red soil from Sicily for building Maltese fields in the early days. This is now discounted as unlikely except as ballast for the ships. Nevertheless in Malta and Gozo, soil material removed from sites before construction of buildings are required by law to be transported to designated areas which are known to benefit from added soil material. Farmers place a high premium on the Terra clays and clay loams, which have a stable, strong microstructure and are the most productive soils. They have made considerable efforts to conserve this even on the remaining karstic wastelands on the hard Coralline limestone; stone walls have been built and maintained not only along the property boundaries but also within the land along contours and across valley-like depressions to trap the soil that may be otherwise carried by runoff. Agriculturally very marginal, steeply sloping, wind-battered coastal cliffs and summits also had been terraced in the past to conserve the soil and water and to grow crops. Many of these are, however, in a state of disrepair now.

In the Blue Clay areas, the slopes are not broken into level terraces. Erosion is minimised by the construction of embankments at intervals of about 50 metres, but the soils maintain their natural equilibrium slopes. Under these conditions, waterlogging of these slowly permeable soils is avoided.

4.1.5 Field size and accessibility

The fields are generally very small in size and irregular in shape in most areas. They are separated from one another by stone walls. Access is along narrow paths or through adjoining fields. Some of these walls could be dismantled if necessary for developing larger scale, mechanised, irrigated farming and generally for improving efficiency of operation. Such walls separate fields lying at the same level. But on the other hand, many walls separate fields at different levels and very often with bedrock exposed on the terrace embankments indicating the shallow nature of the soils. Such embankments need to be maintained. But whether the walls built on these embankments serve a useful purpose such as protection of soil or crops from wind is not clear. At any rate, the physical volume and the economical aspects of dismantling the unwanted stone walls and disposing of the stones are quite discouraging.

The ownership or cultivator pattern is very complicated. An individual often owns or cultivates several fields each separated from one another by one or more fields owned or cultivated by another. Any attempt to rationalize field size and farming operation can be undertaken only by a programme for consolidation of ownership or tenancy by arranging to exchange fields with necessary compensation.

4.2 Soil Forming Factors

The regional pattern of the general features enumerated in section 4.1 will be better understood when considered in terms of the factors affecting soil formation.

The pattern of distribution of the different kinds of soils in Malta and Gozo is frequently complicated due to the superposition of man's activities on the natural processes. Man, in an effort to conserve and exploit his barely adequate soil and water resources, has literally resculptured the land surface by cutting terraces through the soft rock, building stone embankments and walls and redistributing the stones and soil material on the terraces.

The original natural pattern of distribution is largely determined by the parent material (in most cases the underlying or country rock), climate (both present and past under which rock weathering and soil formation took place), time (during which the landscape had remained stable), and the topography. But topography or geomorphological pattern itself, in so far as it is moulded by erosion and deposition, is related to bedrock composition, the processes as determined by the past and present climate and finally time; but this pattern is superposed on the tectonically influenced structure (see section 3.3). Biological influence, like the activity of micro-organisms, plants and animals, is another factor influencing soil formation. But it is related to the factors already enumerated and at any rate are now dominated by man's activities, the patterns of which are not as easy to predict or rationalize as the natural factors.

4.2.1 Time, Climate and Biological Processes

Soils of Malta and Gozo are, pedologically speaking, rather young or immature soils. The processes of soil formation on calcareous material are very slow in a Mediterranean or semi-humid climate, because the soils have a low build-up of soil organic matter and hence limited quantities of acidic drainage waters. The shallow, brown, slightly humus-enriched, calcareous soils over limestone bedrock and called Xerorendzinas are the soils formed by exposure to the present climate for the longest period (of the order of several hundred years). Very young, man-made, whitish, humus-deficient Carbonate Raw soils dating back to less than 50 years, the time they were mined by man and spread in front of the undermined terrace backwalls occur side by side with Xerorendzinas in the same field. In fact, the difference between the two groups of soils is very slight, both containing more than 70 percent total calcium carbonate. The third group of soils, the red and reddish-brown, humus-enriched, highly declacified soils of the Terra group were probably formed under a past humid climate. Apart from the incorporation in the surface layers of calcareous dust by wind transport and of calcareous coarse fragments by man's activities of terracing, very little change can be attributed to the present climate. Pedologically, the soils are very young relative to the present environment. Nevertheless for practical purposes, these red, relic products of rock weathering and soil formation can be considered as mature soils, since any distinction between soil and soil material cannot be maintained, much less serve any useful purpose, due to the extensive and profound man-made changes in the agriculturally important soil areas as already described in subsection 4.1.4.

4.2.2 Parent Material

The different kinds of soils of Malta are almost entirely due to the differences in the chemical composition (carbonate content, clay content and other impurities), as well as in the physical constitution of the rock. Climate has had little effect in reducing the differences due to parent rock.

The soils are very calcareous because the parent material is limestone or very calcareous, soft sediments like Blue Clay. The limestone parent materials contain more than 95 percent of minerals like calcite (calcium carbonate) and gypsum (calcium sulphate) which must be completely lost from the profile by soil formation processes to obtain a decalcified soil. In fact, the red Terra material, which is the characteristic decalcified product of weathering of limestone under humid or semi-humid conditions of adequate, sufficiently acidic water for leaching, is actually the impurities present as such in the original limestone bedrock. Hence the thickness of decalcified soil material formed in place on limestone rock is typically small in places of normal relief permitting good runoff, percolation and normal erosion. From other types of rock under similar conditions of climate, topography and time duration, the thickness of soil would have been much greater. This is because even though chemical weathering of limestone (essentially dissolving of the calcium and magnesium carbonates and sulphates) is relatively more rapid than the weathering of rocks like gabbro or granite under similar conditons, the amount of residue left behind by an equal volume of limestock rock, 95 percent pure, is only about one-sixth to one-twelfth of that due to gabbro or granite. If the percentage of impurities drops to 2 percent, the amount of residue left by limestone is one-fifteenth to one-thirtieth of that due to igneous rocks. In addition, the weathering front advances irregularly into the bedrock. Due to the heterogeneity in size, porosity of the constituent particles or due to the presence of fissures, dissolution of the carbonates and leaching of the dissolved constituents proceeds to give solution channels provided the rainfall is adequate and there are entrenched valleys or underground channels through which the percolating water can flow out of the region. As a consequence of the development of solution channels, the percolation and drainage of water in a limestone region is much more rapid than on most other rocks under similar conditions. Consequently weathering of limestock rock nearer the upper surface is slower but favourable for leaching. Water flow is concentrated along solution channels and in these, deep red soils are formed by weathering and leaching or accumulated by local movement from surrounding exposed areas. The well-known karst topography of deep red soil in pockets among outcropping rock surface is the result. Xajhra Series, a Terra Rossa soil on hard limestone is formed this way.

On the softer, porous but less permeable limestone rocks like some Globigerina layers, physical disintegration advances faster than decalcification. Hence deeper, less decalcified, brown soils like Tal Barrani Series (a Xerorendzina) are formed.

When physical disintegration is the dominant process as in man-made, recent soils on softer limestones and on the continually eroded Blue Clay areas, the soil is merely a mechanical mixture of the disintegrated bedrock or sediments, with perhaps some leaching of the soluble salts. The Blue Clay sediments by itself gives rise to the Fiddien clays and in mixture with soft Globigerina gives San Lawrenz soils. The calcareous sandstones from the Upper Coralline limestone and Greensand give the Nadur Series and the calcareous sands of contemporary dunes give Ramla Series. All these soils are Carbonate Raw Soils.

Due to the close occurrence of the different kinds of rocks on the landscape and the effects of natural transport and deposition of soil material in the geomorphic evolution of the present landscape, the distinction between the completely decalcified Terra Rossa soils and the calcareous brown Xerorendzina soils is not sharp. Similarly the distinction between the brown Xerorendzinas and the whitish Carbonate Raw Soil is very diffuse. Thus Tas Sigra is considered to be a Terra Rossa formed on deep, red, decalcified soil material largely transported from adjoining areas. When the incorporated material includes erosion material from partially and barely decalcified soil, the soil ranges in colour from reddish brown to light brown. These soils are called Alcol Series. Similarly incorporation of red Terra material with the downslope whitish weathering products of Globigerina rock gives the transitional brown San Biagio Series.

4.2.3 Topography

The soils are basically lithogenic as already discussed in subsection 4.2.2. A good correlation of soils with topography is observed (see table 3) because within the framework imposed by faulting, the different rock strata due to differential resistance to erosion tend to develop or maintain different topographic aspects. Thus the Upper Coralline limestone is associated with plateaus, ridges, and prominent scarps with almost a vertical drop. The lower lying Lower Coralline limestone also forms ridges, erosion surfaces and prominent scarps with almost a vertical drop. The relatively softer Franka (a Globigerina layer) forms a weakly karst-like erosion surface. The other, much softer Globigerina layers and marly layers form an undulating surface as in south east Malta. The Blue Clay layer forms a scarp slope tapering to a concave steep slope when its upper surface is protected by a resistant cap of Upper Coralline limestone. When there is no protective layer, it forms a broad, sloping summit. Hence the soils associated with the various rock strata have characteristic topographic features.

4.3 Soil Classiciation

The soils of Malta have been classified by Lang following Kubiena's system into three groups: the Terra Rossa, Xerorendzina and Carbonate Raw soils. This grouping is similar to the locally popular identification of red, brown and whitish soils.

The red Terra Rosse soils are highly decalcified and humus-enriched. The brown Xerorendzina soils are only very slightly decalcified and slightly humus-enriched. The whitish Carbonate Raw Soils are essentially physically disintegrated parent rock; they are highly calcareous and humus-deficient.

The Soil Series identified by Lang are designed to fit the landscape and lithology and hence are mappable. But wide ranges within them due to the natural processes of mixing of parent materials by erosion and deposition as in soil creep or due to regional or local differences in chemical composition or physical constitution within a given rock strata were found to be not mappable at a scale of 1:31, 680, and hence are included in the range of characteristics of the Series (see table 3). Such differences are confounded by man-made soils on terraces and by addition of soil and rock materials brought in from outside.

Soil maps are a useful aid for planning agriculture in areas where soils are considered as an immovable asset and are managed and improved with amendments and additions in situ. In Malta, the scarce, shallow, erodible soil material has been used as a precious movable resource. The soil has been spread out to cover extensive areas where it has been deep in patches surrounded by rock outcrops. Soils and disintegrated rock has been brought from unwanted places like building sites and quarries to increase the thickness of soils where needed. Sandy soils have been improved by the addition of clay materials brought in from outside. Similarly, whenever available, the red Terra material has been incorporated into the brown or white soils to improve tilth.

Under such conditions, the soil map based on lithology and landscape as provided by Lang provides the basic information on the distribution of the dominant kinds of soils. The soils, as naturally evolved, are not very different from the soil materials, relic or current, since climatic influence has been very slight, and hence the soil map provides information on the composition of the man-made soils, except where soil material from other soil areas has been carted to the site. Such incorporation of different soil material is quite common in the important agricultural areas outside of the erosional and structural valleys and large sink holes. But this incorporation of material from outside is very local and not extensive. Its occurrence varies from field to field and sometimes even within a field; only a part may be modified by outside material, the remainder of the field appearing to be made up of the original soil material.

The following kinds of soils have been identified:

Carbonate Raw Soils	Ramla Nadur Fiddien heavy clay Fiddien light clay San Lawrenz
Xerorendzina	San Biagio Alcol Tal Barrani
Terra Rossa	Tas Sigra Xaghra

In addition one association and three complexes have been recognised (see Table 3 for details). They are:

Rdum sequence	: a lithosequence on scarp slopes
Armier 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

The tentative classiciation of these soils into families in the USDA Revised System is as follows:

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 Ustorthentic Ustochrept
Alool	: fine loamy (carbonatic, calcareous) Rendollic Ustochrept
Tal Barrani	: fine loamy (carbonatic, calcareous) Rendollic Ustochrept
Xaghra	: fine clayey, mixed, calcareous Typic Ustochrept
Tas Sigra	: fine clayey, mixed calcareous Typic Ustochrept

The tentative classiciation according to the FAO system (key to soil units for the soil map of the world, September 1970) is as follows:

Rampla	: Calcaric Regosol
Nadur	: Calcaric Regosol
Fiddien	: Calcaric Regosol (in some place Chromic Vertisol sodic)
San Lawrenz	: Calcaric Regosol
San Biagio	: Calcic Cambisol lithic
Alool	: Calcic Cambisol
Tal Barrani	: Calcic Cambisol
Xaghra	: Chromic Cambisol
Tas Sigra	: Chromic Cambisol

Table 3. Relationships of Soil Kinds with Parent Material and Topography

Soil Kinds	Brief Description of Soil (Colour, Depth, Texture etc.)	Parent Material	Underlying Bedrock	Topographic Position	Factors Causing Range in Characteristics
Ramla	Brown, deep, loose sand; slightly to strongly terraced	Produced by physical weathering or by man from contemporary or Quaternary dune beds of calcareous, weakly glauconitic sand derived from Greensand; very rapidly permeable	Dune beds of variable thickness over Blue Clay or Globigerina or even Upper Coralline	Locally occurring coastal and slightly inland dunes	Admixture of underlying red Terra material addition of Fiddien Clay by man locally
Nadur	Reddish brown to greenish buff, moderately deep, light textured (usually gravelly gritty loamy sand) commonly strongly terraced	Produced by physical weathering or by man from coarse limestone (Greensand, lower part of Upper Coralline or Quaternary Conglomerate derived from them); very rapidly permeable	Lower part of Upper Coralline or Greensand of variable thickness over Blue Clay; or Conglomerate over Blue Clay and even Globigerina	Scarp slopes exposing Greensand or lower part of Upper Coralline; or broad open valleys of Conglomerate, Greensand or lower part of Upper Coralline	Admixture of Red Terra material from upslope; Glauconitic facies of Greensand, admixture of underlying Blue Clay material
Fiddien heavy	Olive, moderately deep, very heavy textured (clay), massive, often alkaline and sometimes saline also broad, sloping terraces	Newly exposed, slightly physically weathered Blue Clay; very slowly permeable or almost impermeable	Unaltered Blue Clay	Upper part of scarp faces, slump slopes and remnant hillocks of Blue Clay; slopes up to 35°	Rarely, overwash of terra material or of Nadur parent material
Fiddien light	Light olive brown to gray brown, deep, moderately heavy textured (usually gritty clay loam), Granular, non-saline and non-alkaline; slightly to strongly terraced	Colluvial, leached erosion product of Blue Clay; very slowly permeable or almost impermeable	Slightly altered or unaltered Blue Clay	Lower part of scarp faces, slump slopes and remnant hillocks of Blue Clay; slopes of about 16°	Commonly, admixture or overwash of Terra material or of Nadur parent material

Table 3: Relationships of Soil Kinds with Parent Material and Topography (continued)

Soil Kinds	Brief Description of Soil (Colour, Depth, Texture etc.)	Parent Material	Underlying Bedrock	Topographic Position	Factors Causing Range in Characteristics
San Lawrenz	Light olive brown, moderately deep, moderately heavy textured(usually fine sandy clay loam), granular; slightly terraced	Mixed product of weathering of Blue Clay and soft Globigerina colluvium and alluvium; slowly permeable	Upper Globigerina	At foot of scarps of Blue Clay on the Upper edge of the Globigerina plateau	Variable proportion of Blue Clay and Globigerina in the mixed parent material
San Biagio	Pale brown or white shallow to moderately deep medium textured (fine sandy loam to silt loam), subangular blocky, surface crusting; slightly to strongly terraced	Current or Quaternary colluvial deposits of products of weathering of upper and middle Globigerina; rapidly permeable	Upper or middle Globigerina	On Globigerina exposed at foot of scarps and on dissected low plateaus	Eroded or shallow phase on the upper slope and alluvial-colluvial, deep phase on the lower gentle slope
Tal Barrani	Brown and dark gray brown, shallow to moderately deep, light to heavy textured (gravelly sandy loam to gravelly clay loam), weak granular, weak crusting; strongly terraced	Product of slow weathering of fine textured, massive Globigerina similar to and including Franka; tillage of calcareous xerorendzina-like colluvium with underlying terra deposit; mixing of terra soil with rock flour during terracing; moderately to moderately rapidly permeable	Lower Globigerina including Franka	Dissected low plateaus of Globigerina	Admixture of xerorendzina material or rock flour with terra material during tillage or terracing

Table 3: Relationships of Soil Kinds with Parent Material and Topography (continued)

