EFFECT OF ORGANIC AMENDMENTS ON SOILS, DRAINAGE WATERS AND GROUND WATERS IN THE STATE OF BAHRAIN

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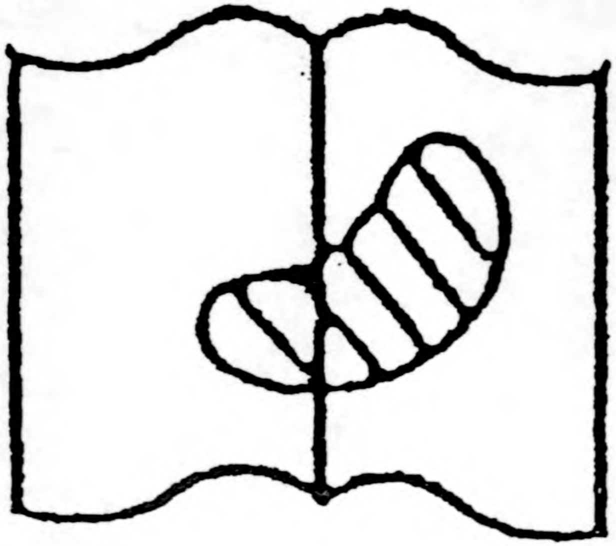

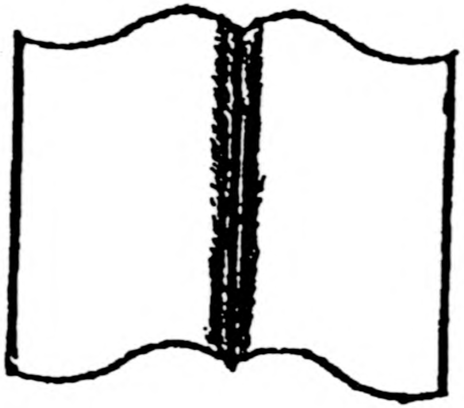

DEDICATION

TO

SASIKALA, SOORAJ AND SURYA

The work presented in this thesis is the result of my own investigation. It has not been nor will be submitted for any other degree.

Ekarath Raveendran.

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ABSTRACT

This research examined the effects of different types of organic amendments at different rates of addition and with different qualitities of irrigation water on two major soil types of Bahrain. The aim was to quantify potential improvements in soil quality, the accumulation of trace metals in the soil, and the release of metals and nutrients to drainage waters, and leaching of nutrients and metals to ground water. Organic amendments, cow manure, chicken manure and sewage sludge were analysed for various physical and chemical properties. Pot experiments, field soil and water analysis in areas of organic amendment were carried out. Drainage waters close to intensive agricultural production, where mineral fertilizers and organic amendments were used, were analysed for nutrients and heavy metals. Run-off water from major farms and local ground waters were also analysed.

From the pot experiments it was found that soil water holding capacity did not change much after the addition of organic amendments except in the case of sewage sludge addition. Total organic carbon and total kjeldhal nitrogen content increased in the 0-5 cm layer. Low TDS water and sewage sludge applications improved aggregate stability to some extent.

Extractable phosphorus was enhanced by the chicken manure treatment more than any others. Addition of different organic amendments did not affect exchangeable cations. pH values did not show appreciable changes and soils were neutral.

Among the trace metals investigated, cadmium, lead, zinc and copper, all were found in the 0-5 cm layer and none were present at toxic levels in soils. Zinc and Copper were the only metals showing a tendency to leach to the lower soil layer. In all cases, the metal concentrations in the surface soil were proportional to the quantities added in the amendments. Concentration of trace metals in the leachate from pot experiments were very low.

Field studies indicated that, use of organic amendments resulted in increased N, P and C in the surface soil. Nitrogen, phosphorus and potassium concentrations in drainage waters near agricultural areas were higher than at other non-agricultural areas. Ground water nutrients did not show any correlation between fertilizer addition and their proximity to the agricultural land except at Al-Akr. Nitrogen, phosphorus and potassium levels in the soil profile indicated that nutrients are present mainly at the 0-5 cm levels and downward movement was minimum.

Application of organic manure before the fertilizer addition apparently retarded the leaching process. Soil surface run-off water from agricultural land also showed high concentrations of nitrate (NO_3). All fertilizer amended plots had lower metal concentrations than the two sites amended with sewage sludge.

The sewage sludge treated sites contained elevated levels of heavy metals at the 0-5 cm layer and plants grown on the sludge treated sites had higher concentrations of heavy metals than the control sites using inorganic fertilizers. Cadmium content of plant materials grown on sludge application sites exhibited higher levels than allowed in plants meant for feeding the animals.

CHAPTER-1

INTRODUCTION

INTRODUCTION

This thesis reports the results of an investigation of the effects of various organic amendments on soils, percolation waters and ground waters in the State of Bahrain.

Even if adequate supplies of irrigation water were available, the agricultural potential of soils in Bahrain would be severely limited by a number of factors. Soils are normally saline and have high contents of minerals such as gypsum. Soil profiles are thin and the water table is frequently near the surface due to low relief. Soil structure is weak and water-holding capacity is small due to the small organic matter content. The small organic matter content is also associated with nutrient deficiencies, most significantly of nitrogen, and hence limited fertility.

For countries such as Bahrain, increases in agricultural production are only possible with extensive use of organic amendments such as manure or sewage sludge and of inorganic fertilisers. Organic matter is of vital importance in promoting good structural development, in increasing water holding capacity, and in adding Nitrogen. Due to the prevailing high temperatures and rates of oxidation of organic matter in the soil, maintenance of an adequate organic matter content in the soil is however, difficult.

Frequent large additions of nutrients to the soil can lead to significant environmental side effects. Not all nutrients added to the soil are taken up by the growing plant. Fixation to a non-available form in the soil and leaching and subsequent contamination of surface and ground waters are problems common to humid and arid countries alike. Fertilisers and sewage sludge materials may add unwanted trace metals to soil and drainage waters, with implications for water pollution and metal uptake by subsequent crops. Organic amendments can also increase biochemical oxygen demand and pathogenic organisms in drainage waters. Excessive use of nitrogen-rich materials is linked to increased nitrate concentrations in surface and ground waters, with consequent eutrophication and human health implications.

Regular additions of organic amendments and inorganic fertilisers have been used over a long period of time in Bahrain to facilitate agricultural production. Supplies of traditional materials such as cow and chicken manure are limiting factors to increased production in many countries and in recent years much attention has been given to the use of organic materials derived from sewage sludge. Bahrain is accumulating about 6200 tonnes of sewage sludge per annum. Sludge is rich in organic matter and the three major plant nutrients N, P and K. Its use as an organic fertiliser for the soil therefore has the twin benefits of waste disposal and of potentially increased agricultural production.

The disadvantage of the use of sewage sludge materials in agriculture are primarily related to their content of unwanted inorganic ions. Sludges contain varying concentrations of B, Cd, Cr, Cu, Pb, Ni, Hg, Ag and Zn. At large concentrations in the soil these elements are toxic to plants, and, if accumulated in the plant, also to animals and humans. Metals applied to the land in sewage sludge should thus be carefully controlled to avoid concentrations in the soil exceeding critical values. There have been many investigations of sludge additions to the soil and of the behaviour of added metals in the soil, and many countries now specify maximum permissible additions of sludge to agricultural soils (e.g Commission of the European Communities, 1986). However there have been relatively few studies of the addition of sludge materials to soils under conditions of extreme aridity, where additions are necessarily large and frequent and where soil pH and chemistry are very different from those in less arid environments.

The objectives of the present study were therefore to investigate the effects of different organic amendments on a range of agriculturally significant soil properties. Farm manures (cow and chicken) and sewage sludge at three application rates were added to pots and irrigated over a six month period with water from two sources of different salinity. Metals, nitrate and phosphate in the drainage waters were compared across the different treatments, and soil structure, nutrient content and metal concentrations at the end of the incubation period were compared. A field survey was also carried out in soils on farms using these amendments and effects on metals and nutrients in the soil, drainage water and ground water were compared. Results from the experiments and survey were used to evaluate the effects of soil amendments in the arid environment of Bahrain and to predict environmentally sustainable and economically useful application rates for the different organic amendments studied.

CHAPTER-2

BAHRAIN - PHYSICAL ENVIRONMENT, SOILS AND AGRICULTURAL DEVELOPMENT.

2.0 Bahrain - Physical environment, soils, and agricultural development.

2.1 Physical Geography.

Area: 692.52 Sq.Km

Location of The Country : Lat : 26 16 N: Long : 50 37 E.

The State of Bahrain achieved its political independence in August, 1971. It is composed of an archipelago of 33 islands, mainly without relief. It is situated on the East side of Saudi Arabia between Kuwait and the Qatar peninsula (Figure-2.2). Three of the islands have an economic importance. The biggest is Bahrain island which has a length of about 50 km and a width of 10 to 16 km. On this island lies Manama, the Capital, Mina Sulman, the largest port, as well as the petroleum wells, a refinery and the industrial and commercial community. The other two islands are Muharaq and Sitra. The major industrial areas are located midway down on the east coast around Sitra Island.

Apart from a narrow strip of fertile land extending some 6 km along the northern coast, the islands are rocky, bare limestone rock covered with varying depths of sand. About 19 km from the northern end of the island, (Figure-2.3) there is a compact group of hills, the highest point of which is Jebel

Ad-Dukhan (122 M). The northern part of Bahrain island and part of the west coast are well irrigated and fertile.

The remainder is desert, and it is there where the petroleum and natural gas resources are located. To the north of Bahrain, the Island of Muharaq, has the airport, a large dry dock, and an iron and steel factory.

2.2 Climate:

The climate of Bahrain is characterised by high summer temperatures, scanty and irregular rainfall, high relative humidity, and a persistent wind from the north west. Monthly wind rose diagrams show that the prevailing wind direction year-round is from north/north-west, followed by South/South-east winds. During the summer between May and October, the daily maximum temperature exceeds 30°C. The winter months are cooler with temperatures around 20° C. The mean annual temperature is 26°C, the minimum 9.5°C, and maximum 44 °C. The average annual rainfall is about 10.8 mm with a recorded range of 0.0 to 106.8 mm. The scant and irregular rainfall is mostly concentrated between

December and February with a total absence of rain in the summer. The influence of the sea on the relative humidity levels is evident in the records. The mean daily maximum humidity is about 80 % throughout the year. Table - 2.1 shows that during the month of February, the mean daily maximum humidity reaches 87 % whilst during the month of June the mean daily minimum relative humidity is 33 %. This plays an important part in the level of irrigation water requirement as it influences evapo-transpiration losses.

2.2a Evaporation:

Actual evaporation rates range from 4 mm per day to approximately 10 mm per day in summer. Table - 2.2 gives the annual evaporation and calculated estimates of potential evapotranspiration, which shows that the water consumption by plants is relatively high and the gap between the rainfall and evaporation throughout the year is very large.

MONTHLY VALUES OF RELATIVE HUMIDITY, TEMPERATURE, RAINFALL, SUNSHINE, EVAPORATION AND WIND SPEED FOR 1988

Table-2.1

MONTH	(%) RELATIVE HUMIDITY			TEMPERATURE °C					WET BULB °C		RAIN-FALL (mm)	AVERAGE DAILY SUNSHINE (Hours)	EVAPO-RATION (mm)	MEAN WIND SPEED (Knots)	MAX GUST DEG / KNOT
	MEAN	MEAN MAX.	MEAN MIN.	MEAN	MEAN MAX.	EXT. MAX.	MEAN MIN.	EXT. MIN.	MEAN MAX.	EXT. MAX.					
JANUARY	71	86	55	16.2	19.4	23.0	13.2	10.2	14.8	19.0	14.7	8.0	2.9	10	330 / 31
FEBRUARY	74	87	60	17.9	21.0	25.7	15.0	12.3	16.8	21.0	106.8	6.5	3.0	10	330 / 37
MARCH	67	83	49	20.5	24.3	34.3	17.2	14.2	18.1	32.0	1.8	7.5	4.4	11	330 / 38
APRIL	61	78	41	25.3	29.7	36.6	21.8	18.6	21.5	25.8	2.3	7.0	7.0	8	310 / 42
MAY	53	69	36	30.1	34.4	39.7	26.2	23.3	24.3	26.5	0.0	11.3	9.0	11	360 / 28
JUNE	51	72	33	32.9	37.5	42.5	28.6	26.5	26.6	30.2	0.0	11.5	12.6	11	320 / 34
JULY	59	77	39	33.9	38.3	41.5	30.3	27.5	28.8	31.0	0.0	9.8	8.9	8	350 / 26
AUGUST	60	80	39	34.5	39.0	44.0	30.5	29.4	29.5	31.7	0.0	11.3	8.2	8	340 / 28
SEPTEMBER	64	81	44	33.0	37.1	41.2	29.0	25.9	28.9	30.2	0.0	10.3	6.5	7	330 / 23
OCTOBER	64	82	43	30.0	34.4	37.3	25.8	22.7	26.3	28.0	0.0	10.1	5.1	7	330 / 22
NOVEMBER	67	82	49	23.8	27.9	32.6	20.3	14.8	21.4	26.3	3.0	9.3	4.0	10	110 / 34
DECEMBER	71	84	54	19.6	23.0	26.5	16.5	9.5	18.0	21.1	0.6	6.8	2.8	9	330 / 29
$\bar{x}$	63.5	80.08	45.2	26.5	30.5	35.4	22.87	19.6	22.92	26.9	10.77	9.12	6.2	9.17	

Source: Meteorological Dept., State of Bahrain.

TABLE - 2.2

Estimated Evaporation and evapotranspiration in Bahrain.

Month	Potential open water Evaporation (Penman) Budaiya (mm)	Observed Class A - Pan Evaporation Budaiya (mm)	Potential Evapo-Transpiration (Blaney-Criddle) Muharraq (mm)
January	99	71	98
February	120	112	111
March	170	136	138
April	222	186	164
May	295	265	195
June	325	273	220
July	321	295	224
August	308	250	221
September	266	214	198
October	206	161	182
November	142	111	151
December	102	85	110
Total	2576	2157	2012

Source : Sutcliffe (1967), ERCON (1973).

2.2b Sunshine hours:

The number of sunshine hours throughout the year is very large. Table -2.1 shows that in the month of February the mean daily hours of sunshine is 6.5 whereas in June it reaches 11.5 hours. The annual average is calculated to be about 10 hours per day.

Sunlight tends to burn the leaves of plants, if they are irrigated during daytime. To avoid this crops are irrigated after sunset.

2.3 Vegetation:

The natural vegetation of Bahrain is influenced by physiography, climate, soils and ground water. The scarce rainfall in winter and the shortage of soil moisture in most areas, especially in summer, limits plant growth, but when soil moisture and temperature are favourable, several plants (halophytic) spread, annuals complete their growth cycle in a short period, and Perennials which have relatively deep root systems grow for longer periods.

In Bahrain very little attempt has been made to study the natural vegetation and its ecology. A general study of the plant ecology has been carried out by the Arab Organization for Agricultural Development (AOAD, 1978). This study divided Bahrain into four phytogeographical regions (Fig-2.1) and plant species found in each area were identified and recorded. A total of approximately 450 plant species have been identified.