Soil Kinds	Brief Description of Soil (Colour, Depth, Texture, etc.)	Parent Material	Underlying Bedrock	Topographic Position	Factors Causing Range in Characteristics
Alcol	Yellowish red to light yellowish brown, very deep, medium to heavy textured (sandy clay loam to clay loam), granular; unterraced or slightly unterraced	Alluvial and colluvial, thick, stratified, poorly sorted deposits of Terra, Rendzina and Carbonate Raw materials; moderately slowly permeable	Usually Upper Coralline Limestone, Lower Coralline Limestone or Globigerina but can be any other rock also	Broad, flat valley floors	Extremes encountered in colour, texture and travel content are due to proportions from different kinds of sources of original parent material
Xaghra	Dark red to brown, very shallow to very deep, heavy textured (usually a clay or gritty clay loam), strong granular; unterraced to slightly terraced	Decalcified residue of weathering of Upper Coralline, Lower Coralline, or Franka formed under a past humid climate with subsequent surface addition of calcareous dust by wind and of rubble by man; moderately slowly permeable	Upper Coralline, Lower Coralline, or Franka	Karst topography with lapies on high level plateau of Upper Corraline or on low level surface of Franka and Lower Coralline	Range in depth due to irregular weathering; range in consistence due to nature of residue in limestone rock; range in added stones and rubble due to man's carting and terracing operations; yellower and more calcareous on Franka than on Upper or Lower Coralline
Tas Sigra	Reddish brown, shallow to very deep, heavy textured (clays and clay loam), strong granular unterraced to strongly terraced	Decalcified residue of weathering of the hard limestones as in Xaghra but with subsequent movement at least locally, and deposition; moderately permeable	Usually Upper Corraline, Lower Corraline or Franka but can be other Globigerina also	Weakly karstic landscape without lapies on Franka; dolines in karstic landscape of Corraline; broad valleys of transported Terra material	Range in depth, consistence, colour and calcareous content is as for Xaghra

Table 3: Relationships of Soil Kinds with Parent Material and Topography (continued)

Soil Kinds	Brief Description of Soil (Colour, Depth, Texture etc.)	Parent Material	Underlying Bedrock	Topography Position	Factors Causing Range in Characteristics
Rdum Complex (a parent material sequence)	Very shallow to moderately deep soils - Nadur, Fiddien heavy, Fiddien light, San Lawrenz and San Biagio - forming a lithosequence; unused, or strongly terraced and some now abandoned	Steep slopes of Upper Coralline, Franka & Lower Coralline are bare cliffs. Weathering products of Upper Coralline & Greensand at food of Upper Coralline cliff, spreading out over the slumping Blue Clay which itself overruns the upper part of the less steep slopes on the softer Upper Globigerina	Part or whole of the sequence of bedrock from Upper Coralline through Greensand, Blue Clay and Globigerina to Lower Coralline	Steep coastal slopes and cliffs, with slopes averaging 1 in 2 to 1 in 4	One or more members in the lithosequence of soils may be missing depending on the presence or absence of corresponding parent rock and on the slope
Armier Complex (a parent material sequence)	Ramla, Xaghra and transitional soils; terraced in parts	Wind-borne calcareous sand ranging from a thick deposit to a mere thin overlay on red Terra materials; mixing of thin layer of sand with underlying red clay is due to tillage	Upper Coralline	Karstic plateau surface near coast	Differences due to mixing by tillage and terracing

Table 3: Relationships of Soil Kinds with Parent Material and Topography (continued)

Soil Kinds	Brief Description of Soil (Colour, Depth, Texture etc.)	Parent Material	Underlying Bedrock	Topographic Position	Factors Causing Range in Characteristics
L'Inglin Complex (man-made)	A complex of pale brown to red, shallow to moderately deep, light to heavy textured soils resembling San Biagio and chiefly Tal Barrani and Xaghra or Tas Sigra soils; strongly terraced	Carbonate Raw Soils, rock flour Xerorendzona and Terra Soil mixed by strong terracing	Upper Coralline or Lower Coralline or Franka (the lower part of Globigerina)	Valley sides of Karst lands	Variations in colour and texture due to relative proportions of unweathered, slightly weathered and decalcified materials used in terracing
Tad Dawl Complex (man-made)	Pale brown to red, shallow to deep, medium to heavy textured soil over few to several feet of man-laid rubble; slightly terraced fields below ground level in abandoned quarries	Rock flour and Terra soil material	Franka or Lower Globigerina	Dissected plateau on Lower Globigerina	Variations in colour and texture due to relative proportions of rubble, rock flour and Terra soil material used in filling

Table 4: Summary of Chemical Characteristics of the Soils of Malta and Gozo (Lang, 1960)

Soil Kinds	pH surface soil	pH sub-soil	Conduct-ivity (mill. mhos/cm	Total $CaCO_3$ (%)	Active $CaCO_3$ (%)	N (%)	Organic Matter (%)	Total P (%)	Avail-able P (p.p.m.)	C.E.C. (me/100 gm.)	Individual Cations (as % of total)			
											Ca^{++}	Mg^{++}	K^+	Na^+
Ramla	8.7	9.3	0.13 n.d.	84	10	0.06	0.5	0.2	15	20	89	9	2.3	0.6
Nadur	8.5	8.9		90	13	0.08	1.5	0.05	20	27	90	6	2.6	0.8
Fiddien light	8.0	8.5	0.15	51	15	0.10	1.4	0.19	22	42	84	12	2.9	1.2
Fiddien heavy	8.7	8.7	2.60 n.d.	29	13	0.9	1.6	0.12	23	36	65	24	4.8	5.3
San Lawrenz	8.5	8.8	n.d.	54	15	0.11	1.8	0.21	19	16	85	8	3.6	2.6
San Biagio	8.4	8.8		65	17	0.12	2.1	0.25	21	18	86	11	2.0	1.4
Alcol	8.7	9.0	0.15	70	16	0.11	1.8	0.16	15	25	86	9	2.9	1.2
Tal Barrani	8.4	8.8	0.49	81	15	0.23	4.6	0.39	118	31	85	8	3.8	1.3
Tas Sigra	8.5	8.6	0.44 n.d.	n.d.	12	0.17	2.7	0.22	79	39	74	16	4.4	5.7
Xaghra	8.1	8.4		13	5	0.25	3.6	0.22	36	40	87	10	2.7	1.6

n.d. - not determined

Footnote: The data presented represent the median value (if many results were available), or the average (if only 2 or 3 figures were available), or the single figure (when only one is given as typical). They serve to show the remarkable similarity among the soils of the Maltese islands; the few differences are attributable to the very coarse or very fine texture, the result of decalcification in Xaghra and the relatively high Na and Mg in some soils.

4.4 Soil Series Descriptions

The following Soil Series descriptions are based on Lang's soil survey report (1960); the author's field observations are in agreement with them.

Ramla Series

Ramla Series is a deep, brown, loose sand. It is a very young, raw soil, low in humus and with an (A)C profile formed on calcareous parent material.

Ramla soils are formed on calcareous stratified sands of contemporary or Quaternary dune beds by natural physical disintegration with very little chemical changes besides dissolution of any weak secondary calcareous cementation like that observed in the underlying dune bed. In places, the soft dune beds have been quarried by man and the resulting soil is indistinguishable from the natural one since in both there is no horizon differentiation except for the presence of some plant roots and other residues in the surface horizons.

They are only of a very limited extent, occurring locally on the northern coastal slopes either alone as in Ramla valley in Gozo or in a complex with Tas Sigra soils as in Il Quortin tan Nadur in Gozo and Marfa Ridge in Malta.

The soils are extremely light coloured and appear to lack any noticeable quantity of soil organic matter or humus, particularly in cultivated areas. Under grass vegetation, a prominent leaf mat is formed on the surface, and below it a root network covers the soil with a density decreasing with depth; many of the loose grains are strung together on fine roots.

Transitions to a redder sand with a sandy clay loam subsoil occurs on thin blown deposits over Terra material. Locally Fiddien clay material has been incorporated by man to make texture of the surface soil heavier.

The soils warm up quickly but do not get too hot because of the light colour. Water holding capacity is very low. Moisture loss by capillary rise is negligible because of the loose packing of the sand grains. The soils are used for tree crops and would do well under irrigation. Early vegetable crops can be grown in areas that are naturally slightly heavier like a sandy loam or in soils in which Fiddien clay material has been incorporated by man.

The soil is very calcareous. The $CaCO_3$ content in the surface horizon is about 84% while in the subsoil below it is about 88%.

pH is about 7.8 to 8.7 in the surface horizon and increases with depth to 9.0. Soluble salt content, however, is only 0.05% (corresponding to 0.13 millimhos/cm)

Soil organic matter in the surface horizon is very low in the sandy soils being about 0.5%. In the heavier, less well drained sites, values are higher (1.3%). The C:N ratios are 7.5 and 10 respectively.

Total phosphorus in the upper horizons is 0.1 to 0.2% while the available phosphorus is only 15 p.p.m. in the soil with 0.2% total phosphorus and 50 p.p.m. in the soil with 0.1%. This variability obviously indicates that the available phosphorus is related to phosphorus in soil organic matter and not to total phosphorus.

Cation exchange capacity in the whole profile is 20 me/100 gm. Ca accounts for almost 90% of base saturation while K and Na amount to less than 3% of base saturation. K may become insufficient for plant growth.

Nadur Series

Nadur Series is a shallow, reddish brown to yellow, light textured (usually a gravelly, gritty, loamy sand or sandy loam), loose soil. It is a very young, raw soil, low in humus and with an (A)C profile, formed on calcareous parent material.

Nadur soils are formed by physical weathering or by man from coarse soft limestone like the Greensand, lower part of the Upper Coralline Limestone or from the Quaternary Conglomerate of soft, poorly sorted colluvium derived from such coarse soft limestone.

The soils are of very limited extent. They occur as thin strips on the scarp slopes on the lower part of the Upper Coralline Limestone and on the Greensand (as around the southern part of the mesas of Xaghra and Nadur, round the Rabat-Dingli plateau and on the east side of its valley); it occurs as more extensive areas in broad open valleys covered by the Quaternary Conglomerate (as in the east of Wied ta Dahlet Qorrot) and on gentler slopes where the Greensand appears to be extensive at the expense of Blue Clay (as on the northern side of the mesas of Xaghra and Nadur and on the west side of the central valley of the Rabat-Dingli plateau). The soils on the steep scarp slopes are strongly terraced.

The wide range in colour from the natural pale yellow of the sand grains is due to varying amounts of staining by the red Terra fine material washed down the scarp slope from the overlying karst landscape. With higher amounts, transitions to Tas Sigra are exhibited. On highly glauconitic facies of the Greensand outcrops, greenish buff soils are observed, Near Blue Clay exposures, a heavier texture like a gritty clay loam occurs. The clay, however, remains as a non-intimate admixture with the sand grains; this indicates that very little chemical weathering has accompanied the physical processes of mixing. These are all variants of only minor areal extents.

The soils on the whole are relatively coarse, loose, and very easily worked. They are excessively well drained and dry out rapidly and hence more liable to suffer from drought. But on the other hand they are quick warming and hence suited for early vegetable crops if irrigation is possible. Oats, sulla and perennials including vine are also grown.

Only 30 to 35% of the total soil is less than 2 mm in size and is used for the laboratory analyses.

The total $CaCO_3$ is very high about 80% and the active $CaCO_3$ is also very high (about 13 to 15%) like in San Biagio soils.

pH is more than 8.0 like in other Maltese soils.

Soil organic matter is 1 to 2% which is about average for carbonate raw soils; but on a total soil basis it becomes only 0.3 to 0.7% and this could probably be the cause of the poor structural development.

Total phosphorus is also very low being about 0.05%. In glauconitic parent material, the value is about 1.2% which is quite satisfactory.

Cation exchange capacity is about 25 me/100 gm. On a total soil basis, this becomes about 8 me per 100 gm. Ca and Mg occupy more than 96% of the base saturation and K and Na the balance 4%.

Fiddien Series, Heavy Textured Type

Fiddien Series, heavy textured type is an 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 Fiddien heavy clay is a very young, raw soil, extremely low in humus and with an (A)C profile, formed on calcareous clayey parent material.

It occurs on the upper slopes of scarps and remnant hillocks and on flat valleys of Blue Clay lying above the dissected plateau of Globigerina. The soil has formed in place from the Blue Clay with apparently very little chemical weathering except oxidation of the newly exposed clay. Rarely, an overwash of Nadur material or Terra material from upslope may give the surface horizon a different colour and lighter texture or better structure.

Except the very heavy textured soils and the soils on slopes greater than 35°, the Fiddien clay is cultivated. Broad, moderately sloping terraces protected by widely spaced stone embankments from slumping or sliding down are tilled and manured. The rapid runoff possible on the moderate slopes helps to avoid the waterlogging problem that would otherwise occur on terraces of very slowly permeable sticky clays.

The surface horizon has a prismatic structure that breaks down to medium subangular blocky structure while the subsoil has usually a coarse, polygonal, prismatic structure.

The Fiddien heavy clay is quite calcareous though the amounts observed (29 to 36% $CaCO_3$) are much lower than in other Raw Carbonate soils. The amount of active $CaCO_3$ is 10 to 13% which is comparable to that in other Raw Carbonate soils. Its proportion, however, is quite high as would be expected from the existence of the total $CaCO_3$ in a much finer state than in other soils.

pH is above 8.0 but below 8.5 in the surface horizon, and it increases to about 8.7 in the subsoil. Sometimes, about 1.0% of soluble salts is present throughout the profile making it saline. Exchangeable sodium percentage is often higher than 6 and as much as 37 in the surface horizon though the pH values are below 8.5. Ca and Mg occupy more than 85% of base saturation, and the proportion of Mg is higher than in other soils, being commonly above 20% of base saturation.

Fiddien Series, Light Textured Type

Fiddien Series, light textured type is a moderately deep, gray brown, gritty clay loam with a fine granular structure in the surface horizon. It is commonly non-saline and non-alkaline. The Fiddien light clay like the Fiddien heavy clay, is a very young raw soil, extremely low in humus with an (A(C profile on calcareous clayey parent material.

Like the heavy clay, the Fiddien light clay has a coarse prismatic structure in the subsoil and occurs on the scarps, ramnant hillocks and flat valleys of the Blue Clay lying above the Globigerina dissected plateau. But unlike the heavy clay type, the light clay is found on the lower slopes and has formed on locally transported colluvial Blue Clay material which has undergone in the process a preferential loss of the very fine particles. Very frequently there is, in addition, an overwash of Nadur material or Terra material from upslope giving the surface horizon a lighter texture or better structure.

The Fiddien light clay contains about 50% $CaCO_3$ which is higher than in the heavy type. Active $CaCO_3$ is about 13 to 17% which is only slightly higher indicating loss of some of the fine particles.

pH is however, usually as high as about 8.7 in both the surface horizon and subsoil, though percentage soluble salts and exchangeable sodium percentage are very low.

Cation exchange capacity is lower in the light clay as would be expected from textural differences. The percentage exchangeable Ca is much higher while that of Mg and Na are much lower than in the heavy type.

San Lawrenz Series

San Lawrenz soils are moderately deep, light olive brown, medium to heavy textured (usually a fine sandy clay loam) soil with a moderate granular structure. They are very young, raw soils, low in humus, with an (A)C profile and formed from calcareous parent material.

San Lawrenz soils occur at the foot of the scarp of the Blue Clay and on the upper edge of the Globigerina plateau. The parent material is a mixture of alluvium and colluvium from the Blue Clay and the soft Upper Globigerina and it rests on the Globigerina rock. The texture of the soil varies from a fine sandy clay loam to a light clay according to the relative proportion of materials derived from the Blue Clay and the Globigerina.

These soils are found as a thin belt below the Fiddien soils and above the San Biagio soils. They are very similar to the Fiddien light clay in colour and texture differing only in slope and structure. San Lawrenz soils occur on slopes of 5^o to 10^o and have a blocky or granular structure throughout the profile while the Fiddien light clays occur on the natural slope of 10^o and have a prismatic structure at least in the subsoil. The transition from Fiddien series light clay type to San Lawrenz Series is nevertheless often quite gradual and the boundary line becomes arbitrary. The distinction between San Lawrenz soils and San Biagio soils, on the other hand is more well-defined; the latter are loamy and not clayey, since they have no Blue Clay material incorporated in them. Hence, the San Biagio soils dry out quickly to a brilliant white soon after a shower while the San Lawrenz soils would yet be moist and yellow brown.

Total $CaCO_3$ content is about 55% and the active $CaCO_3$ content is about 16%.

pH is rather high being between 8.4 to 9.1 but soluble salts and exchangeable sodium are low.

Cation exchange capacity is between 11 and 31 me/100 gm. Ca occupies more than 85% of base saturation with Mg, Na and K occupying the remainder.

San Biagio Series

San Biagio soils are shallow to moderately deep, whitish, medium textured, soils with a weak medium subangular blocky structure. They are slightly decalcified, slightly humus-enriched soils with an A C R profile developed on calcareous materials.

The San Biagio soils occur on the moderate slopes at the foot of the main scarps and in the moderate to gentle slopes of the dissected low plateaus. The soil is formed on a parent material developed on the Globigerina soft limestones and marls. Similar material may occur as a colluvial deposit over Franka or similar rock but the soils formed on the material whether transported or developed in situ are similar. Phosphatic nodules present as several layers in the Globigerina limestone are incorporated in the present parent material during the original rock weathering as well as during the terracing and levelling operations.

Terracing varies with slope, being negligible on flat tops and very strong on steep slopes of rock resistant to erosion yet not very hard to work.

No natural soil can be found even on the level summits. The whole area of these soils, the most extensive soil in agricultural use, has been reworked.

The soil surface is white when dry. The tilled surface horizon is gray while the untilled lower horizons are brighter and usually yellower. The texture is usually a silt loam and often becomes very slightly heavier with depth.

The soils look poor but are widely used because they are easily worked. The crust that develops in the early summer season on the fine sandy loam type on hill tops is up to 10 cm. in thickness and becomes softened by the winter rains. The problem of ploughing occurs only when the rains are late.

The heavier types, the silt loams and silty clay loams have thinner crust and a better water regime; the light sandy loams which have the surface crust that retards infiltration, also dry out very quickly.

The total calcium carbonate content varies from 57 to 80%; the active fraction being 16.5% of the total soil.

These highly calcareous, non-saline soils are only weakly alkaline as indicated by the pH which is about 8.0 and rarely exceeds 8.5.

Soil organic matter content is about 2% which is higher than would have been expected for such whitish soils.

Total phosphorus is high to satisfactory being about 0.5 to 0.2% but the available phosphorus is only about 25 p.p.m. which is low especially in view of the high total content but this is not serious. Even near phosphate nodule beds, when the soil phosphorus is about 0.6%, the available phosphorus is only 34 p.p.m.

The cation exchange capacity is low, about 20 me/100 gm. because of the relatively light texture. Ca and Mg have a high percentage base saturation while Na and K have very low values. Lime induced chlorosis is likely but can be corrected. The soils are easily worked and very responsive to good farming.

Alcol Series

The Alcol group of soils are 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 having an AC profile on a calcareous parent material.

They occur on long gentle slopes of the broad, flat, valley floors. These valleys of erosional and structural (graben) origin are formed by very deep, alluvial and colluvial deposits of material eroded from the terra, rendzina and carbonate raw soils and underlying layers of the adjoining highlands during fluctuaations of climate during the Quaternary period. The material is often stratified but not always well sorted; it is usually heavy textured but a few sandy types and intercalated sand, gravel or boulder horizons occur.

The Alcol soils like all the other soils in Malta do not show any pedogenetic horizon differentiation except that due to tillage and organic matter accumulatinn in the surface layers.

On account of their favourable depth, texture, topography and areal extent, the Alcol soils are well suited for intensive irrigated mechanised agriculture. The whole area is actually under cultivation except for the very small extents of coastal areas subject to secondary salinisation. The Alcol soils are heavy like San Lawrenz soils, Fiddien light clays and clay loam and the Tas Sigra soils, but are easier to work than the San Lawrènz and Fiddien soils.

The soil organic matter content is low though it is not confined to a thin surface horizon due to the widespread activity of varied soil fauna including ants, worms, snails and beetles. The physical state of these soils can be improved through an increase in soil organic matter content and consequent increase in activity of soil organisms. The relatively less plastic, heavy textured soils could thus maintain their good structure and improve further the soil-water relations.

Total calcium carbonate content varied from 57 to 70% while the active component varied from 9 to 18%. The amounts are, in general, least among the reddish strata.

pH is high being 8.5 at the surface and reaching 9.0 (indicating strong alkalinity) at a depth of 90 cm. below the surface. Soluble salt content, however, is low (0.15 millimhos/cm. at the surface). The alkalinity is probably due to the carbonates of sodium and potassium even through these two cations account for only 1.5 to 3.0 me/100 gm. of the soil, less than 8 percent of the total base saturation.

Soil organic matter is 1.7% at the surface and decreases to 1.0% at a depth of 30 cm.

The total phosphorus (as P_2O_5) varies from 0.42% to 0.06% in the red clay loam strata while in the coarser, more calcareous material, it is more nearly constant at 0.15%.

The readily available phosphorus (as measured by solubility in acetic acid) varies from 15 to 40 p.p.m. in the surface horizon and 6 to 14 p.p.m. below.

The cation exchange capacity of the soils varies from 20 to 40 me. per 100 gm. Ca especially and Mg form the dominant cations in the base saturation while Na and K occupy very small proporti ns. Mg and Na increase in relative proportion with depth and are probably due to accumulation from irrigation water.

Tal Barrani Series

The Tal Barrani group of soils covers 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. They are moderately decalcified, with a humus-enriched surface layer and having an A C D profile on a calcareous parent material.

They occur on the broad, low hills, strongly dissected with rounded shoulders and smooth slopes and are found mainly in Southern Malta. The Tal Barrani soils are believed to have developed on massive, fine textured Globigerina limestone similar to and including Franka, the variety used for building stones. Slow weathering of these rocks in the past climate could have given rise to a partially decalcified residue of sesquioxides which account for the brown colour. Uniform brown parent material could have developed also in areas with a naturally occurring, thin, calcareous colluvium overlying terra material due to tillage over long periods of time. No soil showing the natural horizon development was encountered. The soils are developed on highly disturbed or even artificial, man-made soil parent material layers formed in the course of terracing the shallow soils of slopes - cutting the rocky hummocks and upper part of sloping ground and distributing the rubble to fill the hollows and lower part of the sloping ground to give almost level or gently sloping steps on which finally the soil material is spread evenly. The mixing of thin terra soils on terraced areas with rock flour would also give a brown parent material. The larger fields on summits though not apparent are equally man-made like the soils on the strongly terraced slopes.

The soil formed on the highly disturbed or highly mixed brown parent material has a surface horizon relatively high in organic matter. There is no other natural horizon development in the brown gravelly clay loam or silt loam resting on man-laid rubble and gravelly clay loam. The surface is frequently littered with the undecomposable residue - tin cans, plastic, and glass pieces - of the town refuse used to increase soil organic matter and tilth. A thin, weak surface crusting is observed in the dry season.

The sandy loams and loams are inferior to the clay loams and are similar to the San Biagio soils in soil morphology. They have a weakly developed structure and exhibit surface crusting.

The clay loams have a moderately good soil structure and are better than San Biagio. Annuals like potato and cereals are favoured. Tree crops and vine are few. The soils have rapid infiltration and hence erosion is negligible except in low lying areas underlain by calcrete deposits when runoff is higher.

Total calcium carbonate content varies from 70 to 80%, while the active component is 12 to 18%, enough to induce iron chlorosis.

pH is above 8.0 but rarely above 8.5. Soluble salt content is low; conductivitiy of 1:5 soil water extract is 0.42 millimhos/cm only.

Soil organic matter is high in Tal Barrani Soils, being less than that of Terra soils only.

The total phosphorus is 0.2%, while the readily available phosphorus is also high being 70 p.p.m. presumably due to its presence in the humus.

The cation exchange capacity is 30 me/100 gm. in the surface horizon of cultivated soils. Ca and Mg are the dominant cations while K and Na occupy less than 7% of the base saturation. The only significant change with depth is a decrease in the K content.

Xaghra Series

Xaghra Series represent very shallow to very deep, red, heavy textured (clay and clay loam), decalcified soils with a strong subangular or angular blocky structure, and occurring intermittently among hard limestone bedrock outcrops on the karst landscape. The soils are strongly decalcified, with a humus-enriched surface and having an ACD profile on an almost completely decalcified B horizon soil material of a relic soil formed during an earlier climate.

These soils are invariably associated with the karst landscape. They are mostly distant from the centres of human habitation and are relatively slightly altered by man. The principal areas of Xaghra Series are on the Rabat-Dingli plateau, the coastal hills between Sliema and Salinas, a strip along the south coast west of Zurrieq, the ridges of Wardija, Baida, Mellieha and Marfa in northern Malta, and in Comino.

The Xaghra soils form on hard limestones, like Upper Coralline, Franka layer of the Globigerina, and Lower Coralline, which develop irregular surface outcropping due to preferential weathering along solution channels and fissures.

The soils occur in isolated pockets on the hard rock surface and are really the residue of leaching, being the impurities in the limestone. They are heavy textured, but the plasticity varies from slightly plastic to plastic and stickness from nonsticky to sticky. Percentage of land surface in which bare rock is exposed varies from less than 50% in the inland plateau to more than 90% near the coastal cliffs. In the remaining area covered by soil, depth of soil can vary form an inch to 8 to 9 feet or even more.

Much of the land has been covered by stone walls to trap the soil washed from upslope. In depressions where more extensive and deeper soils are probably encountered, some cereals are grown.

The strongly terraced L'Inglin, Tad Dawl and Tal Barrani soils were probably similar to Xaghra or perhaps only slightly higher in the volume of available soil material.

Tas Sigra Series

The Tas Sigra soils are 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 having an AC profile believed to have formed on strongly decalcified B horizon soil material of a relic soil formed under a previous humid climate.

These soils are found on nearly level land and are characterised by an almost complete absence of terracing or of rock outcrops. They occur on deep alluvial deposits (as in Pwales Valley and near Marsascala), in valleys and dolines of the main karst area (as near St. Martins), and in the weakly karstic Franka limestone where rock outcrops are absent. The parent material of the B horizon soil material of the relic Terra Rossa soil may be thus regionally or only transported.

The subsoil is stone-free but the surface layer usually contains limestone rubble added by the farmer and also fine calcite blown in by wind.

The soils under long cultivation have a more friable, open structure, but in uncultivated areas, the soils tend to be compact in place in the subsoil beneath the biologically active surface layer.

Secondary deposits of calcium carbonate are observed in several places in the subsoil. These are attributable to pedological processes operating in the current climate on the surfac additions of carbonate by wind or man.

The Tas Sigra soils though formed on probably completely decalcified material now contains 25 to 60% of total carbonate in the surface layers due to additions of calcite dust by wind and limestone rubble by man in his terracing and soil improvement operations. Acti--e carbonate is, however, reported to be low, less than 6%. Hence lime induced chlorosis is considered unlikely in these soils.

pH is about 8.1 increasing with depth to 8.4.

Soil organic matter is about 3.6% or more. This is among the highest in Maltese soils.

Total phosphorus ranges form 0.1 to 0.4% and is considered satisfactory. The available phosphorus varies from 2 to 105 p.p.m. This considerable variation in availability is probably correlated with soil organic matter.

Cation exchange capacity varies from 23 to 55 me per 100 gm. Calcium is the dominant exchangeable cation occupying about 87% of the total capacity. Magnesium is also appreciable being about 10%. Potassium level is about 2.7%; this is considered adequate.

4.5 Interpretation of Laboratory Data

4.5.1 Purpose and Methods

The main purpose of undertaking laboratory work was to determine if salinity or alkalinity is now or would become in the future a limiting factor for continued irrigated agriculture in the selected areas (see section 4.6). The existing data on soil characteristics in Lang's soil survey report (1960) were considered to be adequate for an appraisal of the suitability of the soils for general agriculture. The field sampling and laboratory determinations were confined to the areas selected for their potential for agricultural development on the basis of reasons given in subsection 4.6.1. No attempt was made to cover all the soils or regions of Malta as this would have been outside the scope of the terms of reference. The facilities of the WHO Project laboratory which was developed for, and was actively engaged in water and sewage analyses was available only for soil analyses that were not very complicated by time, procedure, apparatus or chemicals.

Under these circumstances, the analyses undertaken were:

1. Total calcium carbonate (by dissolving in dilute hydrochloric acid). The purpose was to determine the extent and amount of calcium carbonate in the soils.

2. pH in a soil - water paste and on dilution to 1:1 and 1:10. The purpose was to determine the presence of hydrolysable salts, like sodium carbonate, which cause an increase in pH.

3. pH in a 0.01M $CaCl_2$ - The purpose was to determine the inherent pH of the soil free from soluble salt effect.

4. pH in 0.IN KCl. The purpose was to determine broadly the nature of the exchange complex - whether it is dominated by exchangeable hydroxyl ions as in sesquioxides or by exchangeable hydrogen ions as in humus and silicate clays. pH in 1:1 soil - 0.IN KCl is lower than pH in 1:1 soil - water for soils dominant in humus and silicate clays and is higher for soils dominant in sesquioxides.

5. Conductivity of extract of soil paste. The purpose was to determine the present salinity hazard on the levels and changes in salinity with depth.

6. Conductivity of 1:5 soil water suspension. The purpose was to determine from difference in conductivity of suspension extract and conductivity of paste extract, the relative proportion of slightly and easily soluble salts like gypsum and sodium chloride respectively.

7. Amounts of common cations like calcium, magnesium, sodium and potassium and anions like carbonate, bicarbonate, chloride and sulphate to determine composition and hence the kind of salinity hazard. High contents of calcium sulphate or bicarbonate are harmless but high contents of sodium carbonate or even sodium chloride and magnesium sulphate are not good.

8. Conductivity of 1:5 soil water extract also serves as a check on total soluble salt determination and on the total composition of cations and anions.

These were all carried out according to the methods outlined in Soil Chemical Analysis by M. L. Jackson.

The results of the various determinations are interrelated. Since they are easy to carry out, they were all done in order to provide a built-in check on the reliability of the data as well as to provide a more complete picture of the composition of the soil solution. Unfortunately, pH determinations were not completed since a replacement for the malfunctioning glass electrode was not obtained.

Sodium and potassium were determined using a flame photometer housed in another institution, a few kilometres away. The absence of some sodium and potassium values is probably due to loss of test solutions in transit.

4.5.2 Summary of laboratory results

The San Biagio soils of Ta Qali are quite shallow, commonly being 18 to 27 inches deep; occasionally in isolated pockets, they are as deep as 63 inches. They are a grayish brown, cobby silty clay loam, highly calcareous with no horizon differentiation except for the humus-enriched surface layer. The area surveyed in the rainy season was all under natural grass that is graded. There is no cultivation. The calcium carbonate content increases from 50 to 60 percent in the surface layer to about 70 to 80 percent in the subsoil. pH in 0.01M $CaCl_2$ is between 7.6 and 7.9 in the surface layer and between 7.5 and 8.3 in the subsoil but is usually higher than in the surface layer. pH in 1N KCl was much lower indicating that the exchange activity is largely due to silicate clays and humus, and not sesquioxide clays. pH in water increases with dilution indicating the present of alkaline carbonates. Conductivity is frequently in excess of 1 millimho in some part of the profile, sometimes even reaching 2 millimhos. The soil water extract indicates that bicarbonate, and calcium ions generally are relatively higher in the surface layer but decreases in amount with depth. Calcium ions may occasionally remain constant. Potassium ions are usually constant but occasionally the surface layer shows a high content. Magnesium, sodium, sulphate and chloride ions usually increase with depth though one or more of them may be nearly constant in a given profile.

The San Biagio soils of Qormi are similar to those of Ta Qali regarding the composition of the soil solution. The Qormi soils are deeper varying from 50 to 60 inches in depth and are more calcareous. Calcium carbonate is about 75 to 80 percent in the whole profile but otherwise there is no significant difference in the profiles. These soils are used intensively for crops in winter and spring, but are fallow in summer.

The Tas Sigra of Ghaxaq vary in depth from 24 to 36 inches. They are red, calcareous clay loams with no horizon differentiation except for the humus-enriched surface layer. The soils are used intensively for crops in winter and spring but not as intensively in summer due to lack of adequate boreholes. The calcium carbonate content is only around 50 percent and decreases with depth in the subsoil and may increase again in the substratum of parent rock material. From the available pH in 0.1N KCl indicates that the exchange activity is dominantly due to sesquioxides. There is no increase of pH on dilution in the upper subsoil and surface layers. The slight increase in the lower subsoil indicates the presence of small amounts of sodium carbonate. Conductivity is generally low; hence total salts are low. The dominant ions are calcium and bicarbonate. Sodium, magnesium, chloride and sulphate ions are low.

The Tal Barrani soils of Zejtun are shallow to moderately deep, varying in depth from 18 to 43 inches. They are red, calcareous, clay loams with no horizon differentiation except for the humus-enriched surface layer. The soils are used intensively for crops in winter and spring but are fallow in summer. The calcium carbonate content is about 60 to 70 percent in the surface layer and it slightly increases with depth. The soils have a low conductivity and the dominant ions are calcium and bicarbonate.