2.3.1 Area.1. The North-Eastern coastal Region:

This region includes North eastern coast of Bahrain island, Muharaq, Sitra and Nabi saleh islands. Three different plant communities have been identified as Mangrove (Avicenia marina), Suaeda (Suaeda vermiculata), and Date palm (Phoenix dactylifera) communities.

2.3.2 Area.2: The West Coastal region:

This coastal region is characterised by calcareous sandy soil with relatively low salt content. Only two plant communities have been identified within this region, namely, Suaeda community and Date-palm community.

2.3.3 Area.3: Semi desert region:

This region comprises the largest phytogeographical region and occurs at elevations of 30-50 metres above sea level. The vegetational cover in this region consists of small perennials or succulent shrubs of halophytic types. After rainfall, several species of annual therophytes appear, but in summer they disappear. Main plants in this region are:

Zygaphyllum gatarensis
Heliotropium ramosissim
Fagonia indica
Andrachoe telephoides
Cassia aborata
Alnagi maurorum
Cressa Cretic
Tragonum nudatum
Anabasis setifera
Static suffruticosa

2.3.4: Area 4 : Desert region:

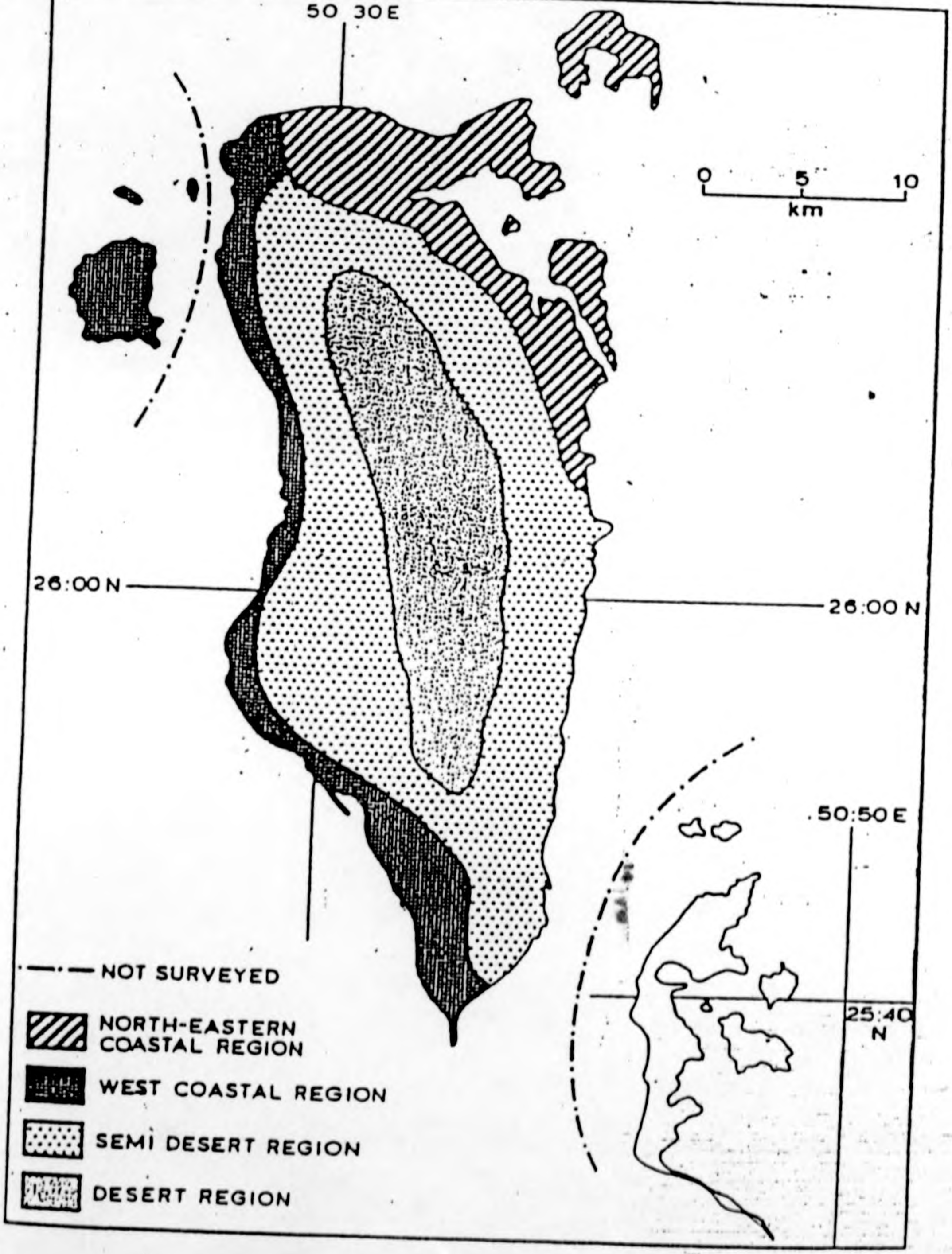
This region occupies the central area of Bahrain island and has an elevation which exceeds 50 metres above sea level. The vegetational cover is sparse and consists of perennial xerophytic shrubs which depend principally on rainfall. The vegetation includes the following species:

Panicum turgidum
Zygophyllum gatereusis
Calligonum comosun
Calatropis procera
Avera javanica
Faqonia bruquiera
Helianthemum tabhiricum

(A.O.A.D, 1978)

Figure-2.1

PHYTOGRAPHICAL REGIONS OF BAHRAIN



Source:

Arab Organization for Agricultural Development
(A.O.A.D. 1978)

2.4 Geology:

Geologically Bahrain is an elongated dome created by folding of Tertiary limestones and shales but with a central erosional depression. The dominant structure is the north-south trending axis of the main dome, with minor crossfolds predominantly trending from North East to South west. In general the strata are gently inclined towards the coast from the centre of the main island. Jebel-ad-Dukhan, the highest point lies in the centre of the island at an elevation of 122 meters above sea level, and consists of rocks of Miocene age laid unconformably on the Eocene strata beneath (Doornkamp et. al., 1980). This summit is surrounded by residual hills at elevations ranging from 20-70 metres which are themselves surrounded by an interior basin (Table-2.3). The inward-facing multiple escarpments lies outside these residual hills (BSMRS, 1976 a)(Figure-2.2 and Figure -2.3).

The fringes of Bahrain are covered by more recent marine and aeolian sand dunes which were derived from the Arabian Peninsula during a period of low sea level and of dry land connection across the present Gulf of Salwa.

Table-2.3 Geological Sequence in Bahrain

Age		Formation	Thickness(m)	Lithology
Recent- Pleistocene		Surface deposits	<5-10	Aeolian deposits, limestone, sabkha.
Miocene- Oligocene		Jabal Cap	33	Dolomitic limestone algal coral breccia
			10-60	Claystone,marl
Eocene	Dammam Formation	Alat Limestone	15-25	Dolomitic limestone
		Alat Orange Marl	9-15	Orange brown marl
		Khobar Dolomite	30-39	Dolomitic limestone
		Alveolina Limestone	10	Friable doloarenite
		Shale	8-20	Shale, limestone
	Rus Formation	Dolomitic Limestone	60-150	Chalky dolomitic limestone,shale, anhydrite,gypsum
Paleocene		Um Radhuma Formation	200-350	Dolomitic limestone calcarenite, bituminous
Cretaceous		Aruma Formation	400	Shales, limestone, dolomitic and argillaceous

UNEP,1988

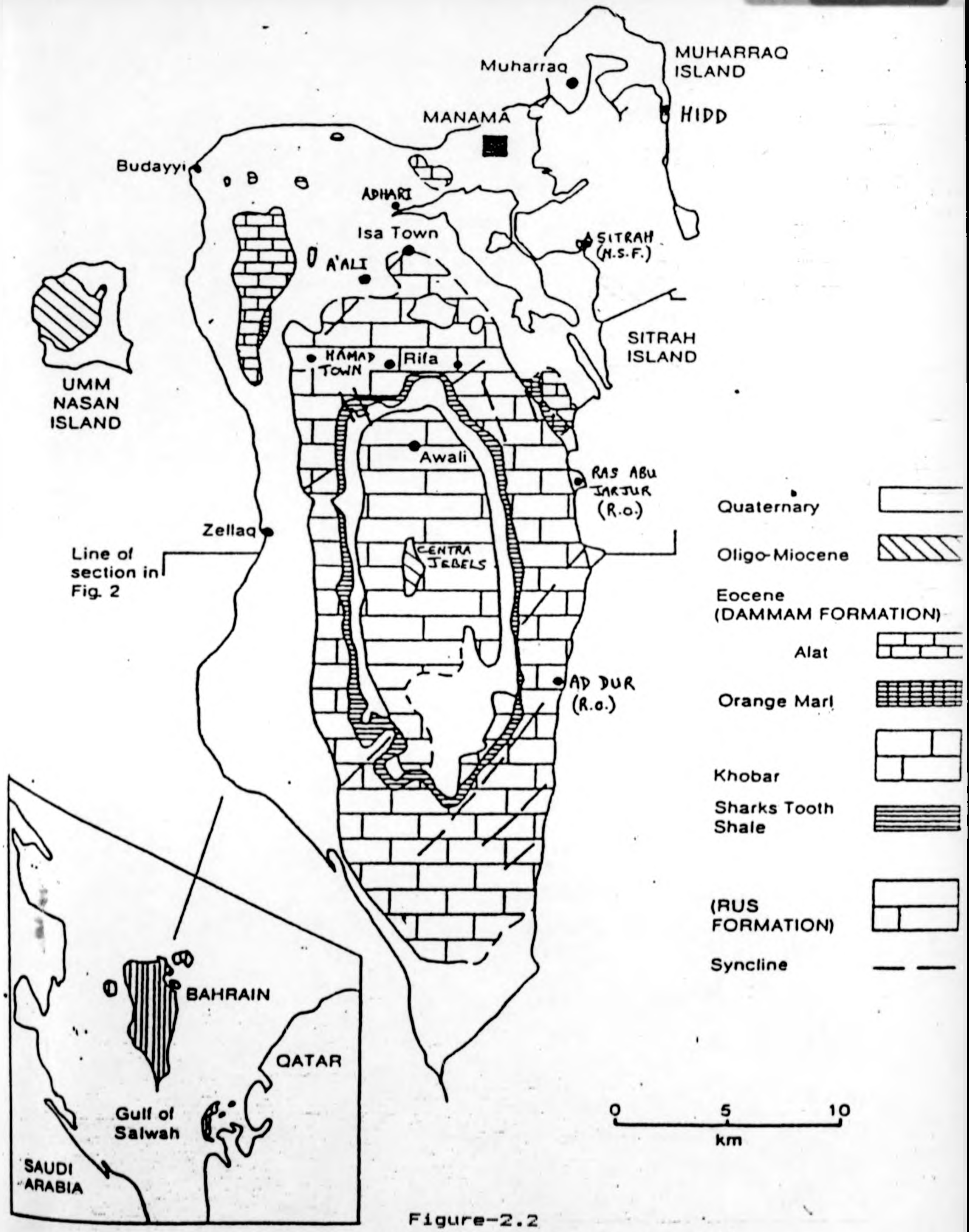


Figure-2.2

Geological map of Bahrain
(Source: Bahrain Petroleum Company)

2.5 Geomorphology of Bahrain :

Bahrain has been divided into five physiographic regions which reflect the geology and geomorphology of the major islands (BSMRS, 1976a). These regions occur as concentric belts and their main characteristics may be summarised as follows (Figure-2.3).

2.5.1. The Northern Plain:

The lands of northern part of Bahrain together with the adjacent islands of Muharaq and Sitrah, forms a low plateau with an elevation of less than 10 metres above sea level. The northern coast (Figure-2.3) has a thin veneer of sand and beach material overlying a Quaternary beach rock or a limestone probably of Miocene age (24 million years B.P.). Approximately 500 metres inland there occurs a second more extensive area of sands, probably related to a former coastline, which ranges up to 15 metres above sea level. Large areas of the northern plain are composed of unconsolidated sandy clay loam sediments which accumulated as a result of the extension of mangrove swamps and overlie sands at depths ranging from 1 to 3 metres. Areas of sand dunes are particularly obvious in the northwest of the mainland around Diraz and on the island of Muharaq. The main agricultural areas are within this region. At one time there were about 6000 hectares of cultivated land in this area but this has now declined to about 3700 hectares (BSMRS, 1976a).

2.5.2. The South west and South Sabkhas:

Sabkhas occupy two large areas of low lying lands on the south-west coast and southern tip of main island. Sabkhas were formed by accumulations of sand and beach-ridge deposits which have grown southwards to form extensive areas of low lying land. Both sabkhas are still growing southwards as sand is transported from more northerly sand dunes by strong winds. The ground water in this area is highly saline and the surface is strongly gypsiferous. The beach ridges are composed of sand and numerous shells of the gastropod Cerithium have been found mixed with this material.

2.5.3. The Multiple Escarpment and Dammam Backslopes:

The broad anticlinal dome of Bahrain Island is developed in Neogene and Eocene sedimentary marine carbonates, shales and evaporites. At the centre of Bahrain is an oval scarp-rimmed depression formed by the removal of rock strata on the crest on an anticline. From the rim of the escarpment, which has an elevation of between 50 and 60 metres the backslopes dip gently seawards and vary in width from 2 to 3 kms. A separate small backslope occurs on the north-west side of the Bahrain Island near Hamala and is characterised by medium-grained sediments with some sand dunes in its southern part.

2.5.4. The Interior Basin:

The Interior Basin is characterised by asymetric rings of lowlands filled with desert detritus, fine sand, and stone pavement in some parts, whilst the other basins of the centre have deep clay and silt sediments. This low area of approximately 7.5 x 22 km, occupies the middle part of the island and flanks the central high ground of Jebel-ad-Dukhan and adjacent plateaux and residual hills. Inland drainage is the main feature of the Interior Basin, but in the present climatic conditions drainage is endoreic.

2.5.5. The Central Plateau and Jebels:

The highest point in Bahrain is the Jebel ad Dukhan, 122 metres above sea level. There are several residual hills or jabals around this area.