The Alcol and Tas Sigra soils of Pwales are quite similar. They are deep (varying from 49 to 63 inches) clay loams. The Alcol soils are brown while the Tas Sigra are red, but no consistent difference in chemical composition was observed. The soils are used intensively for crops throughout the year. In both soils, the content of calcium carbonate in the surface layer varies from 25 to 40 percent, occasionally being as high as 50 percent. The carbonate content tends to remain constant or decrease slightly with depth. The surface soil has a pH in 0.01M $CaCl_2$ of 7.6. pH increases with depth to about 8.0. The available pH values show that the pH increases on dilution indicating the presence of sodium carbonate. Conductivity is high; commonly conductivity is around 1 micromho and increases to more than 3 micromhos in the subsoil. Calcium and bicarbonate ions are high as in other Tas Sigra soils but sodium, chloride and to a less extent magnesium and sulphate are much higher in the soil solution particularly of the subsoil layers.

The Tas Sigra soils of Ghadira are similar to the soils of Pwales in all aspects. They are also used intensively for crops throughout the year. They are also deep, red, calcareous clay loams. The soils are intensively cultivated the year round since there is an adequate supply of groundwater. Calcium carbonate varies from 25 percent in the surface to about 60 percent in the substratum. The subsoil usually contains slightly less amounts than the surface layer. Conductivity is high and is estimated to increase from 1 to 3 micromhos with depth. Calcium and bicarbonite ions are high but sodium, chloride and sulphate are dominant especially in the subsoil layers.

The Alcol soils of Bur Marrad are deep (around 60 inches), brown sandy clay loams and clay loams, highly calcareous with no horizon differentiation except for the humus-enriched surface layer. They are used for crops throughout the year but are not as intensively used in the summer as in Pwales or Ghadira valleys. The conductivity is low and so is the soluble salt content. Calcium and bicarbonate ions are dominant. Sodium, magnesium, chloride and sulphate are low except in some profiles which have a high conductivity (estimated to be 3 micromhos) and a high sulphate and chloride content but low calcium content.

The Fiddien clays of Fiddien valley are shallow, olive or gray, calcareous clays on soft Blue Clay sediments. They are used for crops in the rainy season only. From the available data, conductivity and salt content are low. Calcium and bicarbonate are the dominant ions. Sodium and chloride originally present in the parent material has been probably leached to levels comparable to those in soils of Coralline or Globigerina limestone.

The San Biagio soils at Luqa and Hal Far airports are commonly shallow (about 21 inches) occasionally deep (about 60 inches) grayish brown, cobbly or stony silty or sandy clay loams, highly calcareous with no horizon differentiation except for the humus-enriched surface layer. The area is not cultivated but was under natural grass during the rainy season. The available data indicate that conductivity and soluble salts are low and that calcium and bicarbonate are the dominant ions.

Table 5. ANALYTICAL DATA OF SOILS – pH VALUES

Lab. No.	Soil Series Location Pit Number	Depth in.	pH values				
			1 N KCl	0.01M $CaCl_2$	paste H_2O	1:1 H_2O	1:10 H_2O
1	San Biagio (Ta Qali 1)	0–9	7.2	7.7	7.8	7.8	7.9
2		9–43	7.4	8.1	8.2	8.2	8.5
3		43–80	7.6	8.1	8.2	8.3	8.6
4		80–111	7.6	8.1	8.2	8.3	8.7
5		111–150	7.7	8.1	8.4	8.4	8.8
6		150–160	8.0	8.2	8.4	8.7	9.0
7	San Biagio (Ta Qali 2)	0–6	7.4	7.7	8.0	8.0	8.2
8	San Biagio (Ta Qali 3)	0–6	7.3	7.8	7.9	8.0	8.3
9		6–21	7.5	8.0	8.1	8.3	8.6
10		21–27	7.8	8.1	7.9	8.5	8.8
11	San Biagio (Ta Qali 4)	0–5	7.4	7.8	8.0	7.7	8.0
12		8–12	7.4	8.1	8.2	8.3	8.4
13	San Biagio (Ta Qali 5)	0–5	7.4	7.9	8.0	7.8	8.2
14		8–12	7.6	8.3	8.1	8.1	8.4
15		12–16	7.7	7.9	8.1	8.2	8.8
16	San Biagio (Ta Qali 6)	0–5	7.2	7.6	8.0	8.3	8.5
17		7–11	7.6	7.9	8.3	8.3	8.7
18	San Biaigio (Ta Qali 7)	0–6	7.2	7.4	7.7	8.0	8.2
19		12–18	7.2	7.9	8.1	8.3	8.5
20	San Biagio (Qormi 8)	0–14	7.7	7.9	8.4	8.6	8.7
21		14–27	7.6	7.7	7.8	8.0	8.3
22		27–46	7.6	8.0	8.0	8.4	8.7
23		46–54	7.7	8.0	8.3	8.5	8.8
24	San Biagio (Qormi 9)	0–7	7.7	7.9	8.2	8.5	8.7
25		7–13	7.7	8.0	8.4	8.6	8.8
26		13–14	7.4	7.5	7.9	7.7	7.9
27		24–37	7.4	7.5	8.1	8.1	8.1
28		37–60	7.4	7.6	8.2	8.1	8.3

Table 5. ANALYTICAL DATA OF SOILS - pH VALUES (continued)

Lab. No.	Soil Series Location Pit Number	Depth in.	pH values				
			1 N KCl	0.01M $CaCl_2$	paste H_2O	1:1 H_2O	1:10 H_2O
29	San Biagio (Qormi 10)	0-9	7.4	7.7	8.1	8.0	8.2
30		9-16	7.4	7.7	8.1	8.0	8.3
34		16-19	7.5	7.7	8.3	8.1	8.3
32		28-44	7.4	7.7	8.3	8.1	8.3
33		44-51	7.5	7.7	8.3	8.2	8.4
37	Tas Sigra (Ghazaq 11)	0-6	7.4		7.6	7.2	7.8
36		6-16	7.3	7.6	8.3	8.1	8.2
35		16-24	7.3	7.7	8.3	8.2	8.4
38	Tas Sigra (Ghazaq 12)	0-7	8.0		7.8	7.3	7.9
39		7-18	8.0		8.2	7.3	7.9
40		18-31	8.0		8.1	7.3	7.9
42	Tas Sigra (Ghazaq 13)	0-8	8.0		8.0	7.4	7.7
43		8-14	8.0		8.8	7.5	7.9
44		14-18	8.0		8.2	7.5	7.8
46		28-36	8.0		7.6	7.4	7.8
47	Tas Sigra (Ghazaq 14)	0-10	8.0		7.6	7.4	7.8
48		10-22	8.0		7.6	7.5	8.1
82	Alcol (Pwales 27)	0-12		7.6	7.8	8.0	
83		12-23		7.8	8.1	8.3	
85		36-46		8.0	8.0	8.2	
86		46-60		8.0	8.0	8.4	
87	Tas Sigra (Pwales 28)	0-8		7.6	7.8	8.1	
88		8-22		8.1	8.2	8.6	
89		22-39		8.1	8.0	8.4	
90		39-50		8.0	7.9	8.2	
91		50-62		7.9	7.7	8.0	

TABLE 6: ANALYTICAL DATA OF SOILS – SOLUBLE SALTS

Lab No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract: Condy. micro-mho/cm	Solub. Salt %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
1	San Biagio (Ta Qali 1)	0-9	60	7.7	310	225	0.7	1.0	0.3	1.8	0.11			(0.8)	0.0
2		9-43	68	8.1	330	268	0.04	0.8	0.4	2.4	0.05			(0.8)	1.3
3		43-80	73	8.1	450	237	0.02	1.0	0.2	1.9	0.04			(0.8)	1.1
4		80-111	75	8.1	620	306	0.06	1.1	0.3	2.2	0.04	0.1	1.4	(0.8)	1.2
5		111-150	79	8.1	950	300	0.10	1.2	0.2	2.1	0.05	0.2	1.3	(0.8)	1.3
6		150-160	86	8.2	670	237	0.03	0.8	0.8	2.1	0.04	0.1	0.9	(0.8)	1.3
7	San Biagio (Ta Qali 2)	0-6	66	7.7	460	300	0.05	1.6	0.2	1.6	0.06	0.2	1.7	(0.8)	1.3
8	San Biagio (Ta Qali 3)	0-6	49	7.8	1 045	202	0.11	1.7	0.3	1.0	0.07	0.6	1.6	0.42	0.5
9		6-21	60	8.0	538	202	0.15	1.4	0.2	1.1	0.02	0.4	1.6	0.42	0.5
10		21-27	80	8.1	759	165	0.09	0.8	0.6	1.4	0.03	0.0	1.3	0.42	0.3
11	San Biagio (Ta Qali 4)	0-5	57	7.8	482	200	0.19	1.8	0.6	0.7	0.04	0.2	2.2	0.34	1.0
12		8-12	58	8.1	398	170	0.20	1.0	0.6	1.0	0.03	0.2	1.4	0.51	0.9
13	San Biagio (Ta Qali 5)	0-5	49	7.9	1 330	207	0.45	1.6	0.3	1.0	0.03	0.2	2.0	0.42	0.8
14		8-12	50	8.3	1 645	218	0.30	1.1	0.7	1.7	0.03	0.1	1.7	0.76	1.0
15		12-16	71	7.9	1 957	236	0.19	1.1	0.6	1.7	0.04	0.0	1.4	0.93	1.4
16	San Biagio (Ta Qali 6)	0-5	51	7.6	1 142	219	0.10	1.3	0.6	1.3	0.04	0.2	1.8	0.59	1.4
17		7-11	73	7.9	802	191	0.14	0.9	0.3	1.4	0.03	0.0	1.2	0.42	0.5
18	San Biagio (Ta Qali 7)	0-6	50	7.4	1 110	274	0.14	1.8	0.4	1.6	0.06	0.2	1.9	0.5	1.2
19		12-18	52	7.9	1 730	160	0.10	0.7	0.3	1.4	0.03	0.0	1.1	0.3	1.0

TABLE 6: ANALYTICAL DATA OF SOILS - SOLUBLE SALTS (continued)

Lab No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	Condy. micro-mho/cm	Solub. Salt %	1.5 Soil Water Extract							
								Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
20	San Biagio (Qormi 8)	0–14	78	7.9	1 360	214	0.19	1.1	0.1	1.7	0.04	0.1	1.4	1.1	0.9
21		14–27	72	7.7	1 685	293	0.19	1.9	0.3	1.6	0.03	0.1	1.4	0.8	1.5
22		27–46	67	8.0	686	175	0.07	1.0	0.1	1.1	0.03	0.0	1.1	0.5	1.3
23		46–54	77	8.0	512	166	0.06	1.0	0.0	1.2	0.03	0.0	1.0	0.3	0.4
24	San Biagio (Qormi 9)	0–7	72	7.9	748	193	0.17	1.0	0.1	1.4	0.04	0.1	1.4	0.4	0.0
25		7–13	79	8.0	610	188	0.17	0.7	0.1	1.7	0.04	0.0	1.6	0.5	0.1
26		13–14	77	7.5	1 060	218	0.13	1.2	0.4	1.4	0.03	0.0	1.5	0.8	0.8
27		24–37	74	7.5	1 098	248	0.14	1.0	0.2	1.3	0.03	0.0	1.5	0.8	0.2
28		37–60	76	7.6	915	218	0.09	1.1	0.4	1.6	0.03	0.1	1.1	0.7	0.8
29	San Biagio (Qormi 10)	0–9	76	7.7	552	183	0.16	1.1	0.2	1.4	0.04	0.2	1.7	0.8	0.4
30		9–16	76	7.7	678	180	0.08	1.2	0.2	1.3	0.03	0.2	1.6	0.7	0.9
34		16–19	77	7.7	650	171	0.09	1.1	0.6	1.0	0.05	0.2	1.3	0.6	1.0
32		28–44	75	7.7	707	177	0.09	1.1	0.1	1.2	0.02	0.1	1.1	0.5	1.0
33		44–51	73	7.7	590	183	0.08	0.9	0.3	1.2	0.02	0.0	1.1	0.5	0.9
37	Tas Sigra (Ghaxaq 11)	0–6	50		494	196	0.09					0.1	1.9	0.7	
36		6–16	45	7.6	585	165	0.06	1.0	0.3	1.1	0.06	0.2	1.4	0.4	0.5
35		16–24	56	7.7	507	167	0.06	0.9	0.2	1.5	0.02	0.2	0.8	0.4	0.4
38	Tas Sigra (Ghazaq 12)	0–7	56		615	228	0.20	1.5	0.2			0.1	2.1	0.7	
39		7–18	52		500	205	0.03	0.9	0.3			0.1	1.7	0.6	
40		18–31	43		600	218	0.02	1.1	0.4			0.2	1.4	0.6	

TABLE 6; ANALYTICAL DATA OF SOILS - SOLUBLE SALTS (continued)

Lab No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract									
						Condy. micro-mho/cm	Solub. Salt %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
42	Tas Sigra (Ghazaq 13)	0–8	48		358	184		1.3	0.3			0.2	1.4	0.4	
43		8–14	52		197	177		1.0	0.1			0.0	1.7	0.7	
44		14–18	46		247	196		1.0	0.3			0.2	1.5	0.5	
46		28–36	64		309	184		1.2	0.3			0.0	1.6	0.6	
47	Tas Sigra (Ghazaq 14)	0–10	67		284	174		1.2	0.4			0.2	1.5	0.8	
48		10–22	49		315	171		0.9	0.5			0.1	1.8	0.7	
55	Tal Barrani (Zejtun 16)	0–9	70		510	165	0.07	1.5	0.2	0.2	0.05	0.1	1.8	0.5	0.4
54		9–18	72		480	147	0.06	1.2	0.2	0.3	0.04	0.1	1.7	0.4	0.4
52		34–43	75		520	182	0.08	1.1	0.3	0.3	0.05	0.0	1.7	0.6	0.6
56	Tal Barrani (Zejtun 17)	0–9													
57		9–21	60		220	137	0.04	1.1	0.1	0.3	0.05	0.1	1.6	0.4	0.4
58		21–35	72		422	169	0.08	1.3	0.3	0.3	0.04	0.1	1.8	0.5	0.0
62	Tal Barrani (Zejtun 18)	0–12	71		410	139	0.05	1.2	0.0	0.2	0.09	0.1	1.5	0.2	0.3
61		12–24	74		580	182	0.08	1.5	0.3	0.2	0.07	0.1	1.8	0.4	0.2
60		24–31	73		525	173	0.09	1.5	0.5	0.2	0.07	0.1	1.6	0.6	0.4
66	Tal Barrani (Zejtun 19)	9–20	67		480	154	0.06	0.8	0.6	0.3	0.06	0.2	1.7	0.2	0.0
65		20–31	86		685	162	0.08	1.3	0.2	0.3	0.13	0.2	1.8	0.6	0.1
67		31–54	49		684	163	0.06	1.3	0.2	0.1	0.07	0.1	1.2	0.4	0.3
71	Tal Barrani (Zejtun 22)	0–5	71		245	134	0.05	1.4	0.1	0.2	0.04	0.1	1.5	0.3	0.0
79	Tal Barrani (Zejtun 25)	0–8	62		659	151	0.03	1.4	0.2	0.2	0.05	0.1	1.3	0.5	0.2
76		8–18	70		240	138	0.06	1.2	0.2	0.3	0.04	0.1	1.6	0.3	0.0

TABLE 6: ANALYTICAL DATA OF SOILS – SOLUBLE SALTS (continued)

Lab. No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract									
						Condy. micro-mho/cm	Solub. Salt. %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
82	Alcol (Pwales 27)	0–12	42	7.6	1 183	388	0.21	1.6	1.9	2.8	0.11	0.2	1.9	0.8	2.7
83		12–23	39	7.8	405	268	0.13	1.3	1.0	2.4	0.05	0.2	1.8	0.7	1.6
85		36–46	50	8.0	1 275	354	0.14	1.5	0.6	2.6	0.05	0.1	1.5	1.3	0.8
86		46–60	40	8.0	717	321	0.16	0.8	0.5	2.9	0.04	0.2	1.7	1.0	2.2
87	Tas Sigra (Pwales 28)	0–8	40	7.6	934	356	0.20	1.4	0.8	2.2	0.36	0.4	2.5	0.9	0.9
88		8–22	36	8.1	309	388	0.21	0.5	0.5	3.3	0.08	0.3	2.7	0.7	1.7
89		22–39	34	8.1	1 770	482	0.19	1.1	0.2	3.9	0.04	0.2	1.9	1.1	3.0
90		39–50	33	8.0	3 360	716	0.28	2.5	0.7	6.1	0.06	0.2	1.4	1.7	4.8
91		50–62	14	7.9	3 490	753		2.5	0.6	5.9	0.06	0.2	1.4	3.1	2.7
92	Tas Sigra (Pwales 29)	0–12	36			184	0.14	1.3	0.4	1.0	0.12	0.2	1.8	0.3	1.1
93		12–32	20			242	0.17	0.8	0.1	2.5	0.04	0.1	1.9	0.6	0.6
94		32–49	20			388	0.15	1.3	0.3	2.3	0.07	0.1	1.6	1.0	0.8
95	Tas Sigra (Pwales 30)	0–13	26			264	0.18	1.1	0.5	1.9	0.17	0.0	2.4	0.7	0.1
96		13–26	16			373	0.16	1.1	0.1	3.4	0.05	0.1	1.9	1.5	0.8
97		26–51	10			506	0.23	1.6	0.5	3.7	0.04	0.1	1.5	2.5	1.1
98		51–60	4			560	0.13	1.8	0.4	4.0	0.06	0.1	1.5	3.3	0.8
99		60–63	55			403	0.20	1.2	1.1	2.6	0.06	0.2	1.7	2.2	0.5
100	Alcol (Pwales 31)	0–6	25			283	0.17	0.8	1.2	2.2	0.08	0.1	2.7	0.8	0.4
101		6–12	24			417	0.38	0.5	0.2	10.8	2.45	0.0	1.9	1.9	0.8
102		12–27	23			775	0.48	1.6	0.4	15.0	1.40	0.0	1.4	4.8	1.0
103		27–42	28			745	0.46	1.4	0.3	15.2	0.60	0.0	1.6	4.6	1.3
104		42–55	26			710	0.11	1.2	0.2	15.8	0.40	0.0	1.4	4.4	0.8

TABLE 6: ANALYTICAL DATA OF SOILS -SOLUBLE SALTS (continued)

Lab. No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract: Condy. micro-mho/cm	Solub. Salt %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
105	Tas Sigra	0-9	27			200	0.16	0.7	0.4	5.2	3.30	0.0	2.1	3.0	0.3
106	(Pwales 32)	9-24	79			252	0.32	0.8	0.2	6.8	2.90	0.1	2.6	1.5	0.0
107		24-41	26			407	0.29	0.6	0.3	11.2	0.65	0.1	1.8	1.8	0.7
108		41-57	53			462	0.38	1.1	0.2	10.6	0.40	0.0	1.5	2.2	0.9
109	Tas Sigra	0-10	51			204	0.13	0.7	0.6	4.6	7.00	0.0	2.1	1.0	0.1
110	(Pwales 33)	10-22	50			314	0.34	0.5	0.0	10.6	9.70	0.2	3.1	0.4	0.1
111		22-32	59			343	0.31	0.3	0.2	10.4	2.30	0.2	2.6	0.5	0.6
112		32-53	29			970	0.57	1.5	0.7	19.6	1.30	0.1	1.0	6.8	1.2
113		53-62	37			970	0.62	2.0	0.5	19.6	0.80	0.1	1.7	7.2	1.1
114	Alcol	0-8	39			192	0.12	1.2	0.4	2.8	3.05	0.1	1.9	1.0	0.5
115	(Pwales 34)	8-16	35			130	0.09	1.2	0.3	2.0	1.30	0.1	1.6	1.0	0.1
116		16-24	33			192	0.15	1.3	0.4	2.2	0.30	0.0	1.7	1.0	0.6
117		24-37	34			250	0.19	1.6	0.8	2.4	0.35	0.1	1.6	0.1	0.7
118		37-57	42			207	0.12	1.5	0.4	2.2	0.35	0.1	1.5	0.9	0.3
119	Tas Sigra	0-8	26			326	0.11	0.8	0.3	7.4		0.1	2.4	0.7	0.2
120	(Ghadira 35)	8-16	21			373	0.44	0.5	0.2	9.0	3.80	0.1	2.3	0.9	0.5
121		16-30	15			460	0.38	1.0	0.2	7.5	1.10	1.1	1.8	1.3	1.5
122		30-50	8			870	0.98	1.7	2.2	16.0	0.70	0.1	1.2	5.7	1.2
123	Tas Sigra	0-6													
124	(Ghadira 36)	6-14	22			181	0.33	0.7	0.3	3.4	1.20	0.0	1.8	5.6	0.2
125		14-26													
126		26-41	58			289	0.49	0.3	0.3	5.2	2.00	0.4	2.5	4.8	0.0

TABLE 6: ANALYTICAL DATA OF SOILS – SOLUBLE SALTS (continued)

Lab. No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract									
						Condy. micro-mho/cm	Solub. Salt %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
202	Alcol	33–48				116	0.36	0.9	0.2			0.1	1.4	0.3	0.0
201	(Bur Marrad 40)	48–59				118	0.74	0.8	0.3	1.0	0.03	0.0	1.4	0.7	0.6
205	Alcol	0–3				138	0.78	1.3	0.1	2.1	0.03	0.1	1.5	0.7	0.0
204	(Bur Marrad 41)	3–17				142	0.31	1.2	0.2	0.5	0.05	0.1	1.5	0.9	0.1
203		17–32				113	0.73	1.0	0.6	0.5	0.03	0.0	1.3	0.7	1.7
210	Alcol	0–3				268	0.12	1.5	0.6			0.1	2.1	0.6	0.0
208	(Bur Marrad 42)	3–22				200	0.08	0.5	0.1			0.2	0.6	0.3	0.1
207		22–41				460	0.17	1.1	0.4			0.1	1.3	1.3	3.7
206		41–59				810	0.23	3.0	1.0			0.1	0.9	5.6	0.0
211	Alcol	0–3				268	0.17	1.2	0.3	0.8	0.05	0.0	2.8	0.4	0.1
212	(Bur Marrad 43)	3–12				245	0.15	0.9	0.2	2.6	0.05	0.0	2.7	0.3	0.0
213		12–29				375	0.32	0.6	0.1	4.1	0.05	0.1	2.2	1.9	0.0
215		42–55				178	0.18	0.6	0.2	4.4	0.03	0.1	2.0	2.7	0.1
216	Alcol	0–3				178	0.12	1.4	0.3	0.7	0.05	0.0	1.7	0.9	0.0
217	(Bur Marrad 44)	14–31				119	0.26	1.1	0.2			0.0	1.3	0.3	0.0
218		31–46				113	0.18	1.1	0.0			0.0	1.2	0.4	0.1
219		46–57				113	0.03	0.9	0.5			0.1	1.3	0.3	0.0
221	Alcol	0–2				270	0.21	1.4	0.0	1.8	0.20	0.0	3.0	1.9	0.2
222		2–13				184	0.09	0.6	0.2	1.1	0.03	0.0	3.0	0.9	0.0
225		38–58				480	0.22	0.9	0.2	4.0	0.05	0.0	1.8	3.1	0.0
319	Fiddien	0–3				178	0.06	1.6	0.1	0.6	0.0	0.1	1.4	0.0	0.2
318	(Fiddien Valley 50)	3–14													
317		14–24													
316		24–56				130	0.05	1.3	0.5	0.7	0.08	0.0	1.8	0.7	0.3
315		56–61				190	0.03	0.8	0.5	2.6	0.05	0.0	1.6	0.9	0.0

TABLE 6: ANALYTICAL DATA OF SOILS – SOLUBLE SALTS (continued)

Lab. No.	Soil Series Location and Pit Number	Depth in.	Total $CaCO_3$ %	pH. 0.01M $CaCl_2$	Condy. paste micro-mho/cm	1.5 Soil Water Extract									
						Condy. micro-mho/cm	Solub. Salt %	Ca^{++} me/1	Mg^{++} me/1	Na^{+} me/1	K^{+} me/1	CO_3^{--} me/1	HCO_3^{-} me/1	Cl^{-} me/1	SO_4^{--} me/1
324	Fiddien	0–3													
323	(Fiddien	3–14													
322	Valley 52)	14–22													
321		22–32				165	0.05	0.9	0.5	1.1	0.0	0.0	1.5	0.9	0.0
320		32–60													
327	Fiddien	0–3													
326	(Fiddien	3–17				215	0.06	1.4	0.3	1.1	0.03	0.0	1.4	0.8	0.2
325	Valley 51)	17–60													
226	San Biagio (Ta Qali 80)	3–27				108	0.06	1.0	0.2	0.4	0.0	0.0	1.5	0.7	0.2
229	San Biagio	3–10				113	0.07	1.1	0.2	0.7	0.0	0.0	1.6	0.5	0.0
228	(Ta Qali81)	10–32				82	0.06	1.0	0.2	0.4	0.0	0.0	1.7	0.7	0.0
336	San Biagio (Luqa 60)	20–45				132	0.05	1.0	0.0	1.1	0.0	0.0	1.7	0.7	0.8
341	San Biagio (Luqa 60)	45–60				164	0.06	1.3	0.3			0.0	1.2	1.4	0.3
348	San Biagio (Halfar 61)	0–3				176	0.07	1.5	0.2	1.0	0.08	0.0	1.9	0.8	0.3
347		3–21				130	0.04	0.8	0.3	0.7	0.0	0.0	1.7	0.5	0.4

4.5.3 Conclusions from Laboratory Data

The results available show some trends significant in the study of present and potential salinity and alkalinity hazards under irrigated agriculture.

The soils are all very calcareous. The high contents of total and active (or finely divided) calcium carbonate and of calcium sulphate, which also is common, could furnish a high concentration of calcium ions which will prevent the accumulation of sodium and magnesium ions on the exchange complex. A high concentration of calcium ions needed to suppress the increase of exchangeable sodium can be maintained from calcium carbonate only if the soil has continual adequate additions of organic matter for good microbiological activity. This is needed to maintain high carbon dioxide partial pressure and hence bicarbonate ions in soil solution. Nevertheless, if quality or quantity of water for leaching is inadequate, sodium and magnesium can accumulate as chlorides, sulphates, carbonates and bicarbonates. Hence a high soil reaction (pH) and high salt content may obtain in the soil without the usual accompaniment of poor structure and clay dispersal.

The levels of pH and of soluble salts used in other countries to classify the noncalcareous soils for irrigation suitability may not apply here. The critical levels can be moved towards the higher values because the soils contain ample calcium carbonate and probably a little sulphate. But the very low content of silicate clays and organic matter in the highly calcareous light-textured soils may not give sufficient buffering capacity. Experimental results on different crops are needed to determine the suitability of these highly calcareous soils under different pH values and soluble salt contents.

The trend for irrigated soils to accumulate sodium, magnesium, chloride and sulphate ions in the subsoil is observed in Pwales Valley, Ghadira and in parts of Bur Marrad. This is probably due to the appreciable content of soluble salts in the irrigation water (corresponding to an electrical conductivity of 3,000 micromhos/cm), the regular use of adequate fertilizers and intensive continuous agriculture. Under rainfed agriculture with fallow periods and where probably little fertilizer is used, as in Zetjun, Ghaxaq, Qormi and Fiddien Valley, no such accumulation has been observed.

Though, as already mentioned the critical levels of pH and soluble salt content for calcareous soils are not known, the trend is clear. Many observers have already mentioned the excessive use of water which indicates that there has been ample water for deep percolation. The accumulation now taking place in the subsoil under such adequate deep percolation conditions can gradually continue upward to affect crop yields adversely unless the widely known trend of deterioration of quality of irrigation water is at least arrested, if not improved, to obtain effective leaching of soluble salts.

The soils themselves contain from 30 to 80% calcium carbonate. In many of these soils, calcium carbonate probably provides an appreciable proportion of the active surface available for exchange phenomena. Ionic antagonisms and effects of high pH on plant uptake of nutrients like phosphate are probably aggravated by the calcareous nature of the soil.

But problems of uptake of nutrients like phosphate or iron can be easily and economically remedied. But the trend towards deterioration of tilth and increase in moisture stress due to alkalinity and salinity must be arrested early. Remedial measures at a later stage are much more difficult and expensive.

5. Irrigation Suitability Land Classification

5.2 Irrigation Suitability Land Classification System

The irrigation suitability land classes are based on the system developed by the U.S. Bureau of Reclamation (1953). It is assumed that adequate water of suitable quality will be available at reasonable cost.

Although the distinctions between land classes are based on differences in physical features, the limits for these differences are developed on the basis of agronomic and economic experience and predictions to give categories of approximately equal economic significance. Experimental data and yield or income figures are not available for precise correlation. Hence the proposed limits for the physical features are provisional. The mapping specifications or criteria thus defined are used to determine the irrigation suitability of the lands.

Certain sociological and economic circumstances can influence the actual limits of mapping specifications. Thus in Malta, in addition to the need for developing agriculture to increase production of both current and potential expert crops and import-sustitution crops, the following factors are also relevant:

a) the traditional skills and perseverence as shown by the intensive and almost complete land reclamation, and soil and water conservation by terracing, carting, filling quarries, manuring and by construction of reservoirs, irrigation conduits etc.,

b) the scarcity of large contiguous areas suitable for irrigation development on the scale usually known elsewhere,

c) the small area of the whole country,

d) the very high population density,

e) the alternative system of agriculture dependent on rain alone, which keeps land idle in summer,

f) the possibilities of exploiting the climatic conditions and nearness to markets to reproduce high income crops like flowers and vegetables especially out of season.

Under these circumstances, land that would be considered unsuitable in a larger country with alternate sites, or under lower population density, or unproven technical skills or perseverence may have to be brought into intensive development.

The six classes adapted from the U.S. Bureau of Reclamation classification (1953) are:

Class 1 - Arable: Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops at reasonable cost.

Class 2 - Arable: Lands that are of moderate suitability for irrigation farming, being measurably lower than Class 1 in productive capacity, adapted to a somewhat narrower range of crops, more expensive to prepare for irrigation or more costly to farm.

Class 3 - Arable: Lands that are suitable for irrigation development but are approaching marginality for irrigation and are of distinctly restricted suitability because of more extreme deficiencies in the soil, topographic or drainage characteristics than described for Class 2 lands.

Class 4 - Limited Arable: Lands that have one or more excessive, noncorrectible deficiencies thereby limiting their utility to certain crops or very special conditions like sewage spreading or sewage effluent reuse or sites for greenhouses; or they are capable of supporting a farm family and meeting water charges if operated in units of adequate size, or in association with better lands, or as part-time farming in addition to an income from other sources.

Class 5 - Nonarable: Lands whose arability class can be determined only after additional data become available. This is a tentative class and the lands are changed to one of the arable classes or to class 6 before completion of the classification. Hence class 5 never appears in a final report.

Class 6 - Nonarable: Lands which are considered nonarable becaause of steep, rough topography; strongly terraced, small fields; soils of very coarse or very fine textures; and shallow soils over hard limestone bedrock. These lands do not have a reasonable expectancy of permanent, profitable production under large-scale, organized irrigation. A few individual fields in isolated areas of small extent within such lands can have high suitability and may be actually used under small scale, individually arranged irrigation, but the class 6 lands as a whole are unsuitable.

5.2 Specification for Land Classes

The determination of irrigation suitability land classes is based on:

a) size and shape of fields; frequency of stone walls and embankments; difference in elevation between enbanked terraces.

b) depth, texture, structure and stoniness of the soil in so far as they affect tilth, rooting volume and moisture holding capacity:

c) chemical characteristics such as reaction (pH, salinity (conductivity), alkalinity (exchangeable sodium percentage) and chemical composition (mainly total and active calcium carbonate). Features like exchangeable calcium, magnesium or potassium and base saturation are not considered to be relatively as important as the given factors within any soil; any difference between soils in cation exchange capacity is already taken care of by texture.

d) permeability of subsoil and bedrock, and soil drainage;
These factors influence crop adaptability, crop yields, irrigation method and pattern, level of mechanization, ease of supervision or management, intensity or density of irrigation channels or pipes and of farm drains.

Subclasses are indicated by s, t, d, st, sd, td, or std, where letters s, t, and d indicate deficiency due to soil, topography and farm drainage respectively.

The specifications used for the irrigation suitability classification are given in table 6. These specifications have been defined on the basis of their predicted relevance to the agronomic and economic value of the lands under consideration.

For each condition, the minimum or maximum limit allowable for a given class when all the other conditions are optimum can be defined. But when one or more of these other conditions deviate from the optimum, the limits of the condition under discussion will vary because the various conditions are interdependent. It is not practical to enumerate limits of each condition for each of the innumerable combinations of the limits of all the other conditions. Hence the limits of each condition when all the other conditions are optimum are given. When one or more of these other conditions are worse than the limiting values for a given class, the final land class can be one or more levels worse. But, on the other hand, if one or more conditions are better than the limiting value, the limit of another condition will not necessarily be lowered nor the class changed to a better one. No fixed rules can be elaborated to cover all situations. In practice, the procedure is to consider all the pertinent factors, and judgement of a proper balance between the compensating factors is made before assigning the land to an appropriate irrigation suitability land class.