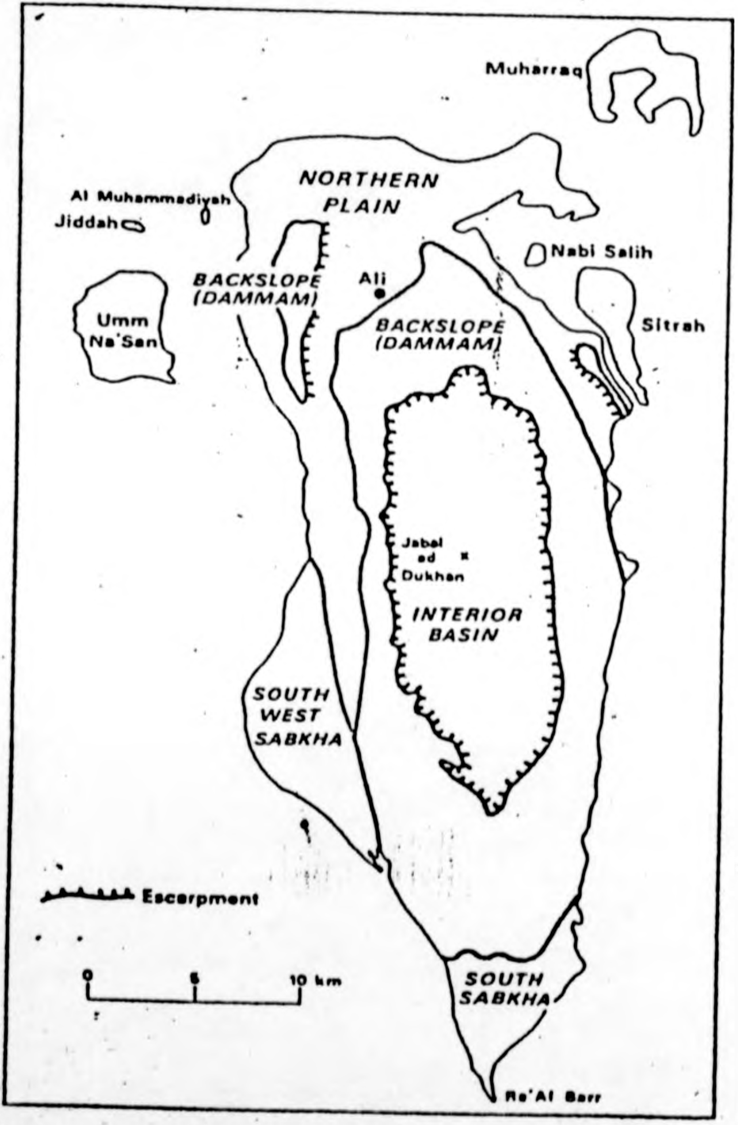


Figure-2.3 Physiographic Division of Bahrain

(From BSMRS, 1976a)

2.6 Soils:

2.6.1 Introduction:

In addition to the soil forming factors of Parent material, Climate, Organisms, Relief and Time identified by Jenny, 1941, man has had an important influence in the development of soil in parts of Bahrain. This is due to the long period of human occupance and has left its effect through irrigation practices, land levelling, salt leaching, manuring, removal of parent soil material, raising soil levels by adding sweet sand, and cultivation for thousands of years (BSMRS, 1976a).

During 1976, BSMRS made an extensive soil survey for the main islands of Bahrain. The soils of Bahrain were mapped and classified into soil groups which have been sub-divided into subgroups and 26 mapping units on the basis of soil texture, depth, location, parent material and salt content. Using the system of the FAO/ UNESCO, World Soil Map legend the soils of Bahrain can be placed into four groups: Solonchaks, Regosols, Yermosols and Fluvisols (Figure-2.4). A correlation table relating the local soil groups to the USDA system and the FAO/UNESCO soil mapping system is given in below in Table-2.4

Table-2.4

Correlation of soil classification systems

Bahrain (BSWRS)	USDA, 1960	FAO/UNESCO, 1974
1. Cultivated Solonchaks	Calciorthids or Gypsiorthids	Orthic Solonchaks or gypsic yermosols
2. Natural Solonchaks	Calciorthids gypsiorthid, or salorthids	Orthic Solonchaks gypsic yermosols or Calcic yermosols
3. Regosols	Torripsamments or Torriorthents	Calcaric Regosols
4. Raw Mineral soils	Torrifluvents or Torriorthents	Calcaric Fluvisols or Lithosols
5. Rock Dominated areas	-	Lithosols.

Solonchaks are extensive on the northern plain and have been considerably modified for agriculture. Two further sub-groups of uncultivated soils, Regosols and Yermosols occur on the sabkhas. Regosols were formed from aeolian sands. Yermosols or raw desert soils include soils of the detrital fans and shallow desert pavement over limestones. Fluvisols are represented by the soils of the sedimentary basins and beach deposits. Some areas of rock outcrop possess no natural soils and in other areas the surficial weathered material and soil has been removed for use as landfill. Both are shown as rock dominated areas. Other miscellaneous land categories include areas of abundant ancient burial mounds and urban and industrial areas where natural soils no longer exist.

Figure-2.4

Soils of Bahrain
Produced from Doornkamp et al (1980)
Legends on next page.

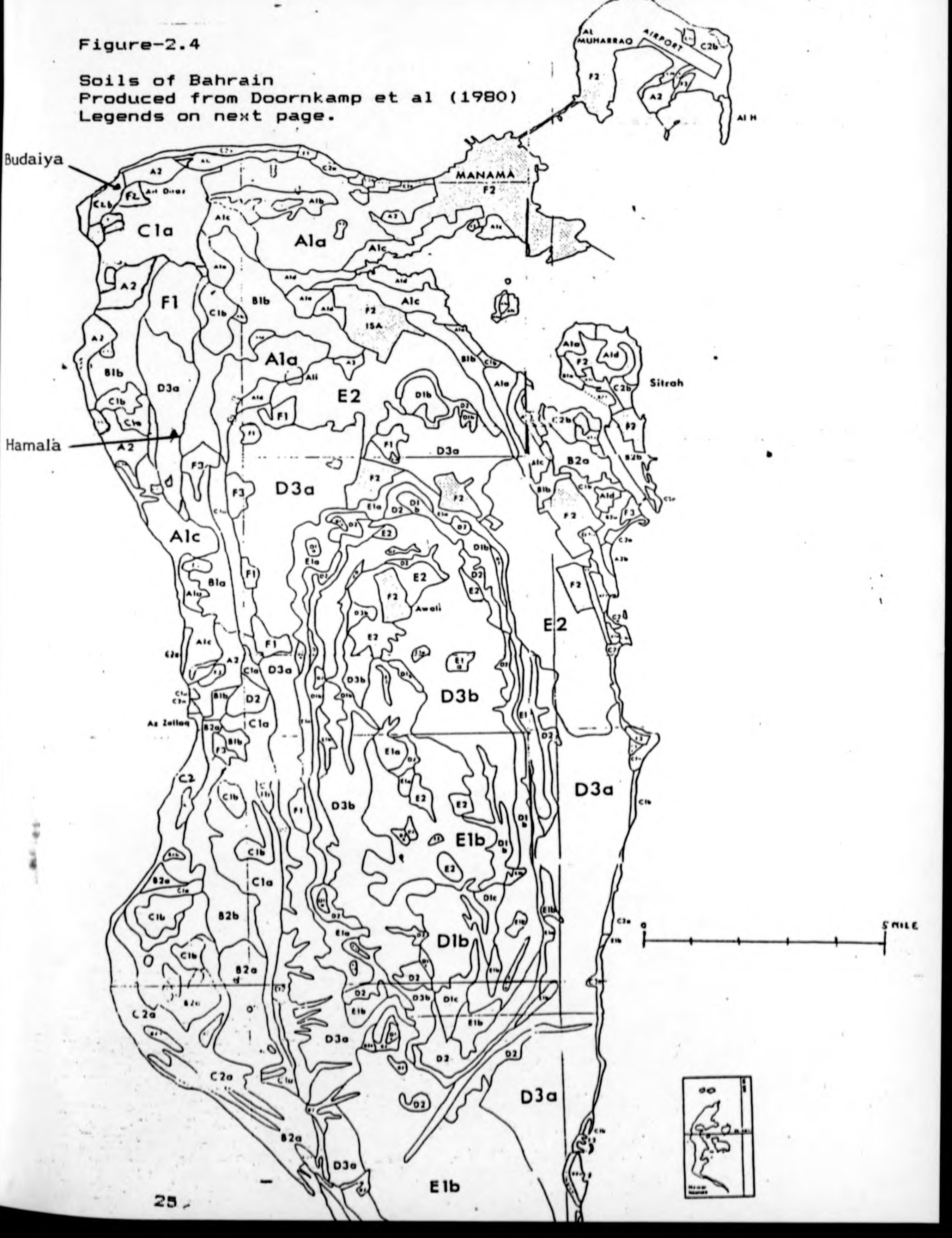


Table-2.5 Soils of Bahrain

LEGEND

Soil Group	Subgroup	Mapping Unit
A Cultivated Solonchak	A1 Loamy	A1a Loamy soil at least 1 m deep
		A1b Loamy soil with limestone at less than 1 m
		A1c Loamy soil with water-table at less than 1 m
		A1d Loamy soil with saline water-table at less than 1 m
	A2 Sandy	A2 Sandy soil with water-table at less than 1 m
	A3 Clayey	A3 Clayey soil with water-table at more than 1 m.
B Natural Solonchak	B1 Gypsiferous Solonchak	B1a Mainly loamy soils with water-table at less than 1 m.
		B1b Mainly sandy soils with water table at less than 1 m.
	B2 Sebkhas	B2a Quartz-gypsiferous sands
		B2b Carbonate-rich silts with gypsiferous sands.
		B2c Salt pans
		B2d Embanked marine mudflats
C Regosols	C1 Aeolian sands	C1a Stable sands
		C1b Dune sands
	C2 Recent beach deposits	C2a Beach sands with shells
		C2b Beach sands with shells cemented below 40 cm.
D Raw mineral soils	D1 Soils of interior basins	D1a Clays and silty clay loams
		D1b Silts and fine sands.
		D1c Sands overlying playa deposits.
	D2 Soils of detrital fans	D2 Gravelly and sandy soils of detrital fans.
	D3 Soils with stone pavement.	D3a Gravelly soils of backslopes.
		D3b Gravelly soils of interior basin.
E Rock dominated areas	E1 Areas of little or no soil naturally.	E1a On scarp slopes
		E1b On other surfaces
	E2 Worked ground with most soil removed.	
F Miscellaneous land categories	F1 Areas with abundant Dilmun mounds.	
	F2 Urban and industrial areas.	
	F3 Undifferentiated disturbed ground.	

2.6.2 Soil types :

2.6.2.1. Solonchaks :

Solonchaks have been defined as "those soils having a high salinity (E.C.> 1.5 S m-1) and lacking diagnostic horizons other than an A horizon, an H Horizon, a cambic B horizon, a calcic or a gypsic horizon (FAO/UNESCO,1974). The term Solonchak has been applied to soils in which capillary rise of solutions results in a significant accumulation of soluble salts in the upper part of the soil profile. In order that a Solonchak may develop it is necessary for ground water to exist at a depth which can supply water for evaporation by means of capillary rise through the soil. The height to which this rise occurs is usually about 1 m in medium to coarse sand but can attain at least 2.5 m in loamy soils.

Solonchaks in cultivated areas are developed from the coastal marine sediments of Pleistocene and Recent ages. Solonchaks vary considerably and although they are generally sandy to sandy loams, occasionally clayey members with poor to moderate drainage occur. The predominant salt present in the Solonchaks of Bahrain is gypsum, but there is also some calcium carbonate. As a plentiful supply of calcium is available, the morphological characteristics of alkali soils do not develop when the soils are leached Although sodium is a common cation "natric horizons "and dark coloured, deflocculated surface horizons are rarely found. The pattern of salt accumulation in solonchaks ensures that the electrical conductivity (E.C.) is always highest near the surface except during and immediately after irrigation. Once irrigation ceases the pattern of salt accumulation at the surface is re-established. E.C. of surface horizons can be up to 16.0 S m^{-1} whereas that of sub-soils is rarely in excess of 5.0 S m^{-1}.

Below the crust of many Solonchaks on formerly cultivated land there is frequently a horizon of pinkish white or pale brown fine-grained gypsum crystals with a very low bulk density. The surface of considerable areas of the northern plain of Bahrain is dominated by 30 cm high, vegetation-held dunes (nebkha) formed of sand-sized gypsum crystals deflated from nearby soils.

2.6.2.1 a).Loamy Solonchaks:

The parent materials of these soils have accumulated as marine or estuarine sediments under the influence of mangrove (Avicenia marina). Soils developed in loamy materials predominate on the northern plain and the eastern coastal fringe but are of limited extent on the western coastal plain. The loamy solonchaks vary considerably according to the amount of gypsum present and the length of time since irrigation took place. Analyses indicate that these soils contain 25 - 50 % gypsum and as the amount of precipitated gypsum increases the material becomes whiter and more sandy, and tends to have single-grain structure.

2.6.2.1.b).Sandy Solonchaks:

Sandy solonchaks are found in the western and northern parts of the northern plain of Bahrain. These soils have developed from a parent material which originated as blown quartz sand from the Arabian mainland, crossing the dry floor of the Arabian Gulf. These soils have a uniform profile and are characterised by a water-table within 1 m of the soil surface (Bridges and Burnham, 1980).

2.6.2.1. c).Clayey Solonchaks:

Clayey soils are rare in Bahrain but occur locally where small wadis discharge into the northern plain. In the area near A-Ali, these soils are associated with saline ground-water.

2.6.2.1.d). Solonchaks of the Sabkhas:

The sabkhas of Bahrain are interesting features geomorphologically, chemically and pedologically. The topographic map of Bahrain indicates small salt pans associated with the lowest parts of the south-west sabkha. Soils of this area belong to Ochric Solonchaks. They remain moist even during the dry hot summer as the water table here is at less than 50 cm depth.

2.6.2.2 Regosols :

Soils developed in unconsolidated deposits, other than alluvial materials, with an ochric A horizon but no other diagnostic horizons, and lacking hydromorphic properties are referred to as Regosols. In Bahrain, soils developed in quartzose sands are particularly important as they possess deep profiles and free drainage. Quartzose aeolian sands have accumulated in several places in Bahrain and must have contributed to virtually all soils of the island. In the north-west of Bahrain, near Budayyi, degraded dunes occur, composed of medium-grained quartzose sands with 12-15 % Calcium Carbonate and 2 % gypsum. Similar stabilized sands occur along the foot of the dipslope of the escarpments on the western side of Bahrain. Soils mentioned as Regosols are generally calcaric Regosols, but where the ground water lies within 50 cm of the surface the term Calcaric Gleysol would be appropriate (Bridges and Burnham, 1980).

2.6.2.3. Yermosols :

Soils of this type are actually Raw Mineral Soils found in the regions of the interior basin and the escarpments which surround it. Soils which occur under an aridic moisture regime with very weak A horizons are classed as Yermosols. Cambic or Argillic B horizons, often weakly developed, together with calcareous or gypsiferous concretions may be present in the lower horizons of the soils. Two mapping units are designated, based on the geomorphological situation in which each occur.

2.6.2.3 a). Soils of the detrital fans:

These are composed of debris weathered from the scarp faces of the inward facing rim escarpments and from the break up of areas of desert pavement and weathered material from the more elevated parts of the interior basin. Soils of the detrital fans are freely drained and variably cemented with gypsum.

2.6.2.3 b). Soils with desert pavement:

Stone pavement soils in Bahrain are widely developed on the limestone backslopes forming the rim of the interior basin. Almost all of these soils are bare with a very shallow depth.

2.6.2.4. Fluvisols :

Recent alluvial deposits, form the parent materials of Fluvisols. Such materials show signs of stratification as a result of receiving successive increments of fresh sediment at regular intervals. Fluvisols have been identified in the alluvial basins of the interior of Bahrain and along the coast.

2.6.3 Physical and chemical properties of Bahrain soils :

2.6.3.1 Physical properties :

The most important physical properties of the soils are particle size, cementing, soil structure and consistence, infiltration rate, moisture retention and availability, and drainage characteristics.