TABLE 7. LAND CLASSIFICATION SPECIFICATIONS

Characteristics	Class 1 - Arable	Class 2 - Arable	Class 3 - Arable	Class 4 - Arable	Class 6 - Non-arable
SOILS					
1. Texture	Fine sandy loam to friable clay loam	loamy fine sand to permeable clay	Loamy sand to fine clay	Gravelly loamy sand to clay	Sand to heavy clay
2. Depth to permeable bedrock	More than 120 cm. (deep)	More than 75 cm. (moderately deep)	More than 30 cm. (shallow)	More than 30 cm. (shallow)	Less than 30 cm. (very shallow)
3. Alkalinity	pH more than 5.5, and less than 8.3 unless soil is calcareous, total salts are low and exchangeable sodium is negligible	pH more than 4.5, and less than 8.8 unless soil is calcareous, total salts are low and exchangeable sodium is negligible	pH more than 4.5, and less than 8.8 unless soil is calcareous, total salts are low and exchangeable sodium is less than 10%	pH more than 4.5, and less than 8.8 and exchangeable sodium less than 15%	pH less than 4.5, or more than 8.8 and exchangeable sodium more than 15%
4. Salinity as measured by conductivity of saturation extract	Less than 2 millimhos per cm.	Less than 4 millimhos per cm.	Less than 8 millimhos per cm.	Less than 8 millimhos per cm.	More than 8 millimhos per cm.
5. Total $CaCO_3$ content	Less than 70%	Less than 85%	Less than 95%	Less than 95%	More than 95%
6. Active $CaCO_3$	Less than 15%	More than 15%	More than 15%	More than 15%	More than 15%

TABLE 7- LAND CLASSIFICATION SPECIFICATIONS (cont'd)

Characteristics	Class 1 - Arable	Class 2 - Arable	Class 3 - Arable	Class 4 - Arable	Class 6 - Non-arable
TOPOGRAPHY					
1. Slope a) Average slope of individual fields if land is terraced	0.1 to 2.0%	Less than 5%	Less than 10%	Less than 15%	More than 15%
b) Average general slope if land is unterraced	0.1 to 3.0%	Less than 8%	Less than 15%	Less than 25%	More than 25%
2. Degree of terracing	Unterraced to slightly terraced	unterraced to moderately terraced	Unterraced to strongly terraced	Unterraced to very strongly terraced	Unterraced to very strongly terraced
a) Size and shape of fields	75% of **fields** more than 20 metres wide. Less than 10 fields per hectare.	75% of fields more than 20 metres wide. Less than 25 fields per hectare.	75% of fields more than 10 metres wide. Less than 50 fields per hectare.	75% of fields more than 5 metres wide. Less than 50 fields per hectare.	75% of fields less than 5 metres wide. More than 50 fields per hectare.
b) Average drop in elevation from one terrace to the next.	0 to 0.5 metres	0. to 1.5 metres	0. to 3 metres	0 to 3 metres	0 to 3 metres
c) Stones	Few high walls	Few to common, high walls.	Few to many high walls.	Few to many high walls.	Many thick high walls. Many stones on surface.
DRAINAGE					
1. Surface runoff	Sloww	Slow to rapid	Slow to rapid	Slow to rapid	Slow to very rapid
2. Subsoil permeability	Moderately rapid to moderately slow	Moderately rapid to slow	Rapid to very slow	Rapid to very slow	Very rapid to very slow

Variations outside the permissible range of a given property often occur naturally and also since lands of good and potentially good agricultural value have been formed by mixing by tillage, terracing and carting to very variable degrees even within a single field. In fact there is often as wide a range in the relevant characteristics between two parts of one field as there is between two distant fields in a given landscape.

The quality of water available for general agricultural use is taken as one with an electrical conductivity of 2000 micromhos per cm. If water of better quality were made available at reasonable cost, a wider range of crops could be grown but the relative classes are not expected to change. On the other hand, if water of quality worse than one with an electrical conductivity of 3000 micromhos per cm. were available, the land areas can be expected to move down by at least one class (i.e., class 1 becomes class 2, class 2 becones class 3 and class 4 become class 6).

The risks of contamination of the nation's water supply if biologically impure water, like sewage effluent treated to various levels of purification, is used for irrigation are not taken into account in this classification. It is assumed that the irrigation of any of the selected areas will be with water of a quality that does not involve any risks of contamination of ground water.

Table 8: Irrigation Suitability Classes of Demarcated Areas In Malta and Gozo

Area No. on map	Location	Size (Ha)	Soil Kinds	Elevation (meters)
	MALTA			
	Class 1 Land			
20	St. Martins	11	Tas Sigra	172-180
25	Wied il Ghasel	310	Alcol, Tas Barrani	2- 30
26	Pwales Valley	98	Alcol, Tas Sigra	2- 30
	Class 2 Land			
2	Hompesch Arh	25	Tas Sigra, Tal Barrani	45- 52
7	Bir-id-deheb	51	Tas Sigra, Tal Barrani	53- 60
23	Bingemma North	232	Tas Sigra, L'Inglin	75-105
24	Bingemma West	41	Tas Sigra, L'Inglin	75-105
25	Wied il Ghasel	310	Tal Barrani, San Biagio	2- 30
26	Pwales Valley	98	Tas Sigra	2- 30
27	Mizieb	62	Tas Sigra	30- 53
29	Il Ghadira	31	Tas Sigra, Alcol	0- 15
	Class 3 Land			
3	Wied ta Mazza	114	Tas Sigra	30- 52
4	Ta San Girgor	20	Tas Sigra	38- 52
8	Santa Lucia	429	Tas Sigra, Tal Barrani & San Biagio	30- 84
10	Ta' Balvun	57	Tal Barrani, Tas Sigra & L'Inglin	38- 76
13	Wied-il-Mixta	32	L'Inglin, Tal Barrani	30 -45
14	Tal Kittienja	239	Tas Sigra, San Biagio	75- 98
16	Ta Qali	863	San Biagio, Tal Barrani & Tas Sigra	83-150
17	Tal Ghaqba	136	Tal Barrani, San Biagio	75-105
19	Wied is Sewda	178	San Biagio	30- 53
25	Wied il Ghasel	310	San Lawrenz, Fiddien	30- 53
28	Il Hofra	48	Tal Barrani, Tas Sigra	0- 30
	Class 4 Land			
1	San Leonardo	55	Tal Barrani, Tas Sigra	38- 52
5	Ta Lombardi (Marsaxlokk East)	205	San Biagio, Tal Barrani	7- 45
6	Marsaxlokk West	76	L'Inglin, San Biagio & Tas Sigra	7- 45
9	Il Brolli	59	Tas Sigra, San Biagio	23- 83
11	Halfar	125	Tas Sigra, Tal Barrani & San Biagio	52- 67
12	Bubaqra East	99	Tas Sigra, Tal Barrani L'Inglin	90-129
15	Ta'San Niklaw	113	Tas Sigra, Tal Barrani & L'Inglin	105-130
16	Ta Qali	863	San Biagio, Tal Barrani & Tas Sigra	83-150
18	Ta Hlas	135	San Biagio	45- 90
21	Fiddien Valley	233	Fiddien, Nadur & Alcol	128-187
22	Wied L'Armla	102	Fiddien, San Lawrenz, San Biagio and Tal Barrani	97-182
	GOZO			
	Class 2 and 3 Land in about equal proportion			
	Victoria-Xewkija	363	San Biagio, San Lawrenz, and little Tal Barrani and Fiddien	57-100

5.3 Land Class Descriptions

Class 1 lands

Class 1 lands total only 419 hectares (see table No. 9). The soils are, on the whole, deep clay loams with a good structural stability. They occur in large fields, only slightly or not terraced. The irrigation can be done either by sprinkler or by furrow.

St. Martins (Area No. 20 on map) is only 11 hectares. At present water of suitable quality, because it comes from the high level or perched aquifer, is available only for St. Martins. But this area is very small and not quite accessible.

The Wied il Ghasel or Bur Marrad Valley (Area No. 25 on map) is the largest single area of class 1 soils. The extent is about 310 hectares in the central part of the valley. Fields are large, terraces are far apart and the height differences are small. Water supply is the critical problem. As already mentioned in section 5.1, the suitability classification is based on the assumption that water in adequate quantity and of acceptable quality will be available. The W.H.O. Laboratory found the conductivity of water at Wied-il-Ghasel pumping station to be 1.65 millimhos on December 2, 1969, 1.70 millimhos on December 10, 1968, 1.98 millimhos on February 11, 1969 and 2.40 millimhos on March 21, 1969. As will be seen in section 6.1, irrigation water with conductivity higher than 2 millimhos is not suitable for an economically viable irrigation development. Increase in salinity and alkalinity is observed in the subsoil only in a few places. But salinity and alkalinity hazards are bound to increase in the soils if organic matter is not deliberately built up by including leguminous green manure crops in the rotation and if the intensive crop cultivation in the summer months with water of such high conductivity is continued. If adequate water of acceptable quality can be provided, the Wied-il-Ghasel or Bur Marrad Valley on account of its contiguous size and access roads can rapidly develop as the most important agricultural production area of Malta for all kinds of field crops climatically adapted to Malta.

The Pwales Valley (Area No. 26 on map) has an area of 98 hectares. The fields are large, terraces are far apart and height differences small except along the sides adjoining the valley walls. In addition, the area is sheltered by uplands from winds blowing from the northerly or southerly or even westerly directions. At present the area is being very intensively cultivated. The area benefits from the runoff on the adjacent uplands directly or from cistern storage. Provisions for diverting the excess runoff waters into the sea at times of heavy downpours are also constructed. The water used for irrigation in the area has been reported sometimes to have a conductivity as high as 3 micromhos. This area is very intensively cultivated throughout the year using high amounts of irrigation water. The soils have a high conductivity in the subsoil increasing with depth from 1 to 3 millimhos; the content of sodium, chloride, magnesium and sulphate ions are also high in the subsoil. These are correctible deficiencies if water of suitable quality is used for irrigation and if soil organic matter is deliberately built up by including a leguminous green manure crop in the crop rotation. On account of the compact and rectangular shape of the area, the effective network of access roads within the area and reasonable sheltering from winds, the Pwales Valley can rapidly develop into an important centre for the sustained production of all kinds of crops climatically adapted to Malta, if water of good quality is available for irrigation and leaching requirements.

Class 2 lands

Class 2 lands total 850 hectares (see table No. 9). The soils are mostly productive clay loams with a strong structural stability. But they occur in moderately large fields, slightly or moderately terraced with stone walls sometimes thick and high. Hence they all have a topographic limitation and hence only sprinkler irrigation is possible. Except for the area near Hompesch Arch (Area No. 3 on map), all the other areas in class 2 are not uniformly deep and hence have a soil limitation also. All the areas are intensively cultivated in the wet season and in each area the parts served by the installation of boreholes are cultivated in the summer. From the areas sampled and studied in the laboratory, a tendency for salinity and alkalinity to develop in the subsoil has been observed. This is attributable to the use of water with conductivity higher than 2 micromhos, and the use of such low quality water in excess of optimum needs of the plant during the peak season of evaporation.

All these areas are in class 2 on the assumption that adequate amounts of water of good quality will become available. They are lower than class 1 in suitability because of the unfavourable topography which increases the cost of laying out the irrigation channel network and which makes furrow irrigation difficult and costly.

Class 3 lands

Class 3 lands total 2420 hectares (see table 9). The soils are moderately deep to shallow and medium or heavy textured. The fields are moderately large to small and are commonly strongly terraced. Hence they are all affected by both soil and topographic limitations.

They will respond to irrigation in the dry season but the economic benefits of such investment on irrigation are bound to be low. But even such low returns can be sustained only with the use of good quality water provided to the farmer at costs comparable to the total capital and recurrent expenditure involved for pumping water from boreholes by farmers.

Class 4 lands

Class 4 lands total 2065 hectares (see table 9). The soil and topography are limiting factors for the areas listed in Class 4 except for Ta Qali, Hal Far, Fiddien Valley and Wied L'Armla (areas No. 11, 16, 21 and 22 on the map), because they have very shallow to shallow, highly carbonatic, calcareous soils, and are slightly to strongly terraced. The Fiddien Valley and Wied L'Armla soils are very slowly permeable clays on gentle valley slopes. The Ta Qali and Hal Far areas have very shallow to shallow soils on levelled land.

These class 4 lands are not normally economically suited for the development of irrigated agriculture even though small patches within the areas are being irrigated by farmers from boreholes or springs. They are capable of producing only low intensity, low value crops like sulla, alfalfa and are not suited for intensive cultivation with crops like high value vegetables requiring high input and high management. They are capable of supporting a farm family and meeting water charges if operated in units of adequate size, or in association with better lands or as part-time farming in addition to an income from other sources.

The areas in class 4 except Fiddien Valley (area no. 21) and Wied L'Armla (area no. 22) have a permeable subsoil and substratum. If sewage effluent of adequately low salinity and no health hazard to ground water source were available at low cost, these areas could take advantage of this additional water since the present low level of agricultural productivity of these lands will be improved while any restrictions in crop selection or timing are not very serious.

Since land is in critically short supply in Malta and water is also very scarce, the level lands of Hal Far and Ta Qali are suited for the installation of greenhouses for specialized out of season or high value vegetables, flowers cuttings or seeds using small of good quality water most efficiently, or for improved pasture and cereals. But Hal Far is part of a military airport area.

Class 6 lands

All the remaining land is considered as unsuited for large scale development of irrigation, even though in several places in the remaining agricultural areas, irrigation from boreholes is used successfully by individual farmers on small tracts of land.