2.6.3.1 a). Particle Size:

The texture of Bahrain soils is extremely variable, and ranges from coarse sand to sandy loam in most places, and silty clay loam in some places. A normal loamy Solonchak (AIa) has sand, silt and clay 50 %, 26 % and 14 %, a sandy Solonchak (A2) 90 %, 4 % and

6%, and a Regosol in stable sand (CIa) 96 %, 2% and 2 % respectively (Doornkamp et al 1980). The clay content in the surface layer varies between 3-35 % (Ali, 1985). The abundance of Gypsum crystals in the soils of the nebkha plain and margins is responsible for the coarser textures, but it should be noted that the determination of particle size in such gypsic soils is unreliable either in the field or in the laboratory (Groundwater Development Consultants, 1978)

2.6.3.1. b). Cementing:

Soil layers cemented by gypsum or calcite are common in many of the soils. Gypsum cementing is common in the upper 0.5 m of all the typical Solonchaks. Due to the very coarse pore sizes of some "honeycomb" layers they form a barrier to the rise of capillary water but allow very rapid downward infiltration. The occurence of calcium carbonate cementing in the form of dense hard cemented petrocalcic horizons is seen at Salmabad and Isa Town areas.

2.6.3.1.c). Soil Structure and Consistence:

Soil structure is poorly developed in all the soils. As salts are leached from the soils some compaction will occur and porosity will be reduced, although little difference in consistence was observed between irrigated and non-irrigated sites (G.D.C, 1978).

2.6.3.1.d). Infiltration rate:

Very fast infiltration rates are recorded in most agricultural areas (1.3 - 83.1 cm hr^{-1}), (ERCON, 1973, ITALCONSULT, 1971, VIRGO, 1979). This is true in the case of coarse textured soil while the presence of shallow water table, salt crusting, fine texture or a cemented layer will reduce the infiltration rate and thus make salt leaching difficult and cause drainage problems.

2.6.3.1. e). Moisture retention and Availabilty:

The available water capacity (AWC) of a soil is defined as that portion of the total waterholding capacity which is available to roots to sustain plant life. To absorb water from the soil the plant root has to overcome suction forces which hold the water in the soil. Most of the irrigable soils have relatively high available capacities (ERCON, 1973). Field capacity of soils ranges from 5-60% by volume whereas the wilting percentage varies between 1-30 % by volume. Available water content thus varies between 4-30 % by volume.

2.6.3.1.f). Drainage Characteristics:

Removal of water by drainage is essential for irrigation. In the case of irrigated soils, since infiltration rates are high, water movement through the soil is rapid. Saturated hydraulic conductivity tests carried out on Bahrain soils (ERCON, 1973), show that as expected coarse-textured soils predominantly have a high rate (68.4 cm hr^{-1}) while the fine-textured soils have a low rate (0.54 cm hr^{-1}) of movement. Since the soils are saline, large quantities of water are required for leaching the accumulated salts.

2.6.3.2 Chemical properties :

In Bahrain chemical properties of soils are strongly affected by climate, vegetation and topography, whilst the parent material plays a secondary role (Dregne, 1976). Chemical analyses show the majority of soils to be saline, gypsiferous and highly calcareous. The total gypsum and calcium carbonate (gypsum + calcium carbonate) in the upper metre of many soils exceeds 50 % and sometimes rises to 80 %.(GDC, 1978). High concentrations of calcium sulphate can cause nutritional imbalance and highly gypsic soils have very low Cation Exchange Capacity and are therefore unable to retain nutrients in the root zone. This necessitates frequent application of fertilizers in view of the higher leaching requirements (Associated Consulting Engineers, 1984).

Gypsum is slightly soluble in water and as such could lead to solution collapse when irrigation water dissolves sub-soil gypsum and causes the surface soil to collapse into the cavity created.

Large concentrations of calcium carbonate were also recorded in soils of Bahrain. Mineralogical studies have shown that most calcium carbonate is present in the silt fraction. Large calcium carbonate contents raise the pH of the soil and can cause micronutrient deficiencies in crops.

pH of the soils in Bahrain ranges from 6.8 to 8.4. Furthermore, $CaCO_3$ content of the soil has the effect of buffering pH reductions. The average micronutrient content of the soils of Bahrain are shown in Table-2.6. Cu, Zn and Fe were extracted by DTPA, Mn using ammonium dihydrogen phosphate, Co and Se with 0.05M EDTA, and Mo with ammonium oxalate- oxalic acid solution.

TABLE-2.6

Average and Range of Micronutrient content of the Soils (mg kg^{-1})

Soil Parameter	Average	Range
Extractable Fe	1.71	0.10 - 7.20
Extractable Zn	2.18	0.10 - 11.10
Extractable Cu	1.18	0.02 - 7.20
Extractable Mn	20.00	2.00 - 66.00
Water solu B	0.80	0.27 - 1.70
Extractable Co	0.72	0.55 - 0.97
Extractable Mo	0.16	0.10 - 0.30
Extractable Se (ppb)	19.00	1.00 - 88.00

Source : Ali, (1986)

From the Table-2.6, it is seen that Bahrain agricultural soils are low in available Fe and Mo concentrations. Cu, Co, Mn and B contents seems to be satisfactory and Zn content adequate (Aubert et al 1977).

The principal chemical characteristic of most Bahrain soils is their very low content of organic matter (0.05 - 1.05%) (GDC, 1978). Nitrogen concentrations are therefore also small (0 .038%). C/N ratio averages 17.3. Phosphorus availabilty is very low (< 1.01 mg 100 $g)^{-1}$ with highly calcareous soils(GDC, 1978). Soils of Bahrain are generally well supplied with potassium.

2.7 Natural resources, Environment and Development.

2.7.1 Water resources :

Ground water is the sole natural water of Bahrain. Ground water in Bahrain is contained in three Eocene aquifers, classified as the Alat (A), the Khobar (B), and the Um Er Radhuma (C). The aquifers are connected laterally with the huge ground water system of the Kingdom of Saudi Arabia and Bahrain acts as a major natural discharge area for the aquifers (Walton, 1987) (Figure-2.5 and 2.6).

The eastward dipping Eocene aquifers receive recharge at their outcrops on the Arabian mainland, and have outflows restricted by overlying low permeability strata. Accordingly upward flow tends to be concentrated in areas of structural weakness (Groundwater Development Consultants, 1978). In the past groundwater discharge has been through sabkha, and marine and land springs. However, due to the reduction in piezometric head caused by a large increase in abstraction a major discharge component is now well abstraction. At present the total Eocene aquifer discharge is about 165 x 10^6 m3/year(1985).

The Um Er Radhuma formation consists mainly of grey, chalky, detrital and calcarenitic limestones. The thickness varies from 115 to 300 m and the formation is normally porous and fissured with high permeability. The porosity of the Umm Er Radhuma aquifer is high often reaching 30 % and the storage coefficient is about 2.10 under confined conditions.

The Alat consists mainly of white, finely crystalline limestone about 15 to 25 m thick (Table-2.3) The Khobar aquifer comprises white, buff and brown limestones with a thickness of about 40 m. Both the Alat and Khobar aquifers possess inter-granular porosity, however, their high permeability is largely due to secondary joints and fissures enlarged by solution. The upper 10 metres of the Khobar strata is full of large openings and has a high transmissibility. The Alat and Khobar strata together form the Dammam formation.

In Bahrain only the Dammam formation contains water of reasonable quality. In Saudi Arabia the Umm Er Radhuma aquifer water is of reasonable quality and this water recharges Dammam formation at the coastal belt and flows through the Khobar and Alat aquifers to Bahrain. The Umm Al Radhuma aquifer is highly saline in Bahrain

(>10000 ppm) (Ground Water Development Consultants, 1978, Nagmoush, 1981, Figure-2.6).

The conductivity contours for the Khobar aquifer of Bahrain are indicated in Figure-2.7. It can be seen that salinity increases rapidly to the south and east. In the region of Sitra island it appears that there has been salt water intrusion due to overpumping.

The piezometric head in Bahrain has declined as a result of increased ground water abstraction from wells. It is estimated that a decrease of 4 to 5 m has taken place since 1925. The piezometric heads are greatest in the north west of the island and gradually decrease to the south east. This gradient reflects the ground water flow which is in a south easterly direction.

Recharge of the Dammam aquifers in Bahrain takes place through direct infiltration of rain, infiltration of runoff, horizontal flow in the aquifers from outside Bahrain and vertical flow from underlying aquifers. Since rainfall is quite sparse in Bahrain, recharge resulting from rainfall is negligible and recharge primarily results from horizontal flow from outside Bahrain. Ground Water Development Consultants International Ltd, (1978) estimated that the throughflow from the mainland exceeds 90 x10^6 m3/year. At the present state of over development of these aquifers about 33 % of the recharge comes from upward leakage of saline groundwater.

It is anticipated that these aquifers can recover fairly quickly, both in terms of piezometric head and salinity once abstraction is brought under control to within the through flow figure.

In the light of the above, aquifer recharge could become an important factor in the overall planning of effluent utilization, particularly for flows in excess of the daily minimum flow. The high transmissibility of the Khobar aquifer suggests it is highly suited for artificial recharge which could be used to control saline water intrusion and increase the capacity of the aquifers. The extent of effluent recharge will depend on water requirements, problems with salt water intrusion, aquifer behaviour, and natural recharge capacity.

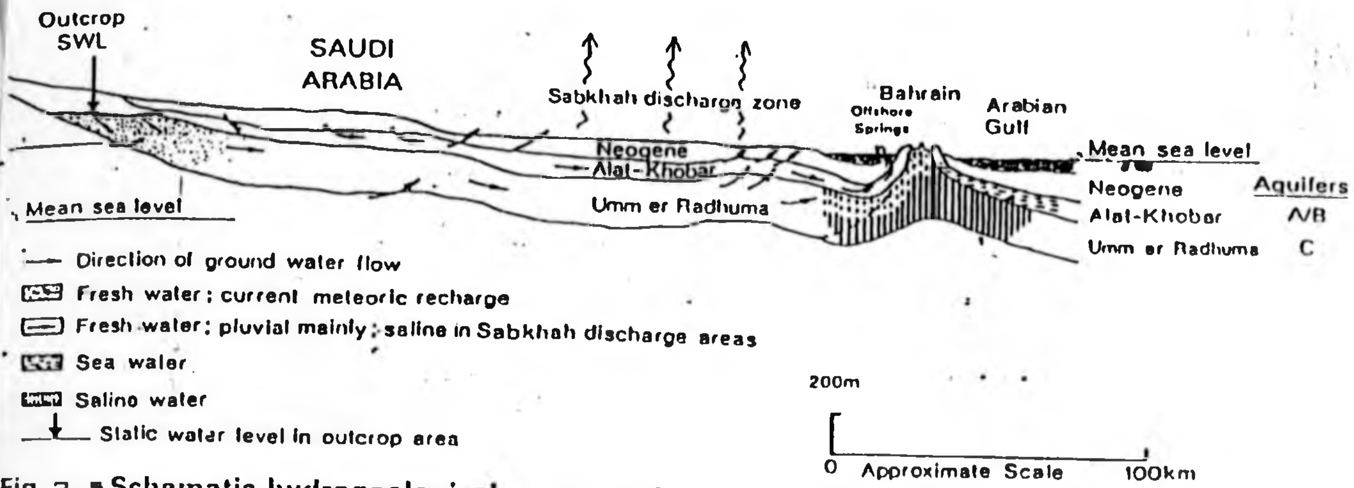


Fig-2.5 Schematic hydrogeological cross-section of the post-cretaceous aquifer system (Source: Groundwater Development Consultants 1983[6])

THE WATER SUPPLIES OF BAHRAIN ISLAND

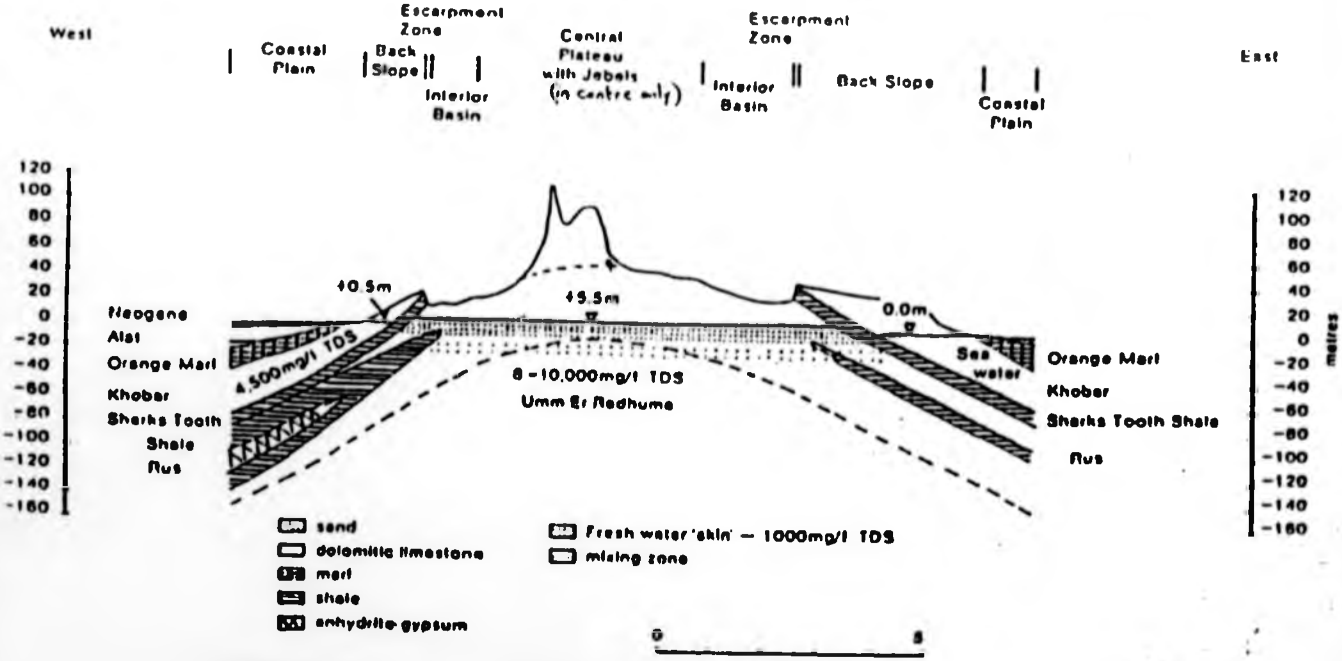
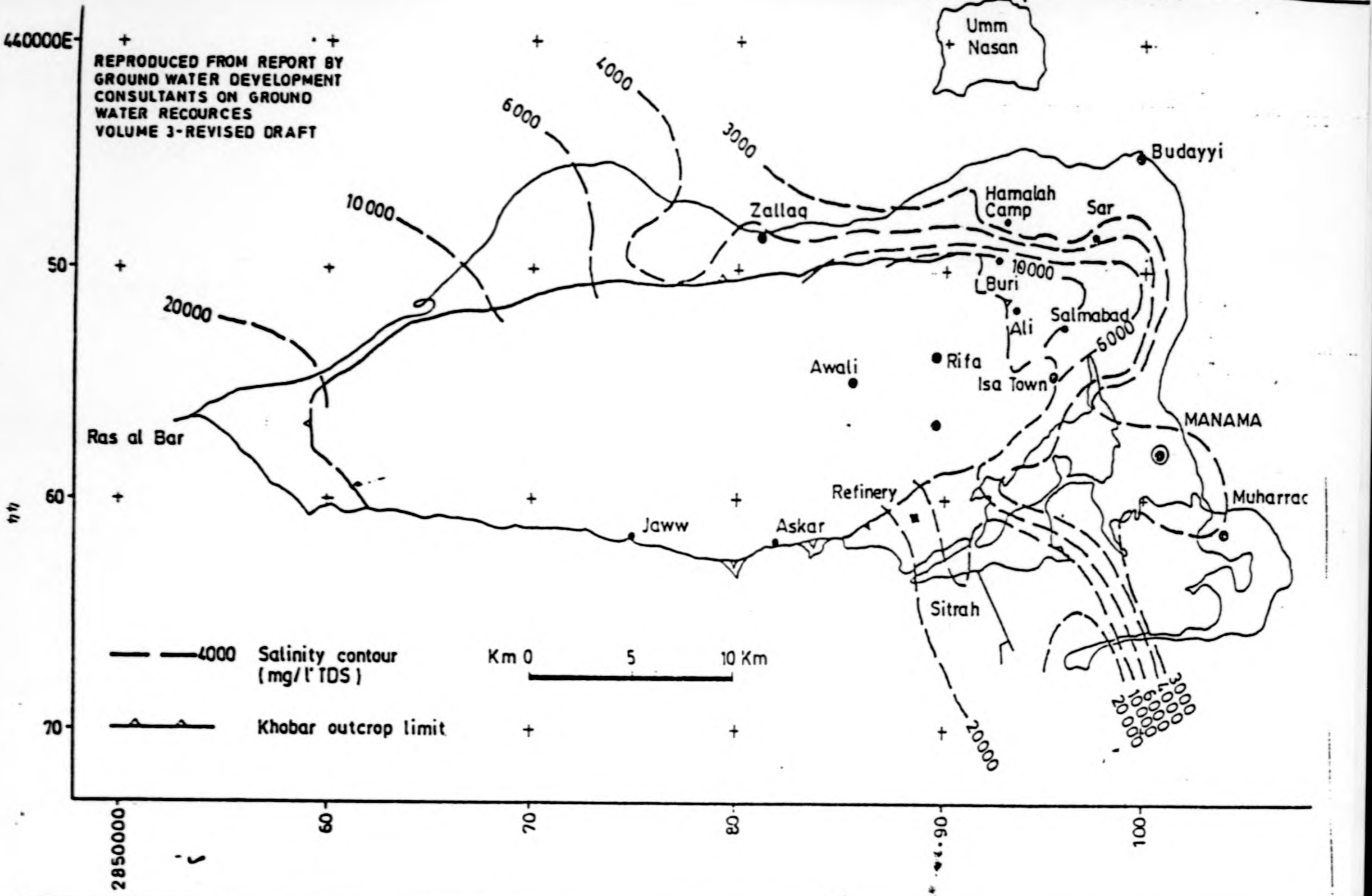