Table 9: Characteristics of Areas Suited for Irrigation

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
1	San Leonardo 55 hectares Class 4, Subclass 4st-	38 to 52 metres; ridge and upper gentle slope	Globigerina in Southwest and Lower Coralline in Northeast; mixture of red decalcified material & pale brown rock flour	Brown and dark gray brown, shallow to moderately deep, light to heavy textured, weakly granular, weakly crusting soils (Tal Barrani) and reddish brown, shallow to moderately deep, heavy textured, strongly granular soils (Tas Sigra)	Strongly terraced, moderately large, oriented fields; thick, high stone walls	Forage (including sulla, alfalfa, sorghum), vegetables, maize; Sprinkler irrigation
2	Hompesch Arch 25 hectares Class 2, Subclass 2t.	45 to 52 metres; upper gentle slope of depression between high ground	Globigerina; mixture of red decalcified material and brown calcareous material	Reddish brown, moderately deep to deep, heavy textured, strongly granular soils (Tas Sigra) and dark grav brown, moderately deep, moderate to heavy textured, weakly granular soils (Tal Barrani)	Weakly terraced, moderately large fields; thick, high stone walls	Vegetables. maize, forage (including sulla, alfalfa, sorghum); Sprinkler or forrow irrigation
3	Wied 114 hectares, Class 3, Subclass 3st	30 to 52 metres; upper gentle slope	Globigerina with Lower Coralline in East; red decalcified material and white rock flour	Reddish brown, shallow to moderately deep, heavy textured, strongly granular soils (Tas Sigra and little L'Inglin Complex)	Terraced, moderately large, fields; thick, high stone walls	Forage (including alfalfa, sulla, sorghum), vegetables, maize; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
4	Ta San Girgor; 20 hectares; Class 3, Subclass 3st	38 to 52 metres; upper, gentle concave slope	Globigerina; red, decalcified material	Reddish brown, shallow to mederately deep, heavy textured, strongly granular soils (Tas Sigra)	Terraced, moderately large, fields; thick, high stone walls	Forage (including alfalfa, sulla, sorghum), vegetables, maize; Sprinkler irrigation
5	Ta Lombardi or Marsaxlokk East 205 hectares; Class 4, Subclass 4st	7 to 45 metres; summit, upper and lower slopes	Globigerina; pale brown, calcareous weathering product	Pale brown or white, shallow to moderately deep, medium textured, weakly crusting soils (San Biagio and little Tal Barrani)	Strongly to moderately terraced, moderately large fields; thick, high stone walls	Forage (including sulla, alfalfa and sorghum), early potatoes, vegetables, maize; Sprinkler irrigation
6	Marsaxlokk West; 70 hectares; Class 4, Subclass 4st	7 to 45 metres; upper and lower slopes of long ridge-like spur	Globigerina; pale brown, calcareous, weathering product and white rock flour	Pale brown or white, shallow, medium textured soils (L'Inglin Complex, San Biagio and little Tas Sigra)	Moderately and strongly terraced moderately large and small fields; thick, high stone walls	Forage (including sulla, alfalfa and sorghum), early potatoes, vegetables, maize; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
7	Bir-id-deheb south; 51 hectares; Class 2,	53 to 60 metres; saddle-like, upper gentle slope of depression between two hills	Globigerina; dominantly red decalcified material and partly brown calcareous material	Reddish brown, moderately deep, heavy textured, strongly granular soils (mostly Tas Sigra and partly Tal Barrani)	Terraced, moderately large fields; thick high stone walls	Vegetables, forage (including sulla alfalfa and sorghum), maize; Sprinkler or forrow irrigation
8	Santa Lucia; 429 hectares; Class 3, Subclass 3st	30 to 84 metres; upper gentle slope	Globigerina; red decalcified material, brown calcareous material and white rock flour	Red to brown, moderately deep, medium to heavy textured, strongly granular soils (chiefly Tas Sigra in the South and Tal Barrani in the North with patches of San Biagio throughout area)	Terraced, moderately large fields; thick high stone walls	Forage (including sulla, alfalfa & sorghum), maize, wheat; vegetables;
9	Il Brolli; 59 hectares; Class 4, Subclass 4st	23 to 83 metres; gentle sloping ridge	Globigerina; red decalcified material and pale brown calcareous weathering product	Red to pale brown, shallow to moderately deep, medium to heavy textured soils (Tas Sigra in west and San Biago in east)	Strongly terraced, narrow fields thick, high stone walls	Forage (including sulla, alfalfa and sorghum) maize, vegetables; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area Location No. & Size &	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
10 Ta'Balvun; 57 hectares; Class 3, Subclass 3st	38 to 76 metres; gently sloping ridge	Globigerina; brown clacareous material, red decalcified material and white rock flour	Red to pale brown moderately deep to shallow, medium to heavy soils (Tal Barrani in the east, and Tas Sigra and l'Inglin in the west)	Strongly terraced, moderately large fields; high stone walls	Forage (including sulla, alfalfa and sorghum), maize, vegetables; Sprinkler irrigation
11 Halfar; 125 hectares; Class 4, Subclass 4st	52 to 67 metres; flat summit	Globigerina; brown calcareous material, red decalcified material and white rock flour	Pale brown to red, shallow to moderately deep, medium to heavy soils (Tas Sigra, Tal Barrani and San Biagio)	Levelled grass-covered areas between built-up areas for runways and parking apron of airfield	Maize, wheat forage (including sulla, alfalfa and sorghum) under organized management to conform to airport restrictions; Sprinkler irrigation
12 Bubaqra East; 99 hectares; Class 4, Subclass 4st	90 to 129 metres; upper gentle slope of a cuesta-like summit	Globigerina; red decalcified material, brown calcareous material and white rock flour	Red and brown, shallow to moderately deep, heavy and medium textured soils (Tas Sigra with some Tal Barrani and L'Inglin Complex to the west)	Strongly terraced moderately large fields; high stone walls	Forage (including sulla, alfalfa and sorghum), maize and vegetables; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
13	Wied-il-Mixta 32 hectares; Class 3, Subclass 3st	30 to 45 metres; upper, middle and lower slopes of valley-like depression	Globigerina; red, decalcified, material, brown calcareous material and white	Red, moderately deep, heavy textured soils (Tas Sigra); with brown shallow to moderately deep, medium to heavy textured soils (L'Inglin Complex and Tal Barrani) to the east and north	Strongly terraced moderately large fields, high stone walls	Forage (including sulla, alfalfa and sorghum), maize, vegetables; Sprinkler irrigation
14	Tal Kittienija between Zurrieq, Qrendi, Mqabba and Kirkop) 239 hectares; Class 3, Subclass 3st	75 to 98 metres; upper gentle slope of cuesta-like summit	Globigernia; red decalcified material and pale brown calcareous weathering produce	Red, moderately deep, heavy textured soils (Tas Sigra) in the north and pale brown and red, shallow to moderately deep, medium and heavy textured soils (San Biagio and Tas Sigra) in the south	Terraced, moderately large fields; high stone walls	Vegetables, forage (including sulla, alfalfa and sorghum), maize, wheat; Sprinkler irrigation
15	Ta'San Niklaw 113 hectares; Class 4, Subclass 4st	105 to 130 metres; upper, gently undulating slope of cuesta-like summit	Globigerina; red decalcified material, brown calcareous material and white rock flour	Red, shallow to moderately deep, heavy textured soils (Tas Sigra) and brown, moderately deep, medium textured soils (Tal Barrani and l'Inglin)	Strongly terraced, fields; High stone walls	Vegetables, forage (including sulla, alfalfa and sorghum), maize, wheat; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
16	Ta Qali-Halq Dieri-Tal Providenza; 1727 heotares Class 3 & 4 Subclasses 3st and 4st	83–150 metres; gently undulating to almost flat, low level plateau	Globigerina; pale brown to white calcareous weathering product, rubble and rock flour	Pale brown, shallow to moderately deep, medium textured slightly crusting soils (San Biagio) with brown and red, moderately deep, medium to heavy textured soils in some parts on the east (Tal Barrani) and north east (Tas Sigra)	Weakly terraced, large to moderately large fields high stone walls	Forage (including sulla, alfalfa and sorghum), maize, wheat and vegetables; lime induced chlorosis is common; Sprinkler irrigation
17	Tal Ghaqba; 126 hectares; Class 3, Subclass 3st	75–105 metres; summit surface between two valleys	Globigerina; pale brown to brown calcareous weathering product	Brown, moderately deep to shallow, medium textured soils (Tal Barrani) with small patches of pale brown, shallow to moderately deep, medium textured soils (San Biagio)	Weakly terraced, moderately large fields; high stone walls	Forage (including sulla, alfalfa, and sorghum), maize, wheat and vegetables; Sprinkler irrigation
13	Ta Hlas; 135 hectares; Class 4, Subclass 4st	45–90 metres; summit surface and upper slopes of hill between two valleys	Globigerina; pale brown calcareous weathering product	pale brown to brown, shallow to moderately deep, medium textured, slightly crusting soil (San Biagio)	Strongly terraced, fields; high stone walle	Forage (including sulla, alfalfa and sorghym), maize, and vegetables; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area Location & No. Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
19 Wied is Sewda 178 hectares; Class 3, Suclass 3st	30–53 metres; lower gentle valley slopes	Globigerina; pale brown, calcareous, weathering product	Pale brown, moderately deep, medium textured soils (San Biagio)	Weakly terraced, moderately large fields; high stone walls	Forage (including sulla alfalfa and sorghum), maize and vegetables; Sprinkler irrigation
20 Near St. Martins; 11 hectares; Class I	172 to 180 metres; doline, a level slightly lower area in karst topography	Upper Coralline limestone; Red, declacified, material	Red, deep, heavy textured soils (Tas Sigra)	Unterraced, large fields	Vegetables, forage (including sulla, alfalfa and sorghum), maize; Sprinkler or furrow irrigation
21 Fiddien Valley; 233 hectares Class 4, Subclass 4st	128 to 187 metres; lower slopes and gently sloping valley floor	Blue Clay; brownish yellos or olive deep, very sticky, calcareous clay with overlay of coarse sandy material to the west and brown, deep, heavy textured alluvial material in valley bottom	Brownish yellow, deep, heavy textured soils (Fiddien clays) with brownish yellow, deep, light textured soils (Nadur) to the west, and brown, very deep, heavy textured soils (Alcol) along main valley	Sloping large fields with stone embankments to prevent slumping or sliding of soil material	Forage (including sulla and sorghum), and vegetables; Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
22	Wied L'Armla; 102 hectares Class 4, Subclass 4st	97 to 182 metres; steep, scarp slope	Globigerina to the east and Blue Clay to the west; pale brown, calcareous, medium textured, material to the east and olive to brownish yellow, calcareous clay to the west	Brownish yellow, moderately deep, heavy textured soils (Fiddien) and moderately heavy textured soils (San Lawrenz) in the western upper slopes; and pale brown, moderately deep, medium textured soils (San Biagio) and reddish brown, moderately deep, moderately heavy textured soils (Tal Barrani) in the eastern lower slopes	Strongly sloping large fields with stone embankments in the west and strongly terraced small fields in the east.	Forage (including sulla and sorghum) and vegetables; Sprinkler irrigation
23	Bingemma North; 232 hectares; Class 2, Subclass 2st	75 to 105 metres; titled and downthrown fault block valley	Upper Coralline Limestone; red and brown, deep, moderately heavy textured alluvial and colluvial material with red, shallow decalcified material to the west	Red and brown, deep, moderately heavy textured soils (Alcol) to the east and red, shallow to moderately deep, heavy textured soils (Tas Sigra and L'Inglin Complex) to the west	Moderately to weakly terraced, moderately large to large fields; low stone walls	Vegetables, maize and forage (including soils, alfalfa and sorghum); Sprinkler irrigation
24	Bingemma West; 41 hectares Class 2, Subclass 2st	75 to 105 metres; tilted and downthrown fault block valley	Upper Coralline Limestone; red, decalcified material	Red, moderately deep to shallow, heavy textured soils (Tas Sigra and L'Inglin Complex)	Moderately terraced, moderately large fields	Vegetables, maize and forage (including sulla, alfalfa and sorghum); Sprinkler irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
25	Wied il Ghasel (or Bur Marrad Valley); 929 hectares; Class 1 and Class 2 Subclass 2st (valley floor) Class 3, Subclass 3st (western slope)	2 to 30 metres excluding western slope which is 30 to 53 metres; downthrown fault blocks, serving in part as a river valley floor	Globigerina and Lower Coralline Limestone with Blue Clay on western slopes; brown, very deep to deep, moderately heavy textured, alluvial and colluvial deposit in the centre and flanked by pale brown medium textured calcareous, weathering product on the gentle valley slopes & with olive or yellowish brown clayey material on the western slopes	Brown, very deep to deep Moderately heavy textured soils (Alcol and Tal Barrani) in the middle and pale brown, moderately deep, medium textured soil (San Biagio) to the west and north east, and yellowish brown and olive, moderately deep, very heavy textured soils (San Lawrenz and Fiddien) on the western slopes	Moderately to slightly terreced large and moderately large fields; low stone walls	Vegetables, maize and forage (including soils, alfalfa and sorghum); Sprinkler or furrow irrigation
26	Pwales Valley 195 hectares; Class I (valley floor) Class 2 Subclass 2st (valley sides)	0 to 30 metres rift valley, the downthrown block is slightly tilted north	Upper Coralline Limestones; brown to red, very deep to deep (shallow on the valley sides), heavy textured alluvial and colluvial deposit	Very deep to deep, heavy textured, brown soils (Alcol) with very deep to deep, heavy textured, red soils (Tas Sigra) in west central part of the valley, floor, & shallow to moderately deep soils (Tas Sigra) on the valley sides	Unterraced to slightly terraced large to moderately large fields on the valley floor and moderately terraced small fields with thick stone walls on valley sides	Vegetables, maize, and forage (including sulla, alfalfa, sorghum); Sprinkler or forrow irrigation

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land CLASS	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
27	Mizieb 62 hectares; Class 2, Subclass 2st	30 to 53 metres; lower part of tilted block	Upper Coralline Limestone; moderately deep to shallow, heavy textured red collu-vial deposits and red decalcified material	Moderately deep to shall-ow heavy textured red Tas Sigra soils	Slightly to moderately terraced mode-rately large and small fields	Vegetables, maize and forage (inclu ding sulla, alfal fa and sorghum); Sprinkler irriga-tion
28	Il Hofra; 49 hectares; Class 3, Subclass 3st	0 to 30 metres; faulted valley	Upper Coralline Limestone; red, shallow to moderately deep, moderately heavy to heavy textured decalcified ma-terial and alluvial deposits & white rock flour	Red to brown, shallow to moderately deep, modera-tely heavy textured, brown Tal Barrani soils and heavy textured, red Tas Sigra soils	Moderately to strongly terrac-ed moderately large and small fields	Vegetables, maize and forage (inclu ding sulla, alfal fa and sorghum); Sprinkler irriga tion
29	Il Ghadira; 31 hectares; Class 2, Subclass 2st	0 to 15 metres; faulted valley	Upper Coralline Limestone; moderately deep, heavy textured, red decalcified material to the west and brown alluvial or col-luvial deposits to the east	Moderately deep, heavy textured red Tas Sigra soils to the west and moderately deep, heavy textured, brown Alcol soils to the east	Slightly to moderately terra-ced, moderately large fields	Vegetables, maize and forage (inclu ding sulla,alfal-fa and sorghum); Sprinkler irriga-tion

Table 9: Characteristics of Areas Suited for Irrigation (Continued)

Area No.	Location & Size & Land Class	Elevation & Topography	Bedrock & Soil Parent Material	Soil Characteristics	Other Field Characteristics	Land Use Recommendations
	Victoria Xewkija (Gozo); 363 hectares; Class 2 and Class 3 in about equal proportions, Subclass 2st and Subclass 3st	57 to 100 metres; nearly level, plateau-like erosion surface	Globigerina over the whole plateau-like erosion surface with Blue clay on the peripheral slopes to the west, north and north east; pale brown to yellow, deep to moderately deep, heavy to moderately heavy, calcareous product of weathering in situ mixed with colluvial and alluvial deposits	Pale brown, deep to moderately deep, moderately heavy textured soils (San Biagio) and yellow, deep to moderately deep, heavy textured soils (San Lawrenz) with a little reddish brown, moderately deep, moderately heavy textured soils (Tal Barrani); and olive, deep to moderately deep, very heavy textured soils (Fiddien) on the slopes	Moderately to slightly terraced, large to moderately large fields; few low stone walls	Forage (including sulla, alfalfa and sorghum), vegetables. Sprinkler irrigation furrow irrigation possible in the central nearly level areas.

5.4 Selection of Sites for Utilisation of Sewage Effluent

Of the 20 areas demarcated as suitable in varying degrees for irrigated agriculture development in Malta, the final selection of sites for irrigation with sewage effluent will be based firstly on the availability of effluent in adequate volume and acceptable chemical and biological purity for use on crops, and secondly on the certainty that there will be no nuisance or health hazard to the inhabitants of the area and no risk of pollution of environment including the island's ground water.

The first condition requires that only sewage free from sea water contamination could be treated to obtain an effluent of sufficiently low conductivity (at most 2000 micrombos/cm) For the present, such sewage will be from the inland system. But the greater part of the sewage is from the coastal areas and hence any realistic plan to effect water economy must consider ultimately recovering all the sewage before it is contaminated by sea water. The inland sewage on account of low per capita consumption of domestic water supply is considered to give rise to an increase in conductivity by at least 600 micromhos/cm. (Popel,1964). The coastal sewage is considered to have a smaller increase due to higher per capita consumption. Injurious chemical wastes from industries also should be avoided.

Certain areas that are well suited for irrigation development may be near populated areas or areas of tourist attraction and hence are better not taken up for irrigation with sewage effluent. Though as shown in the review by Sciclura-Spiteri (1969), use of sewage effluent is more widespread in the world than commonly realised, its use on vegetables and fruit trees even if done in conformity with all health requirements is best undertaken in areas where effluent re-use is not blatantly exhibited. It certainly does not encourage tourism.

Of the other areas that are well suited for irrigation development, some may not be readily accessible to the sources of large volumes of sewage flow. The relative costs of transporting raw sewage for treatment and treated effluent to the various suitable areas will decide the final selection.

Finally, areas over water galleries or close to Water Works Department bore holes and water galleries can only be recommended if the soil is always thicker than 100 cm. and if bedrock does not come closer than 100 cm. to the surface either under soil cover or on embankments. Such deep soils occur in contiguous bodies only in the central parts of Pwales Valley (area no. 26) and Bur Marrad Valley (area no. 25), Hence areas no. 14, 15, 16, 17, 18, 19, 20, and western part of 12 on the map) are disqualified.

Areas that are well suited for organised irrigation development are already under intensive cultivation in the dry season by the individual farmers using water from boreholes or springs. The salinity of borehole water is reported to be steadily increasing due to over-extraction. It has been suggested (Martin, 1969) that using effluent in areas such as Pwales Valley could lead to less demand on the borehole ground water and hence a reduction in its salt content. Also spring water used for irrigation could be made available to augment the domestic water supply. But Pwales Valley is an important agricultural area successfully producing a wide range of vegetables for the domestic market. Though salinity and alkalinity hazards appear to develop under the present systems of crop rotation and water use, it is doubtful if sewage effluent event if of sufficiently low conductivity can be given as compensation irrigation water for diverting the spring water into the domestic water supply system. The trend of salinity and alkalinity hazards in the Pwales Valley could be arrested by introducing leguminous green manure crops in the rotation and by using water more efficiently. Use of sewage effluent would become an attractive proposition only if the conductivity of the present supply of ground water exceeds 6000 micromhos and the effluent itself has a conductivity lower than 1000 micromhos and the effluent is given as a supplement and not as a replacement for diverting the good quality spring water whose conductivity is generally about 600 micromhos. The effluent will then be used to supplement spring water in keeping soil salinity low and because of the marked reductions in yield caused by the increasing salinity of the ground water, the farmers would be willing to accept restrictions in choice of crops in order to use effluent of low conductivity. Hence it is concluded firstly that the irrigated areas are unsuitable for use of effluent at present and secondly that the possibility of giving sewage effluent as a replacement for spring water to divert it elsewhere will not be practicable since it involves a crop restriction which the farmer would not have otherwise incurred.