Figure-2.6 Hydrogeological cross-section of Bahrain (Source: Wright, E. P., Izatt, D. and Lori, I. 1983[7])


REPRODUCED FROM REPORT BY GROUND WATER DEVELOPMENT CONSULTANTS ON GROUND WATER RECOURCES VOLUME 3-REVISED DRAFT

MINISTRY OF COMMERCE & AGRICULTURE
MINISTRY OF WORKS POWER & WATER
TREATED EFFLUENT, SLUDGE & COMPOST UTILIZATION

KHOBAR SALINITY – BAHRAIN

Figure-2.7

PLATE N°
IV - 4
ACE

2.7.2. Water supply and demand.

Originally Bahrain relied on natural land and sea springs in the northern half of the main island and in other islands for domestic water supplies. Hand-dug and artesian wells followed when the oil companies arrived in the 1930s. Piped water systems of ground water abstracted from boreholes were introduced in the 1940s and served the population exclusively until 1975, when the first desalination plant was commissioned.

Now the total production of desalinated water from the desalination plants is 45 million gallon per day. Bahrain is trying to reduce its public supply reliance on ground water to limited levels, leaving just a few percent abstracted for blending with desalinated water which will be approximately 28 million gallons per day.

The results of trace metal analyses of tap water, blended (ground + desalinated) water and ground water are shown in Table-2.7. The metal concentrations show full compliance with WHO Standards (Raveendran, 1989).

The original water balance representing natural equilibrium has been estimated at about 83 x 10^6 m3/annum outflow, with an original piezometric head at the north western corner of the island of about 5 m ASl, as measured during the 1940s (Walton, 1987).

Recent aquifer abstraction is estimated at more than double this equilibrium or "safe yield" level, with a piezometric head decline of nearly 80 mm/annum, leaving a current head of less than 3m AMSL, in the north west of the island, and less than 1.0 m in the west, central and northern areas.

The difficult problem of reducing agricultural demand for ground water by about 45 percent to meet the equilibrium safe-yield value of 83 x 10^6 m3/annum abstraction has been proceeding slowly but surely, with measures to stop all new well drilling, stopping leaks, subsidizing improved irrigation methods, and making treated effluent available for agriculture in some areas. The water demand per capita is 320 litres/d in urban areas and 273 litres/d in rural areas.

There is a significant variation in water demand between summer and winter with the ratio of maximum to minimum month having been 1.2 to 1.6 over the past 5 years. Domestic water consumption in 1983 was stated as averaging 37.67 million gallon per day. Target water consumption figures have been established at 70 million gallon per day for urban dwellers and 60 million gallon a day for rural areas. To achieve this, a graduated tariff structure is introduced and a metering programme is complete. The peak demand expected for the year 2001 is 68.5 to 75.5 million gallon per day, assuming a per capita demand of more than 120 gallon per day.

TABLE -2.7 a

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QALITY OF DRINKING WATER

. Average concentrations of metals in Bahrainian drinking water in 1987 (all results are in µg/l)

Element	Blending stations	Groundwaters (*n* = 24)	House taps (*n* = 71)	Reverse-osmosis product	Sitra distillate	Sea-water inlet at Sitra
Lead	2.42±1.03 (*n* = 21)	3.72±0.88	3.94±1.37 (*n* = 71)	0.45±0.31	0.34±0.2	9.8
Cadmium	0.114±0.098 (*n* = 21)	0.43±0.43 (*n* = 24)	0.183±0.08 (*n* = 72)	0.08±0.1	0.09±0.08	0.1
Aluminium	18.93±12.56 (*n* = 21)	22.12±6.03 (*n* = 24)	19.56±11.18 (*n* = 56)	24.97±9.3	4.87±0.5	6.8
Chromium	3.48±1.59 (*n* = 21)	6.41±1.87 (*n* = 24)	5.282±3.2 (*n* = 72)	0.28±0.13	0.4±0.26	0.5
Arsenic	< 1	< 1	< 1	< 1	< 1	< 1
Selenium	< 1	< 1	< 1	< 1	< 1	< 1
Iron	15.27±6.73 (*n* = 21)	9.74±4.89 (*n* = 23)	15.52±7.82 (*n* = 65)	22.93±6.0	3.49±3.3	6.2
Copper	6.497±5.06 (*n* = 21)	4.08±2.79 (*n* = 23)	22.08±38.51 (*n* = 64)	7.04±5.49	8.5±3.65	16.2
Zinc	11.68±3.16 (*n* = 21)	10.1±3.96 (*n* = 24)	54.37±126.19 (*n* = 58)	11.83±2.36	7.93±3.58	10.1
Manganese	4.7±1.76 (*n* = 21)	10.37±3.43 (*n* = 24)	6.27±2.8 (*n* = 72)	7.73±0.23	3.37±1.33	5.2
Nickel	< 10	< 10	< 10	< 10	< 10	< 10
Mercury	0.0467±0.034 (*n* = 14)	0.133±0.06 (*n* = 15)	0.083±0.05 (*n* = 48)	0.06±0.014	0.078±0.004	0.098

Table-2.7 b

Average concentrations of metals in the drinking water of Bahrain in 1987; a comparison of WHO guidelines and recorded concentrations of drinking water in other parts of the world (all results are in µg/l)

					WHO guidelines [1]		EC directive (1980) human consumption [10]	
Element	Bahrain (1987)	Qatar [8] (1984)	Kuwait (1986)	New York [9] (1984)	(1984)	(1971) Tentative upper limit	Guide level	MAC*
Inorganic substances of health significance								
Cadmium	0.18	0.25	0.53	5	5	100	—	5
Chromium	5.28	0.25	1.35	30	50	—	—	50
Lead	3.94	2.5	1.43	—	50	10	—	50
Nickel	10	7.5	—	50	—	—	—	50
Arsenic	< 1	0.5	—	40	—	50	—	—
Selenium	< 1	0.5	—	5	—	—	—	—
Mercury	0.086	0.5	0.06	1	—	1	—	—
Other substances								
Aluminium	19.56	—	—	60	200	—	50	500
Copper	22.08	40	1.9	110	1000	50†	100	—
Iron	15.52	73	—	120	300	100† (1000)‡	50	200
Manganese	6.27	0.9	2.7	70	100	50† (500)‡	20	50
Zinc	54.37	60	52.2	10	—	5000† (15000)‡	100	—

*Maximum admissable concentration;
†highest desirable level;
‡maximum permissible level.

Source : Raveendran E. (1989) JWSRT. AQUA , Vol 38, pp 308.

2.8 Agriculture in Bahrain :

2.8.1 Introduction:

Agriculture plays an important part in the life of thousands of people in Bahrain. Bahrain was once considered to be one of the most agriculturally productive countries of the Gulf area. The total available land area in Bahrain is 693 km2. The most favourable lands for settlement are, however limited and confined to the northern and north western portion of the main island. Out of this 693 km2, only 5 % is cultivated. When viewed in terms of population density as calculated from 1987 census the average density is 408 people/km2, but this becomes 2941 people/km2, when only the cultivated land is considered.

In the past cultivation which was dependent on sweet water from natural springs, had reached about 60 km2 distributed in the northern plain of Bahrain island. This area has now fallen to 37 km2, and is restricted to the north western part of the island where reasonably good quality ground waters and deep sandy soils are available.

2.8.2 Land use pattern for agriculture :

In the past an estimated 6000 ha of Bahrain was cultivated for arable crops or as date and other fruit gardens (Table-2.8). A large proportion of this area is now abandoned due to neglect or to salinisation and urbanisation. The best quality land has a level surface, with few stones, naturally drained, has good water retentivity, ground water at considerable depth. Unfortunately such land occurs within the desert area which lacks suitable irrigation water. Moderate quality land is classed as easy to reclaim and improve, not vulnerable to saline water intrusion, can be well leached out. These lands are located mainly in the north where reasonable irrigation water is available. These lands are mostly threatened by urban expansion (Brunsden et al, 1979). Existing land use is shown in Figure-2.8. Table-2.9 outlines the land use plan for the year 2001.

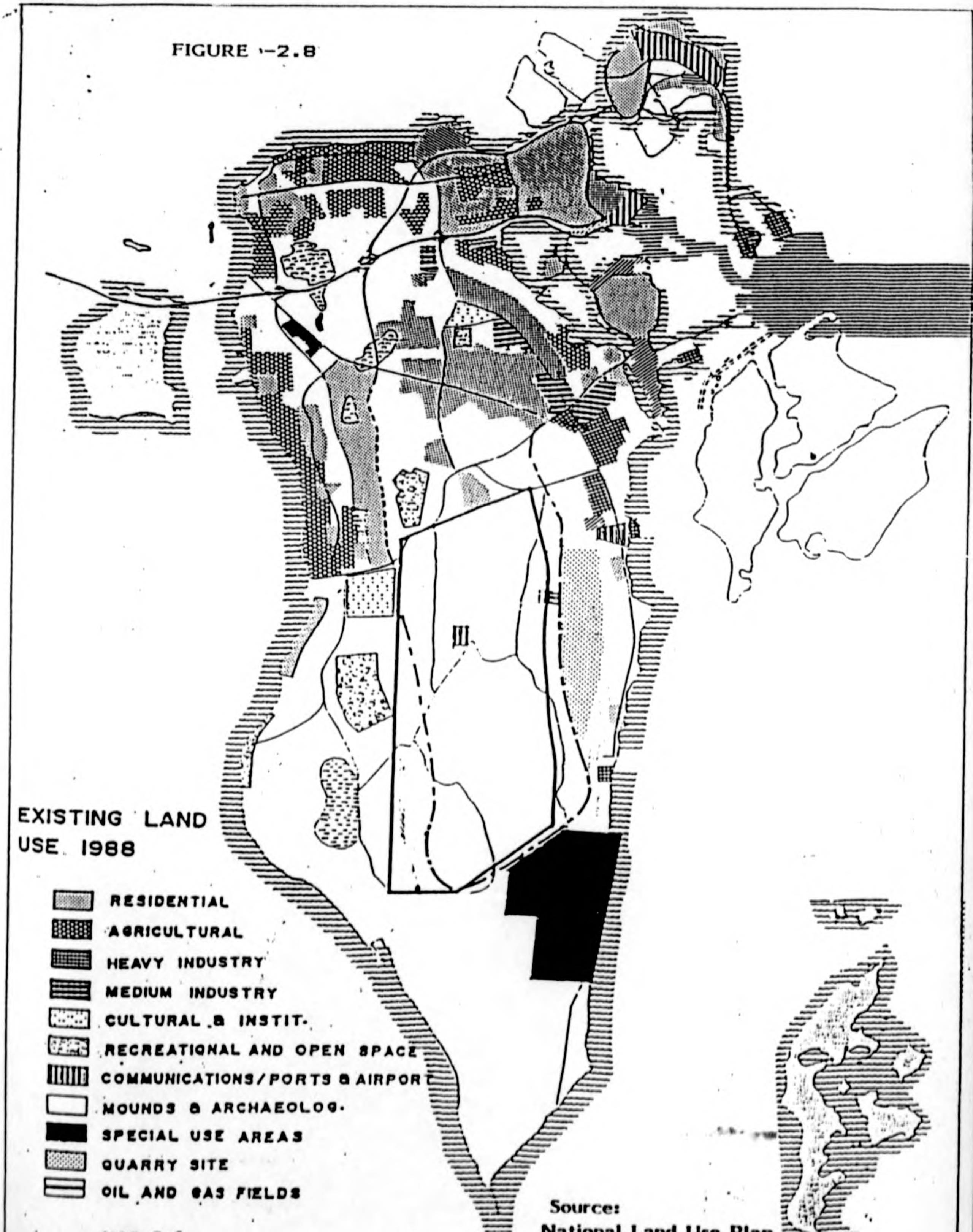
TABLE-2.8

Areas of agricultural land in present use or with signs of past use.

Type of Land Use	Total Area hectares	% of Agricultural land
Well tended date-palms	137	2.1
Date-Palms underplanted with fruit trees.	33	0.5
Date-Palms underplanted with annual crops or alfalfa.	112	1.7
Poorly-tended date-palms.	442	6.8
Abandoned date-palms:choked by regrowth.	48	0.7
Abandoned date-palms:few or no producing date-palms.	3206	49.1
Open stand of date-palms,underplanted with arable crops.	86	1.3
Orchards,nursery gardens,Fruit trees usually with some date-palms and arable crops.	40	0.6
Arable crops,vegetables or alfalfa with no more than occasional date-palms	832	12.7
Former arable crop-land,not under irrigation in 1977 (January)	1595	24.4
Roadside verges planted with trees or shrubs.	58	0.1
Total agricultural land, used or unused	6589	100.0

Source: Groome & Associates ,(1986).