St. Martins (area No. 20) is remote, and very small in extent and topographically high.

Fiddien Valley and Wied L'Armla (areas No. 21 and 22) have clayey soils on gentle slopes and are not suited for irrigation with effluent since percolation is slow. Also they are topographically high.

This process of elimination on the basis of soil, hydrological, cropping and topographical characteristics leaves the following areas as being suitable for consideration for irrigation with sewage effluent: areas no. 1,2,3,4,5,6,7,8,9,10,11,13, eastern part of 12 and northern part of 25. They are all in the south east of Malta. The total area is 1,244 hectares.

Other considerations still narrow the choice of areas for the first phase of sewage effluent use. Areas No. 2,3,4,6,7,8,9,10,13, and the eastern part of 12 are near areas of urban development, scattered settlements and main roads and area No. 11 encloses a military airfield. The northern part of 25 lies near areas of tourist development and, more-over, an adequate amount of effluent is not readily available. Hence areas No. 1 and 5 which are found to satisfy the above criteria of selection are recommended for the first phase of sewage effluent irrigation. Each area is a compact area free from public roads and dwellings. It would be relatively easy to organise and supervise and obtain compliance of farmers with all the operational procedures and restrictions. Problems of soil management, crop rotations, cultivation methods, irrigation systems, farm organisation and environmental pollution control can be studied as they are encountered in actual large scale field operations. When more sewage effluent is produced and its salinity is less than 2000 micromhos, and if the experience in areas No. 1 and 5 are successful, sewage effluent use can be extended by installing additional treatment plants and distribution system to other areas progressively.

An advantage in areas No. 1 and 5 is that they are near the periphery of the ground water lens. Any contamination of ground water will not affect the main body of ground water since the flow of water is, in general, radially outwards. Also these two areas are not under intensive agriculture. Any change with irrigation facilities will be bound to boost the productivity of these areas. Finally, possibilities for surface spreading and quarry filling in the winter to recharge the water table are available. These measures could augment the local ground water supply for irrigation in the summer as well as retard the outward flow of the ground water from the centre of Malta. Studies on ground water recharge, and on changes in ground water composition under actual conditions of irrigating such large areas will then guide subsequent development of areas for use of sewage effluent.

Area No. 1 is 60 hectares and area No. 2 is 155 hectares but it will be less when the part of the area along the coast reserved for industrial development is separated. Considering the whole area for the present, 215 ha., there will be a peak demand of 12,000 m^3/day with an annual consumption of 3.17×10^6 m^3 of effluent of conductivity 3000 micromhos/cm.; when conductivity decreases to 2000 micromhos/cm, the annual consumption will drop to 2.95×10^6 m^3.

5.5 Development of Ta Qali Area

Development of large scale greenhouse enterprises run on semi-industrial lines was recommended by the Joint Mission for Malta. These are primarily meant to supply the local market for fruits and vegetables including the requirements of hotels and restaurants catering to the increasing number of tourists and foreign residents. Production of early season or out of season vegetables (like tomatoes, cucumbers) and flowers (like chrysanthemums, roses and carnations) for the European markets is also a possibility. New techniques of production, storage, packing, marketing, and of management in general are involved.

The Ta Qali area due to its central location is suitable not only for the large scale development of greenhouses but also to serve as a nucleus for the extension and advisory services and marketing operations for satellite private farms in the surrounding areas. These surrounding areas characterised by a nearly level to gently undulating topography and large fields have a potential for increased productivity. They are slightly lower than the Ta Qali old airport area itself and are under agriculture unlike the old airport area.

The Ta Qali old airport area itself is very level having been formerly an airfield. It does not get flooded by runoff from adjoining areas. The runoff from the airport area is slow but may be channeled into cisterns. Abandoned quarries in the north and east of the area can be used for this purpose. The soil, however, is mostly very shallow, raw carbonate soils with a thin, humus-rich, surface layer. Pockets of deep soil are few. Some areas have moderately deep, man-made soils formed on filled material overlying large coarse stones, all presumably brought from outside to level the original depressions, and later the bombed out craters. The airport area is used for grazing and recreation (flying model planes, promenading etc..).

The Ta Qali airport area is characterised by a very shallow thin soil cover. About 370 augur holes were made in the area in a regular grid pattern 200 feet by 200 feet. All the holes had soil for at least the first 10 cm.; and only 8% of the holes had soil for less than 20 cm. But in about 43% of the holes, the soil is shallower than 40cm., and in 21% of the holes, the soil is between 4 and 60cm. deep. Only in 18% of the holes, the soil is between 60 and 100 cm deep, and in another 18%, the soil is deeper than 100cm. But unfortunately the deep soils occur as very irregular strips in between very shallow soils or a small patches in slight or barely perceptible depressions.

Hence, the soils of Ta Qali airport area are not suited for any efficient, conventional cultivation of crops. But the asset of Ta Qali airport area is not the soil on the ground but the land itself: - level topography, central location, excellent access roads, and many quarries adjoining the area for storing rain water runoff. These and the favourable climate temperature and sunshine), and the existing tradition for greenhouse cultivation indicate that the Ta Qali airport has a great potential for the production of specialised and out of season crops.

Water is another scarce resource in Malta like soil and land. If properly husbanded, water would be adequate for the island's present needs. Greenhouse operations require only about a tenth of the water requirements for open air cultivation using the soil on the ground since evapotranspiration is minimal and percolation is nil.

But it is absolutely essential, in view of the high investments involved, that water of good quality is used to ensure sustained and efficient crop production. Such water can be obtained to meet the crop production requirements from the rain water runoff alone. The nearby quarries can be properly sealed and used for this purpose. In addition, good quality water can be obtained from nearby Ta Qali pumping station to replenish the quarry storage since good quality water can be pumped by prior arrangement to reduce rate of extraction for some days.

Commercial horticultural production using peat or even soil-less media (Stoughton, 1969), in view of the high cost of imported peat, has possibilities. The needed training, facilities and organisation for soil-less cultivation can be readily acquired by the inherently industrious people.

6.0 Water requirements

6.1 Evapotranspiration

Loss by evapotranspiration is a critical factor in determining both the overall water balance in Malta and the prospects of developing irrigated culture particularly when the available water is moderately saline (Mitchel, 1958; Martin, 1969).

Fortunately, theoretical, semi - empirical and empirical methods based on the energy balance or the aerodynamic approach or a combination of both have been found to give sufficiently accurate estimates of evapotranspiration under diverse climatic conditions and crop covers (Pear et al.,1954; USDA, 1967). These methods require a few fairly simple, readily observed meteorological, physical and geographical data such as temperature, daytime hours (based on latitude and time of year), solar radiation, actual sunshine hours, actual vapour pressure and saturation vapour pressure. (Penman, 1948; Thorn-thwaite, 1948; Rijtema cited by Verhoeven and van Gessel, 1969; Hamon, 1961, Jensen and Haise, 1963.

Values obtained by the various equations and applicable to Malta are cited from VERHOEVEN and VAN GESSEl (1969) and MARTIN (1969 in Table 10. In addition, values calculated by the method developed by Blaney and Griddle (USDA, 1967) are included for comparison. This method is of interest because significant evapotranspiration changes due to changes in temperature and the stage of crop growth are distinguished (Table 11). The differences between the values by these selected methods are a reminder that any method is only an estimate of evapotranspiration.

For estimating water gains and losses, Martin (1969) uses a value of 63mm for soil storage capacity in connection with the recharge of the different aquifers. This value is too high for the shallow soils and rocky surface of the fractured or karstic limestone uplands and bare valleys. A lower value of say 500mm for the shallower soils of south-east Malta and a higher value of say 100mm for the deep soils of the valleys (Pwales, Burmarrad, Mizieb and Il-Hofra) are more appropriate when determining the recharge or irrigation requirements for such areas.

6.2 Percolation

To use mean monthly data for rainfall in following the actual progress of water gains and losses considerably over-simplifies the situation; for example, percolation shows far more variation when daily rainfall records for each year are used to calculate it instead of mean monthly rainfall.

During the warmer months of the rainy season, total rainfall and distribution within the month are important factors in determining the division between percolation and evapotranspiration. The alternation of short periods of a day or more of heavy downpours with long periods of little or no rain gives rise to short periods of rapid percolation followed by long periods of steady or, more probably, decreasing evapotranspiration; even periods of drought occur when the available soil moisture is depleted. These phenomena of high percolation and high evapotranspiration are more pronounced respectively in the shallow soils or rocky areas with low water holding capacity and in the warmer months when evapotranspiration is higher.

In Table 12, percolation is calculated assuming an available soil moisture capacity of 50mm which is considered reasonable for the shallow soils of eastern Malta. To allow for the not uncommon occurence of two or more consecutive years of low rainfall (eg 1958-59 to 1961-62), it would seem more reasonable when determining leaching requirements to use 154mm, the average for a period like 1958 to 1962 than 223mm, the average amount for the whole period. The soil salinity during the 1961 autumn and particularly the whole of 1962 would be more truly determined by a leaching rainfall component of even less, say 138mm, the average of the three years 1959 - 1962. Despite intensive leaching by heavy rainfall in previous years,

Table 10: Evapotranspiration rates for Malta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Measured[2] data	55	60	90	115	155	185	215	195	130	95	70	60	1425
Penman[2]	48	62	96	129	173	201	226	214	150	105	66	47	1517
Rijtema[2]	45	62	99	132	173	204	226	211	137	102	66	44	1511
Jensen and Harse	37	49	72	92	132	177	198	184	147	86	57	36	1257
Hamon[3]	40	45	58	77	106	158	173	158	158	81	53	39	1110
Blaney and Criddle	96	94	119	134	165	184	199	189	161	138	111	99	1690
Modified Blaney Criddle (Phelan)	60	58	79	97	137	178	209	199	161	122	87	66	1452

Table 11: Crop consumptive use coefficients 1/

Crop	Length of growing season	Average consumptive use	Early growth stage consumptive use coefficient K_c	Peak growth crop cover stage consumptive use coefficient K_c
Alfalfa	Full year	0.80 - 0.90	0.60	1.15
Beans	3 months	0.60 - 0.70	0.50	1.15
Maize	4 months	0.75 - 0.85	0.45	1.10
Cotton	7 months	0.60 - 0.70	0.20	1.05
Grains, small	3 months	0.75 to 0.85	0.30	1.35
Grains, sorghum	4 to 5 months	0.70 to 0.80	0.30	1.10
Potatoes	3 to 5 months	0.65 to 0.75	0.35	1.40
Sulla 2/	6 months	0.80 to 0.85	-	-
Soya Beans	140 days	0.65 to 0.70	0.20	1.05
Tobacco	4 months	0.70 to 0.80	-	-
Tomatoes	4 months	0.65 to 0.70	0.45	1.05
Truck crops, small	2 to 4 months	0.60 to 0.70	0.30	0.85
Vineyard	5 to 7 months	0.50 to 0.60	0.20	0.85

1/ From irrigation water requirements, USDA, Tech. Release No. 21, 1967.

2/ Regarded as being similar to Ladino White Clover.

Table 12: Percentage or yearly rainfall available for leaching assuming no runoff

Year	Rainfall	Percolation 1/	Leaching Percent
1956 - 57	452	164	36
1957 - 58	727	354	49
1958 - 59	586	209	36
1959 - 60	539	240	45
1960 - 61	328	73	22
1961 - 62	410	94	23
1962 - 63	653	345	53
1963 - 64	399	66	17
1964 - 65	906	460	51
		Av. 222.8	

1/Using daily rainfall data and Penman's method for evapotranspiration.

Table 13: Yearly Crop Sequences and Irrigation Needs

Sequence	Months in year	Irrigation (mm)
1) Alfalfa	all	1 010
2) Spring potato Forage sorghum	Dec.-Apr May-Oct	870
3) Spring potato Tomato Autumn potato	Dec.-Apr May- Aug Aug- Dec.	770
		Average: 880

Table 14: Irrigation needs for designated minimal levels of yield reduction and salinity 1/

1) Irrigation water of conductivity ca – 3.000 micromhos/cm

Minimal yield reduction (%)	Minimal soil Extract conductivity (Micromhos/cm)	Consumptive irrigation requirement A_e (mm)	Leaching requirement A_p (mm)	Gross irrigation requirement A (mm)
10	3,000	900	621	1,901 2/
25	4,000	900	279	1,474
	5,000	900	144	1,305
50	6,500	900	36	1,170

2) Irrigation water of conductivity ca – 2.000 micromhos/cm

Minimal yield reduction (%)	Minimal soil Extract conductivity (Micromhos/cm)	Consumptive irrigation requirement A_e (mm)	Leaching requirement A_p (mm)	Gross irrigation requirement A (mm)
10	3,000	900	198	1,373
25	4,000	900	63	1,204

1/ **Assumes:** leaching efficiency, $f = 0.8$
irrigation efficiency, $g = 0.8$
percolation rainfall, $Re = 150$ mm
and based on the relationships

$$A_e = \frac{K + 1}{K - n} Re \qquad \text{and } gA = A_e + A_p$$

where

$$n = \frac{A_p}{A_e}$$

and

$$k = \frac{Ca}{f\,(Cs - Ca)}$$

and $2C_e = C_2$, where C_s is the conductivity of soil moisture at field capacity in micromhos/cm.

2/ Not feasible in practice.

salinity can move to the maximal acceptable level within a year owing to high consumptive requirement and high salinity of the irrigation water. An effective annual rainfall percolation of 150mm, a reasonable compromise between the possible low values of 84mm and 138mm on the one hand and the long - term average of 223mm on the other, is considered to be more relevant for determining leaching requirement as well as the maximal irrigable area.

As a practical measure, the pattern of cropping in relation to irrigation should be re-evaluated when the onset of a second or third consecutive dry year has been recognized.

Martin (1969) has also considered the effect of lower soil moisture contents in decreasing evapotranspiration below the level corresponding to a soil at maximal moisture capacity. Unfortunately, the value of this analysis is considerably reduced by the use of an average of the monthly coefficient (B) he used in determining evapotranspiration; B varies only from 0.914 to 0.979 over the year and therefore appears reasonable constant - but it has an exponential effect. By using one value for all the year, estimates of evapotranspiration losses in the cooler rainy season are very much higher than if the losses were assumed to be from a soil at field capacity.

The actual rates of evapotranspiration are highly modified by the crop. According to figures given by Blaney and Criddle (1967), at peak growth, e.g., pod setting in beans, heading in barley, milk stage in maize, sorghum or wheat, potential evapotranspiration is twice to five or six times as great as that during the early growth stage.

Coefficient (K_c) by which the potential evapotranspiration should be multiplied to obtain the actual evapotranspiration of a specific crop are given in Table II.

6.3 Consumptive use and leaching requirements

When evapotranspiration is high and moderately saline irrigation water is used to supplement the crop consumptive requirement and the leaching provided by rainfall, soil salinity can be kept low more readily by growing crops with a low consumptive water requirement, e.g. pasture, soya bean, snap bean and other vegetable, cotton, melon, grape, citrus and other fruit trees. For one reason or another such as sensitivity to wind and salt, or uneconomic yields, the majority of these crops do not fit into the pattern for developing Maltese agriculture. Alfalfa, forage sorghum, potato and tomato, on the other hand, are suitable but they have high consumptive water use requirements. The three possible cropping sequences suggested in Table 13 have an average annual irrigation requirement of 880mm.

The leaching requirements that would be necessary if these crops were grown under irrigation with effluent of either EC - 3,000 or 2,000 micromhos/cm are shown in Table 14. They would enable soil salinity, as measured by EC_e values, to be kept down to levels corresponding to yield reductions of 10, 25 and 50% as shown in Figure 4.

The cropping sequence spring potato - tomato - autumn potato is of more academic interest than practical value. The three crops can be fitted into the cropping year and it is common practice in Malta for spring potato to follow autumn potato on the same land. Tomato too is popular as a summer crop. In dry farming, transplants are sometimes puddled in and then left to crop without further water. Nevertheless, three solanaceous crops following one another on the same land is to be discouraged for it carries with it too great a risk of building up diseases and pests common to potato and tomato.