FIGURE 1-2.8



Source:
National Land Use Plan
1988. Bahrain.

Table-2.9 Classification of Percent Land Use (1988) & Projected for 2001

Land use Classification	Existing 1988	Proposed 2001	Areas in Ha (2001) Total	% of Bah. Isl	Remarks
Residential & Housing	9195	1700	10895	15.6	Included Zimmah Bay reclaimed area.
Agricultural	3850	1650	5500	7.9	Total cultivated area by 2001 within the 90 Mm3 per ammum. Abstractionf and reduction of water consumption/ha from 66000 m3 to 27500 m3/ha.
Poultry Farms	220	-	220	0.3	
Industrial Areas	2270	1320	3590	5.1	S.Hidd proposed reclaimed area 653.9 ha & 330 ha west of Askar/Jaw proposed 3rd town.
Cultural & Instit.	850	50	900	1.3	
Recreational & Open spaces	2440	500	2940	4.2	
Public Utilities	153	22	175	0.3	
Communications	380	-	380	0.6	
Ports & Airport	805	50	855	1.2	
Roads	2010	85	2095	3.0	

Growth of residential and related services between 1988 & 2001 has been calculated as follows

Askar/Jaw 1st phase	1155 ha
All settlements expansion	315
Infill Muharaq, Manama and Sanabis	100
Zimmah Bay Reclamation	128
Total	1698 ha (1700 ha)

Note: This area does not include the private sector activities in house building.

Table-2.9 (Continued).

Land use Classification	Existing 1988	Proposed 2001	Areas in Ha (2001) Total	% of Bah. Isl	Remarks
Mounds & Archeological	820	-	820	1.2	
Special use areas	3235	-	3235	4.6	
Quarry Activities Areas	800	-	800	1.2	
Oil & gas Fields area	11400	-1400	10000	14.3	
Existing Used Land	38428	3977			
Existing Proposed			42405	60.8	
Undeveloped Land	30695		27375	39.2	
Total area of Bahrains Territory 1988	69123		69780	100.0	

Source : National Land Use Plan for Bahrain Report. 1988.

In Bahrain, urban development has taken place mainly at the expense of the better agricultural land, where economic farming would have been possible.

The first lands to be brought under cultivation were also the first lands to be abandoned, due to the following reasons:

a. Lack of good groundwater supply resulted from the exhaustion of natural springs.

b. Salt accumulation in the soils in large areas,as a result of increased water salinity which was caused by over pumping and subsequent intrusion of sea water.

c. Migration of population from agriculture to other jobs in oil Industry and to the Towns.

d. Urban expansion across land previously used for farming.

According to Ministry of Commerce & Agriculture Annual Report (1988), there are 810 productive farms, occupying an area of about 3848 ha. The average farm holding is 4.8 ha, but 33 % of farms are smaller than 2 ha. Only 218 farms (1220 ha) have a drainage facility at present. About 40 different vegetable crops are grown in Bahrain, as well as the traditional dates, alfalfa and some other fruit crops such as Citrons, Papaya, Mangoes, Almonds and Pomegranates. Among the farms about 40-50 of the area in a holding is used. 48 % of holdings are cultivated by the owners and the remaining 52 % are rented.

2.8.3 Agricultural practices :

Traditional farming is commonly practised in Bahrain and is based on primitive methods and implements that have been in use for hundreds of years (Abdulla, 1978). Despite the lack of modern technology a large variety of crops (vegetables) and dates are grown, and the adoption of alfalfa as the sole fodder crop has been successful because it can tolerate the salinity of the irrigation water. Winter vegetable crops comprise a wide range of winter crops which include mainly tomatoes, onions, cabbage, pepper, lettuce, eggplant, carrots, and radish . Summer crops are limited to melons, okra and cucurbits (cucumber). The majority of these crops are interplanted with date-palm trees which provide shelter against high winds and the hot summer sun.

2.8.4 Chemical fertilizer use in Bahrain :

As the organic matter content of Bahrain soils is very small (max 1.05%), the use of both organic fertilizers and inorganic fertilizers has become necessary. The fertilizers used in Bahrain are as follows.

Total Amounts of Agro Chemicals Used in Bahrain:(1985).

1.	Fertilizers:	UREA (N).	200 t/y
		NPK 15-15-15	950 t/y
		NPK 15-30-15	2.5 t/y
2.	Pesticides:	Powder.	6.348 t/y (1988)
		Liquid.	5648.1 L/y (1988)
3.	Herbicides + Nemetocides:	Powder	2.9 t/y
		Liquid.	0.3 L/y
4.	Fungicides + Bactericide		
	Trace elements.	Powder	2.0 t/y
		Liquid	2.9 L/y.

Bahrains total consumption of N, P, K fertilizers was 230 kg ha-1 of arable land during 1989 which amounts to 1.5 kg per capita (Al-Tawadi, 1990). Micronutrient disorders such as lime induced chlorosis are common problems in the light textured calcareous soils which represent most of the cultivated soils in Bahrain. Plants also vary considerably in their tolerance to micronutrient disorders.

The compound fertilizers mentioned above contain major elements N, P and K and are balanced to meet the requirements of plants under various conditions. It is also important to note that growing interest is being paid to foliar fertilization to overcome difficulties of leaching losses, and chemical fixations (mainly phosphate) in soil application. (Buhler Brothers Ltd, 1985).

2.8.5 Irrigation methods :

Agricultural activity in Bahrain is entirely dependent on irrigation. Irrigation water is scarce and the water is highly saline (2500-5000 mg L^{-1}, TDS) Despite the scarcity of water farmers usually apply excessive amounts of water particularly during the summer months. Wright and Ayub (1972) during an investigation on irrigation efficiency, found that the irrigation water applied throughout the growing season is often 3-4 times the actual irrigation requirement (30000 m3 ha-1 yr-1).

Total crop water requirements have been estimated by Hunting (1979 b) as shown in Table-2.10.

TABLE -2.10

The Water Requirements of Crops in Bahrain.

Crop	m3 /ha /year
Alfalfa	41500
Tomatoes	7940
Cucurbits	10560
Dates	17300
Mangoes	14450
Citrus	16050
Grapes	13230
Other vegetables	6700

Source: Hunting (1979 b).

Italconsult (1971) estimated that each farmer applied about 66000 m3 per hectare per year. Enquiries show that the local farmer makes frequent small applications of irrigation water in the belief that this will avoid salt accumulation in the soil.

Traditionally water is applied in several ways depending upon the type of crops. In the case of date-palms, irrigation is usually carried out by making relatively deep ditches around a square area of about 30 m2 upon which the palm is grown. Dates are watered every 10-15 days. In some locations irrigation is not required as they draw water directly from the shallow water table. For alfalfa and other vegetable crops like radish , okra, lettuce, carrots and eggplant, small basins, commonly 2.5 x 7.5 metres in size are made. For tomatoes, melons, cucurbits, onions, beans and squash small furrows are made generally 12 metres long and 3 metres apart. In all cases water is diverted from a main feeder channel to the furrows or basins and they are filled to a depth of 50-100 mm. (FAO 1977b). There is a great deal of water wastage by this flood irrigation method and recently improved methods of irrigation have been introduced including drip and sprinkler systems.

a. Trickle irrigation (Drip irrigation).

This method of irrigation is widely practised in Bahrain. This method gives the most efficient use of water and it is suitable for most trees and many vegetable crops. Many experiments (Peterson & Ayub, 1974), have shown that for tomatoes a higher yield was achieved when drip irrigation was used. Table-2.11 compares the amount of water applied and yield of tomatoes by using different methods.

TABLE -2.11

Water applied and yield from Furrows and Drip irrigation methods;

Irrigation	water applied m3	yield t/ha	Kg of tomato/m^3 water
Furrows	3276	27.5	0.84
Lined Furrows.	2268	40.9	1.80
Drip Irrigation.	1580	49.1	3.11

Source Peterson & Ayub 1974.

The main water source in this case is either an overhead tank or a well and pump. The larger the area served, the lower are the costs per unit of irrigated land. The main problem of exposed drip irrigation system in this hot climate area is durability.

Drippers get clogged and the PVC pipe cracks thereby reducing the life of the system to 2-3 years. The mains and sub mains used to be buried at 50-75 cm depth to avoid exposure to the sun.

In summary although capital costs of a drip irrigation system are high, these costs can be reduced for large scale systems. However drip systems do not cater for large applications of water for salt leaching.

b. Sprinkler Irrigation:

Sprinkler irrigation is practised on an experimental scale at the Government farm in Hamala,and at Um-el-Nakaila, Muharaq. Water from wells is conveyed through underground PVC pipes to the field and further distributed with portable surface mild steel pipes. The sprinkling cycle is approximately 5 days, and total water consumption 245 m3 ha^{-1}. Sprinkling is carried out at night to minimise scorching of plants.

Over all sprinklers save about 50 % of applied water and nearly 98 % of labour costs and increase the cultivable area previously lost to channels and levees (Dastane & Ayub, 1982).

The greatest adverse effect on crop yields is that resulting from poor quality of irrigation water. Various plot trials carried out in Bahrain (Badawi 1971) using waters of different salinity (2200 ppm to 10500 ppm) showed that best results were obtained using water of 2200 ppm salt. The exception to this was alfalfa which can be grown using water with a salinity of up to 8000 ppm.

2.8.6 Problems facing agricultural practice :

Poor land drainage is a problem in Bahrain, due to the presence of impermeable layer of either limestone or sand cemented with gypsum or carbonate. Excessive use of water in the absence of an adequate drainage system, causes gradual rise of water table level and thus salt accumulation. Ground water used for agriculture is of poor quality with TDS ranging from 2500 to 5000 mg L^{-1} and thus only salt tolerant crops can be grown in Bahrain. Acute shortage of organic matter in all Bahrain soils, makes the farmer to use large amounts of organic manures to improve, basic productivity parameter like soil fertility, aggregate stability and water holding capacity.

2.8.7 Future plans for agriculture in Bahrain :

2.8.7.1. Use of compost as soil amendment:

Studies carried out in Bahrain (Aradi, 1986) on compost made from sewage sludge and town refuse, demonstrated that it was suitable and indeed proved superior to farm manures in improving crop yield. The availability of such materials and the need for organic amendments makes their use vital in Bahrain.

2.8.7.2. Use of treated effluent water for agriculture:

At present (1990) treated effluent water available is of the order of 55000 m3/d, with around 200000 m3/d availability possible by the end of 1991, when the third phase of the Tubli treatment plant will become operational. The effluent is disinfected with ozone in combination with chlorine and then used for

a. Production of fodder crops to be utilized for livestock.
b. Commercial production of vegetables and fruits.
c. Planting of trees, primarily for timber and timber related products.
d. Planting of shrubs and other vegetation primarily for the improvement of the environment.

e. Major urban landscaping schemes for providing recreational areas and beautification.

If the above land use potentials are implemented, the dependence of Bahrain on foreign food markets can be reduced, and environmental quality can be improved.

2.8.7.3. Soil amelioration and improvement:

Soil amelioration of the physical and chemical characteristics of sandy soils is tried by the use of loam (Saudi sand). The addition of different kinds of organic fertilizers with loam has shown good results.

2.8.7.4. More elaborate drainage network:

As the drainage problem is considered the most important factor hindering agricultural production in Bahrain, there are plans to install more drainage network in areas where treated effluent will be used. Consequently the Directorate of Agriculture in Bahrain has started excavation of many main drains needed to lower the water table at farms and control the process of soil salination.

Conclusions:

The factors limiting agricultural development in Bahrain are thus related to irrigation water shortage, salinity of ground water, lack of drainage and mechanisation, and lack of organic material in soils. A plan to remedy these aims at a target of 25 % self-reliance by the end of 1991.

CHAPTER-3

TOXIC METAL PROBLEMS - GENERAL REVIEW

3.0 Toxic metals :

3.1 Toxic metal problems - General review :

Eighty four of the 106 known elements are classified as metals. Thus, the opportunities for metallic pollution are numerous. However, not all the metals represent environmental hazards. Some are non-toxic, while others, even though toxic are very scarce, or their compounds are insoluble. The terms heavy metal and trace metal originated from systems used to sub classify the many known metals. Heavy metals are those with densities greater than 5.0 g/cm3 (that is five times the density of water), but in the study of metal pollution, it is common to refer to all metallic contaminants as heavy metals, regardless of their densities. The term trace metal is used to indicate the natural abundance of the metal. Metals present at concentrations of 0.1% (1000 ppm) of the total (or less) by weight are termed as trace metals (Forstner and Wittmann, 1983). The term " trace element" does not imply unimportance because some are essential for life processes - they are better described as micronutrients (Davies, 1988).

Trace metals are generally more important than abundant metals in terms of environmental pollution because of their effects on living organisms. At least 11 heavy metals are known to be essential for living organisms. These are iron, copper, zinc, cobalt, manganese, chromium, molybdenum, selenium, nickel vanadium and tin (Schroeder et. al, 1967; Thompson, et al 1978, O'Dell, 1984, Stoker et al, 1976). Essential metals always function in combination with organic molecules and most commonly with proteins, either tightly bound in metalloproteins or more loosely bound in metal - protein complexes (Valbe et al 1972., Russell, 1973).

Although at suitable concentrations some heavy metals are essential for enzymatic activity, they also form an important group of enzyme inhibitors when natural conditions are exceeded. Consequently, most heavy metals, whether essential or not, are potentially toxic to living organisms.

The environmental persistence of metals presents special difficulties. Unlike organic pollutants, metals cannot be degraded biologically or chemically in nature. One of the most serious results of their persistence is the biological amplification of metal concentrations in food chains.

As a result of this process, the concentrations of metals in the upper members of the chain can reach values many times higher than those found in air or water. This result can cause some plants or animals to become health hazards when used as food. Humans have a tendency to accumulate metals due to the long half-life period of some metals in the human body, 1460 days for lead and 200 days for cadmium.

3.2 Effects of heavy metal contamination on man and organisms.

Occupational hazards involving heavy metals are well known, but it is evident that much lower concentrations of metals in the diet may be implicated in human diseases (Armstrong, 1967; Warren et. al., 1962.; EPA 1983).

Large concentrations of molybdenum in soils, leading to enhanced concentrations in plants can induce copper deficiency in animals (Davies, et. al., 1985) because molydenum and sulphur interfere with copper uptake in the gastrointestinal tract of ruminant animals. The mechanism of this interference is unclear. An extensive period of research began on lead when it was reported that gasoline exhaust fumes were responsible for higher concentration of lead in vegetation close to highways (Warren, et. al. 1960 and Madany, et.al.1990).

Concern over health effects of cadmium call for guidelines in the upper limits of this element in human food. A maximum of 1 mg kg^{-1} dry matter is reasonable provided that the Zn/Cd ratio is > 200, since zinc is thought to affect cadmium (Keefer, et al 1986). Apart from narrowing the Zn/Cd ratios in several instances, edible portions of vegetables grown on sandy soil amended with four sewage sludges showed no appreciable accumulation of heavy metals. Nevertheless some of the non consumable parts of vegetables accumulated metals to levels which would not be acceptable in the edible portions (Keefer, et al 1986).

In the late 1950 s in Japan a painful bone disease (itai - itai) of elderly women was linked with cadmium pollution of water and (Padi) rice caused by zinc ore processing higher up the valley, (Morishita, 1978). At the same time, at Minamata in Japan discharge of mercury from a plastics factory led to the accumulation of methylmercury in fish, a local staple food, and to an epidemic of nerve and brain damage in local people. Incidents like these stimulated public concern in many countries over the consequences of environmental pollution by heavy metals such as cadmium, mercury or lead, which are widely used in industry.

3.3. Natural sources of trace metals .

Trace metals occur naturally, so all soils contain some lead or cadmium. Just nine of the 83 naturally occuring elements that are detectable in rocks, soils and organisms ie. silicon, oxygen, titanium, aluminium, iron, magnesium, calcium, sodium and potassium account for over 99.5 per cent of the total mass of mineral matter (Davies, 1988). The remaining trace elements are present in living and natural materials at concentrations below 0.1 percent. Under special geochemical circumstances trace metals may be locally concentrated to form ores - the minerals galena (PbS) or cinnabar (HgS) are familiar examples. Usually trace metals occur in minerals in silicate rocks through isomorphous substitution for the major constituents at the time of formation. Sometimes the natural metal content of the soils can be so high that only certain tolerant species may survive. Pure limestones, sandstones, and sandy deposits, are likely to be associated with micronutrient deficiencies. However, composition of other less pure sediments depends on the weathering, leaching, erosion and sedimentary processes which operated during formation. Soils deposited over black marine shales are rich in pyrite (FeS_2) and tend to contain high concentrations of cadmium and molydenum. These heavy metals are soft (Lewis) acids - so they preferentially bind to the soft bases S^{2-} (sulphide) and -SH (e.g. Cystine and Cysteine in proteins). This explains their enrichment in sulphide phases in rocks and underlies their toxicity to mammals (Davies, 1988).

Cadmium occurs in soil predominantly as a divalent cation, adsorbed by clay, but it also forms complexes with hydroxyl and chloride ions (Russell, 1973). Cobalt is capable of chelation and is often associated with manganese. Chromium is very sparingly soluble and its mobility in plants is very small. Copper adversely affects plant growth if its concentration in solution exceeds 0.1 mg dm^{-3} . In the soil copper existing as divalent cation is strongly adsorbed by organic matter and clay minerals. It also occurs as complexes and as chelates. Mercury exists in anionic and cationic forms both forming strong bonds with organic matter and clay minereals. Molybdenum exists in anionic form only and its valency is pH dependent. Nickel is highly phytotoxic and occurs as a divalent cation. Lead is readily adsorbed by organic matter and so is preferentially held at the surface of soil. Bunzl et al (1976) found nearly equal distribution coefficients for cadmium and zinc adsorption by peat in the pH range 3.5 to 4.5.

Very small amounts of trace elements occur as free ionic or chelated forms in true or colloidal solution (West, 1981). The behaviour of trace element metals in food plants has been reviewed by Tinker (1981) who described their chemistry as dominated by their ability to form organic complexes. Mitchell (1964) has reviewed the distribution of trace elements in soil profiles in Scotland and suggested that Cu, Pb and Zn tend to be enriched in surface, organic rich horizons.

3.4 Sewage sludge application & trace metals in the soil.

Application of sludge as a soil amendment offers a potentially attractive solution to the twin environmental problems of sludge disposal and land restoration. Toxic metals added to the soil in sewage sludge has caused considerable concern in recent years and the potential of sewage sludge as a soil amendment depends to a large extent on its concentrations of toxic and harmful substances. Typical metal concentrations found in sewage sludges of different countries are shown in Table-3.1.

A few metals in sludge , being essential to life may enrich a soil at a land treatment site. Zinc is the metal most likely to provide an environmental benefit, because large areas of land have too little zinc for the growth of some crops and because average dietary zinc intake by humans is marginal (US EPA, 1983). Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn are considered to be the most common metallic pollutants (Bolt & Bruggenwert, 1976).

Le Riche (1968) first reported metal contamination of soil resulting from the long term use of sewage sludge. Sludge applied to Woburn, light textured soil in England in a period of 20 years showed that metals were retained in the soil even after the termination of sludge application. Copper, tin and zinc were found in sludges in quantities some forty times that found in normal soil and zinc was present in highly soluble form.

Several workers have found evidence of movement of heavy metals into soil profiles as a result of sewage sludge application. Kirkham (1975) reported substantial increases in Cd, Cu, Ni, Zn and Pb in the 30-61 cm depth of soil in a plot that had received sewage sludge at an average rate of 28 Mg ha^{-1} yr^{-1} for a period of 35 years. Dowdy et al (1984) reported evidence that Cd and Zn had moved from the zone of incorporation to a depth of 0.8-1.0 metre in plots that had received treatments over a 14 year period.

Zinc is also phytotoxic and occurs as a divalent cation, but it is in strong competition for exchange sites with Ca and Mg, some Zn compounds have anionic forms and others can be chelated.

Gibson and Farmer (1986) after a multistep extraction of toxic metals from soil showed that the total concentrations of metals were in the order lead, zinc, copper and cadmium, but in terms of their order of availability, cadmium was released more easily than zinc, which in turn was more easily released than copper. Finally in order of environmental significance, zinc was of greatest concern, followed by cadmium, copper and lead.

Each soil constituent has its own metal sorbing properties resulting in dissimilar adsorption sequences (Elliott et al 1986). Because of these differences, guidelines dictating maximum permissible metal loadings to soils would be more meaningful if a wider range of metal and soil specific factors were included in their development. Current guidelines and regulations for disposal of municipal sludges specify maximum allowable metal loadings based on soil textural class (Baker et al 1985) or Cation Exchange Capacity (CEC), (United States Environmental Protection Agency, 1979). These parameters are unlikely to be the only guides for predicting heavy metal mobility in soils. Other important retention factors such as surface area, iron oxides, and organic matter have not been incorporated to any significant degree into criteria for land disposal of metal containing wastes.

It is thus difficult to be precise about the significance of a stated concentration upon the behaviour of metallic contaminants in soil and suggested threshold values for safety must be interpreted with care. Determination of appropriate safe limits of metallic elements in soil have been largely derived from experience in disposing sewage sludge to land (Chumbley, 1971).

In gardens and allotments where children play and families are likely to consume significant quantities of produce from the soil the figures of 10 mg/kg for arsenic, 3 mg/kg for cadmium, 25 mg/kg for chromium 6+ or 600 mg/kg chromium total, 500 mg/kg for lead, 1 mg/kg for mercury, 3 mg/kg for selenium are thought to be critical (ICRCL, 1987) For parks, playing fields and public open space where human contact with the soil is less , the comparable figures are, 40 mg/kg for arsenic, 15 mg/kg for cadmium, 25 mg/kg for chromium 6+ or 1000 mg/kg for chromium total, 2000 mg/kg for lead, 20 mg/kg for mercury and 6 mg/kg for selenium (ICRCL, 1987). Phytotoxic problems are expected in sandy soils with 130 mg/kg copper, 70 mg/kg nickel and 300 mg/kg zinc, but in loamy and clayey soils problems would emerge only at much larger concentrations (ICRCL, 1987).

Table-3.1

Metal concentrations found in sewage sludges (dry wt)

Country	Cd	Zn	Cu	Pb	Ni
U.K.	2 - 1500	600 - 20000	200 - 8000	50 - 3600	20 - 5300
U.S.A.	2 - 1100	72 - 16400	84 - 10400	800 - 26000	12 - 2800
Sweden.	2 - 171	700 - 14700	52 - 3300	52 - 2900	15 - 2120
Canada.	2 - 147	40 - 19000	160 - 3000	85 - 4000	7 - 1500
Australia	2 - 285	240 - 5500	250 - 2500	55 - 2000	20 - 320
Bahrain	4.83	733.30	505.00	171·33	-
Acceptable conc. in sludges CEC (1986).	20 - 40	2500 - 4000	1000 - 1750	750 - 1200	300 - 400

Source : Tiller, 1986 and CEC, 1986.

Heavy metal additions from fertilizers and manures are also relevant in agriculture. Swaine (1962), Williams and David (1976), Stenstrom and Vahter (1975) have found that the use of commercial fertilizers may give rise to cadmium concentration in soils as well as in agricultural crops.

3.5 Trace metal availability in crops.

Trace metals present in vegetable crops may be derived both from airborne metal contamination or uptake from the soil (Harrison and Johnston, 1987). Concentrations of metals in plants (ug/g dry weight) have been shown to be extremely variable, even for a given plant species (Lepp, 1981). Chamberlain (1983) reported that the absence of a significant correlation between lead in soil and in plants in data from Jones et.al (1973) and Warren (1973) could have been a result of foliar contamination. The relationship between lead in aerosols, plants and soils in quantitatively well established in areas such as busy roads (Ter Haar et al, 1969, Little and Wiffen,1978) and near other pollution sources. All the elements, including lead were closely related to both distance from road and to traffic densities (Cannon and Bowles, 1962; Daines. et.al 1970; Motto et.al, 1970; Rabinnowitz, 1972, Ward et al 1976; Madany et.al.,1990).

Contamination by metal aerosols from sources other than motor vehicles has also been reported. Elevation of the concentration of metals by several orders of magnitude was observed in plant tops and soil when grown or sampled from areas around smelters and power plants (Roberts, 1972; Buchauer, 1973; and Little and Martin, 1974). The above studies showed that accumulation of metals by plants and soil was a result of deposited metal particles. Ratchiffe and Beeby (1980) reported high lead concentrations in plants sampled from sites downwind of a busy road during winter but low concentrations in plants during the summer and shortly after rainfall. Measurements from rural areas have suggested that not all the emitted metal particles are deposited near the source of emission (Cantwell et.al, 1972; Little and Wiffen, 1978), but a considerable amount travel over long distances, contaminating areas away from pollution sources. Even though the majority of agricultural areas are situated well away from pollution sources, appreciable concentrations of trace metals are found in the local atmosphere (Cawse and Peirson,1972; Cawse, 1982; Harrison et al 1982)

In early studies, foliar contamination of vegetable plants was assumed by some researchers to be a surface deposit which could be washed off before consumption (Motto et al, 1970). Nevertheless, others suggested that it could contribute to the inner plant tissues (Ernest and Cramer, 1980). The latter was found to be true in the case of lead (Harrison and Johnston, 1987). This contamination by airborne lead in rural sites was first highlighted by Tjell et al (1979), who established that 99.0% of lead in grass grown in an agricultural area in Denmark resulted from atmospheric lead. Chamberlain (1983) reviewed the published literature on lead in plants and found that if the concentration of lead in the atmosphere is in the range of 0.1 - 0.2 ug/m3, then at least 2 ug/g or 33 - 70% of lead in grass in rural sites could be attributed to atmospheric lead. Regarding other metals, Hovmand et al (1983) found that the total cadmium content in several plant species grown in an agricultural area in Denmark was 0.08 - 0.26 ug/g dry weight, and an average of 0.03

ug/g or 12 - 60 % of that resulted from airborne cadmium, which was approximately 1.3 ng/ m3 in concentration.

3.6. Crop uptake of Cd and Zn.

Determination of the total amount of a toxic metal in a contaminated soil does not generally provide a reliable guide to the effect that metal may have on plants growing in that soil. Available or labile forms measured in suitable extractant solutions are commonly used to predict the uptake by plants in the same manner as with the major plant nutrients. Metal analysis of plants grown in the contaminated soil, is a direct measurement of the amount of toxic metal likely to be ingested if the plant is eaten, but it must be appreciated that differences occur within plants, between roots, shoots and tissues of different ages.

While little information is available on the mechanism by which micronutrients are absorbed by plants from the soil solution, there is an ample evidence that roots are able to absorb micronutrients from extremely dilute solution (10^{-9} M) (Davies, B.E. 1980).

Crop uptake varies according to the particular crop concerned. There are wide differences between species and also between cultivars of the same species. Amongst crop plants, highest concentrations of cadmium may be expected to occur in the leaves of vegetables such as lettuce, spinach and other beets, and cabbages. These plants tend to be rich in oxalate which has an affinity for metals and might explain the uptake ability of the beet family (Chaney, 1982).

Cadmium and zinc reduce crop yield and cadmium may reach potentially toxic levels in plant material (Sikora et al 1986). Cadmium and zinc when added at 75.1 and 759.0 mg/kg respectively, in a sandy soil, showed that zinc content of tops and roots increased quadratically with increased zinc addition to soil. Cadmium addition to soil had no significant or consistant effect on zinc content of roots or tops (Sikora et al, 1986). The absence of any significant effect from cadmium treatments was probably due to the greater concentration of soluble zinc compared to cadmium and the subsequent inability of cadmium to effectively compete for plant uptake and translocation.

Plant uptake of cadmium and zinc can be increased by applying sewage sludge to agricultural soils

(Mullins,and Sommers,1986). Since Cd and Zn reach plant roots by the process of root interception, massflow and diffusion, one or more of these trace element transport processes are altered by applying sludges to soils.

Jarvis et. al. (1976), examined the distribution of cadmium between the roots and shoots of 23 plant species after exposure to a nutrient solution containing 0.01 mg Cd/L. In all except three species (lettuce, kale and watercross) more than 50% of the cadmium taken up was retained in the roots. In the case of rye-grass approximately 88% of cadmium was retained in the roots. It appears in general that cadmium concentrations in plant parts decrease in the order of fibrous roots > leaves > seeds > storage organs. Field sampled plants usually contain 0.02 - 1.0 mg Cd Kg-1 dry matter with a mean concentration of about 0.3 mg Kg-1 (Davis, 1984). Leafy crops will tend to contain cadmium concentrations towards the higher end of the range.

Concern about enhanced concentrations of cadmium in crop plants relates mainly to implications for the human food chain. This is because cadmium is principally a zootoxic element. Concentrations of cadmium in crops which are potentially harmful to man are therefore smaller than concentrations that damage the crop itself. For the principal phytotoxic elements (Cu, Ni, and Zn), the opposite is true and the crops will display symptoms of toxicity before they contain concentrations which could damage human and animal health. In the case of cadmium, crop growth is unlikely to be affected until tissue concentrations exceed 10 mg Cd kg-1 dry matter, but concentrations of much less than this could lead to potentially harmful human dietary intake of the element.

3.7 Metal uptake from soil and toxicity limits.

Researches on metal uptake from soils show that some metals, such as cadmium, chromium, nickel and zinc, are commonly highly available to plants and readily incorporated in substantial quantities in to plant tissues, whilst others, such as lead, are found to be less available (Bingham et.al, 1975; Miller et.al, 1979; Miles and Paricer, 1979; Keefer et al, 1986). The rate of uptake and accumulation of metals by plants is related to their concentration in the soil. Soil characteristics and metal concentration differences, aerial contamination, growth period and other environmental variables have been used as factors to explain the variability of metal concentrations between plants.

Factors which influence metal availability include,

(a). pH.
(b). Cation exchange capacity, (CEC).
(c). Organic matter content and
(d). Presence of other metals. (Mitchell et al, 1978)

When the organic matter content and pH of the soil are both high, the solubility of most metals (except molybdenum) is very low, and therefore they are likely to be less harmful. The availability of the metals appears to be inversely proportional to the cation exchange capacity of the soil and to its organic content. The nature and content of clay and sesquioxides in the soil is a further control (The Institute of Water Pollution Control, U.K. 1978).

Soil organic matter has been of particular interest in studies of heavy metal retention by soils, because of its significant impact on CEC and more important, the tendency of transition metal cations to form stable complexes with organic ligands. In a study with 24 British soils, Mc Laren and Crawford (1973) concluded that the majority of the available copper exists in an organically bound form. Although lack of correlation between total organic matter and retention of Pb, Cu, Zn and Ni may be found, organic matter content can be useful in explaining differences in retention between surface and sub-surface samples of the same soil (Elliot et al 1986).

Decreased pH resulting in increased nitrification (Fuller et . al, 1987) may increase the solubility of trace metals and facilitate transport from soil to surface waters (Heinrichs and Mayer, 1980). Decreases in soil solution pH may decrease the mobility of organic solutes (Hayes and Swift, 1978) and associated trace metals within the soil.

Metals available for plant uptake usually represent only a small fraction of the total metal content of soils. Plant roots draw their micronutrients from the soil solution, which is in equilibrium with metals absorbed on to charged mineral or organic colloidal surfaces (Davies, 1988). In any particular case, the proportion of the metal which is actually available to the crop is determined by using chemical extractants, but the analysis of plant tissues is a more direct and simple way of measuring metal availability, and takes into account differences between soil properties and between crops. The results, used in conjunction with a soil analysis, are likely to give a much more meaningful assessment than a soil analysis alone.

From the viewpoint of phytotoxicity the most important heavy metals are copper, nickel and zinc, whereas cadmium, mercury and lead have been studied closely for bioaccumulation. The limits appropriate to these metals are discussed below.

3.7 a). Copper:

Copper in soil is readily taken up by the roots of plants but is translocated to the leaves and shoots to only a limited extent, an excessive amount of copper restricting root development and producing multiple branched swollen roots similar to those resulting from an attack of cereal cyst eelworm (Webber, 1976).

Copper in sewage sludge originates mainly from industrial waste water. Concentration of Copper in Bahrain sludge was 505.00 mg/kg (present study). Phytotoxicity has been reported in acid soils (Williams, 1975) containing 100 mg Cu/kg dry solids. Since copper in sludge is largely combined in organic complexes its toxicity is reduced. (Webber, 1976).

A systematic study of copper toxicity in relation to soil pH, with equal available copper contents showed that this toxicity increased with decreasing pH. For maize at pH 6, toxicity is noticeable above a value of 50 ppm, growth decreases by one-half for 100 ppm, and is strongly inhibited at 200 ppm (Aubert, H and Pinta, M, 1977). This copper toxicity in relation to pH is due to the fact that the activity of copper ions increases when the pH decreases, on the other hand, the copper retention capacity of organic matter decreases with pH. The toxicity is corrected by increasing the organic matter content (manuring) and by increasing pH (liming). Hodgson et al (1966) reported that more than 98 % of the Cu in soil solution was in an organic complexed form. Later researches confirmed the importance of carboxyl and phenolic groups in binding copper to organic matter (Davies, 1980).

Soil and plant tissue tests are used to determine which nutrients are outside normal limits in soil solution and plant tissue. The micronutrient concentration in mature leaf tissue that may be classified as deficient, sufficient, excessive or toxic are given in Table-3.2. These are generalized ranges but there are considerable differences between species and even between varieties of the same species.

Table-3.2

Approximate micronutrient concentrations in mature leaf tissue that may be classed as deficient, sufficient, excessive or toxic (Jones, 1972)

Concentration in leaves in ppm

Micronutrient	Deficient	Sufficient	Excess or toxic
Cu	< 4	5 - 20	> 20
Fe	< 50	50 - 250	not known
Mn	< 20	20 - 500	> 500
Zn	< 20	25 - 150	> 400

Copper - deficient soils are most often peaty soils or sandy podzolic soils located in the regions of heavy rainfall. The deficiency limit is equal to 1ppm in the sandy and clayey soils of Norway and India. In Japan this limit is 0.5 ppm. In France and Scotland, a number of authors prefers to use total copper content as a measure for diagnosing deficiencies. For a number of crops the threshold showed ranges from 7-8 ppm in distinctly acid soils of the podzolic type. Values of 0.5-3.0 ppm of available copper is considered deficient for a number of crops (Table- 3.2)

It has been suggested (Department of Environment, U.K, 1977) that over a 30 year period the amount of copper in soil with a pH close to 6.5 should not exceed 280 kg/ha, equivalent to 125 mg Cu/kg dry soil (depending on the bulk density of the soil).

3.7 b). Zinc:

Zinc in sewage sludge is derived from both industrial waste water and domestic sources. The concentration of zinc in Bahrain sludge was 733.30 mg/kg (present study).

Zinc in the soil is readily taken up by the roots of plants and translocated to the leaves and shoots, toxicity due to its presence in excess causing severe yellowing or chlorosis of the leaves, and producing stunted plants (Webber, 1972).

When copper and nickel are also present in the soil, the long-term maximum concentration should be based on the zinc equivalent (ZnE), but where the concentration of these metals are only small, it has been proposed that in the long term the amount of zinc in soil with a pH close to 6.5 should not exceed 560 kg/ha (equivalent to 250 mg Zn/kg dry soil)

The proportion of plant-available zinc vary, naturally according to the reagent used and on the soil type. On the whole plant available zinc concentrations are relatively high, representing on an average 5-20 % of total zinc. In certain exceptional cases, the percentage can attain 25 % and even 90 % of total zinc (Aubert et al.; 1977).

Although copper and zinc are phytotoxic, both are also essential elements and grazing animals may benefit from moderate increases in the herbage contents of Cu & Zn following applications of sludge. The upper critical levels for Cu and Zn, beyond which plant yield would decline is 20 mg Cu/kg dry matter, and 200 mg Zn/kg dry matter (Davies, 1988). In comparison to these upper critical levels, background concentrations of the element in crop leaf tissue are approximately 8 mg Cu/kg dry matter and 40 mg Zn/kg.

Toxicity is rare, in the case of zinc. In India, the toxicity limit of available zinc, soluble in 0.1 HCL is estimated at 100 ppm with the deficiency limit at 1 ppm (Aubert et al.; 1977).

Pot trials, normally, overestimate any toxic effects of metals that would occur in field conditions (Kuntze et al.; 1983) and the high value obtained for metals will depend on soil pH and the crop used. Johnston et al (1985) found that a single application of sludge equivalent to 200 kg Cu/ha, and 1600 Kg Zn/ha produced little or no toxic effects to barley, ryegrass and lettuce in field conditions. Williams (1983) has derived " safe maximum" concentrations of Cu, and Zn in soils of 110 mg/kg and 275 mg/kg, respectively.

Zinc equivalent:

In soil, nickel, copper and zinc are potentially the most harmful metals to plant life and it has been suggested that nickel is roughly eight times more toxic and copper roughly twice as toxic as zinc. (Chumbley, 1971). When determining the maximum permissible rate of application of sewage sludge and the maximum permissible concentration in the soil if crops are not to be adversely affected, the concept of "The Zinc equivalent" has therefore been introduced.

Zn equivalent = $Ni \times 8 + 2 \times Cu + Zn$ in mg/Kg dry solids .

In fact it is possible that in general the toxicity of these elements may not be additive, the equation may under-estimate the amounts of metals in sludge which may be safely applied to neutral or calcareous soils.

The recommended limit of addition of zinc equivalent is 560 Kg/ha (Lester, 1982). A maximum safe limit of 250 mg available zinc equivalent per kg dry soil has also been suggested (Department of Environment, 1977)

3.7 c). Lead:

Lead is tightly held in the soil organic matter and usually there is no direct relationship between lead concentrations in soil and in edible parts of crops, unless the crop has been directly contaminated with soil. Some organic matter is rich in chelating components, and binds lead, either promoting its movement out of the soil or fixing the metal, depending on the solubility properties of the complex (WHO, 1977). Under certain soil conditions (including low pH, CEC, organic matter or phosphate concentrations), lead can be taken up by higher plant roots (Koeppe, 1981). It appears, however that this lead is then immobilised in the roots and generally has no toxic effect on the plant (Koeppe, 1981). Lead applied to the land in sewage sludge is thought to be taken up by crops to a very limited extent, and most experiments have failed to demonstrate any significant increase in the lead content of food crops (Webber, 1981). Garcia et al (1981) investigated the lead content of commercially grown crops taken from fields with long histories of sludge spreading, but they could find no correlation between soil and plant levels of lead.

Experiments performed in U.S.A with nutritive solution showed that lead toxicity in plants varies with the pH, the more alkaline the pH, the more toxic is the lead at low concentrations (Auburt and Pinta, 1977).

It has been suggested that (Department of Environment, 1977) until further data become available that in the long term the amount of lead in soil with a pH close to 6.5 should not exceed 1000 kg/ha, equivalent to 450 mg Pb/kg dry solids.

3.7 d). Cadmium :

Cadmium is used in industry in a variety of ways including electoplating, electrical contacts, plastics stabilizers, ceramics, pigments, alloys, fluxes, glasses, lubricant-additives, nickel-cadmium batteries, solar cells and catalysts, and is associated with zinc in nature, both being readily taken up by plants and translocated to the leaves and shoots. Bioavailability of Cd added to agricultural soils is a matter of concern because of the persistance of Cd in the environment, its uptake by plants and its accumulative effects on animals and man (Mahler, et al 1982). Cd availability to crops is affected by soil pH, CEC, organic matter content, soil texture, crop species and interrelationships of Cd with other elements in soil. Since cadmium accumulates in animals and human beings there is concern beyond that of toxicity to the plant.

The concentration of cadmium in Bahrain sewage sludge was 4.83 mg kg^{-1}.(present study). It was found in U.K (Lindsay, 1979) that cadmium concentrations in vegetation grown on horticultural land varied from 0.01 to 1.81 mg/Kg fresh weight, for lettuce to 0.83 mg/Kg for spinach and 0.67 mg/Kg for potatoes, but the concentrations in all other crops was less than 0.25 mg/Kg. Crops vary greatly in their sensitivity to cadmium but since it is so readily absorbed by plant tissues, a slight excess in the soil might constitute a health hazard. Although the toxic effect on animals is reduced as the ratio of zinc to cadmium increases, this does not apply to plants.

When sludge is used on land, rates of application must be controlled so that concentration of contaminants in soil never reach levels which could be harmful to crops or the animals which eat them. Cadmium is a principal factor limiting the use of sludge on land. It has been suggested that (Department of Environment, 1977), until further data becomes available that in the long term the amount of cadmium in soil with a pH close to 6.5 should not exceed 5 Kg/ha, equivalent to 3.5 mg Cd/Kg dry solids (Davis,1989)

As to the forms of cadmium which may occur in sludge it appears that sludges contain a wide variety of sites at which metals may be held by mechanisms which include ion exchange, sorption, chelation and precipitation. Working with digested sludge, Stover et al, (1976) used a sequential extraction technique to rank the forms of cadmium as follows: Carbonate > sulphide > organically bound > adsorbed > exchangeable. They reported that about 80 % of the cadmium in sludge is present in forms which would require conversion to water-soluble, exchangeable or adsorbed forms in soil before uptake by plants could proceed. Of particular interest is microbial oxidation in soil which could result in the solubilization of carbonate, the conversion of sulphide to sulphate and breakdown of sludge organic matter. Any of these processes could dramatically alter the availability of sludge borne cadmium for uptake by plants.

Soils normally contain 0.1 - 1.0 mg Cd/Kg background concentration (Davis, 1984). Tjell et al (1980) have assessed cadmium inputs to agricultural land in Denmark on a national and a local basis. Nationally, sludge contributed only 5 % of the cadmium, the remainder resulted from aerial deposition (70%) and inorganic fertilizers (25%). Locally, assuming that sludge containing 7.0 mg Cd/Kg was applied at a rate of 5 tds/ha year, (Tonnes per dry solids) the contribution from sludge accounted for 90% of the total cadmium input, compared with 8 % from aerial deposition and 2 % from inorganic fertilizer. More recently the input of cadmium to background soils in Denmark has been estimated at 5.1 g/ha per year (Tjell et.al, 1979). The figure was composed of 3.0 g/ha year from fertilizers, 2.0g/ha year from atmospheric deposition and just 0.1 g/ha year from sewage sludge.

Sequential extraction studies on soils have usually found small concentrations of cadmium occuring in the exchangeable and adsorbed forms. This is of particular interest if, as seems likely, these forms represent the fraction which is most available for crop uptake. It is now widely accepted that in order for uptake in the roots to occur, soluble forms of cadmium must exist adjacent to the root membrane for some finite period (Cataldof, et. al 1978).

The soil properties which influence concentrations of cadmium in soil solution are pH value, redox potential, texture, mineral composition (content of clays and oxides of iron and manganese) and profile characteristics, Cation exchange capacity, amount and type of organic compounds in the soil and soil solution, presence of other heavy metals, soil temperature and moisture content and other factors which affect microbial activity (Harmsen, 1977).

CHAPTER-4

MATERIALS AND METHODS

4.00 Materials and methods :

4.1 Pot experiments :

Pot experiments were carried out to quantify the effects of different types of organic amendments at different treatment rates and irrigated with water of different salinity on the physical and chemical properties of two soils and on the chemistry of the drainage waters.

4.1.1 Soils, organic amendments and water.

The soils of Bahrain and their current agricultural usage and potential have been reviewed in chapter- 2. Of the four major groups of soils identified (Solonchaks, Fluvisols, Yermosols and Regosols; (Doornkamp et al. 1980), the Solonchaks have been most extensively used for cultivation (BSMRS, 1976) and are considered to have the greatest agricultural potential (Bridges, E.M and C.P Burnham, 1980). These soils are extensive on the northern plain (figure-2.4, chapter-2) and have been considerably modified by cultivation.

Two soils from the cultivated Solonchak group, representing the two major agricultural soil types in Bahrain, were used for pot experiments to assess the effects of various organic amendments. One was a sandy loam, soil type-1 from Hamala agricultural area and the other was a sandy soil , type-11 from Budaiya agricultural farm area. Locations of the sampling areas are shown in Figure- 2.4, together with the distribution of major soil groups. Both sampling sites were on experimental farms selected to represent the major agricultural soils.

At Hamala the soil was bare without any vegetation, from a parent material of sandy rocks. The surface was nearly level with stones 1-10 cm in size. The Hamala experimental farm area is used for experimental growth of fodder crops using sewage sludge as an amendment in an area of 14.5 ha. This area has been under intensive cultivation for the last seven years. The sample collected was from uncultivated land as uncontaminated soil was necessary for the pot experiment.

At Budaiya, the soil was bare, not cultivated at the time of sampling. Vegetable crops including tomatoes and cabbage had been grown on this field earlier. The surface was level and sandy and the land was poorly drained.

At each site a soil pit was dug and samples were obtained from 0-5 cm, 5-25 cm and 25-50 cm depths. Brief soil profile descriptions, particle size distribution and organic matter content for the two soils are given in Tables-5.1 & 5.2. Samples from all three depths at each site were thoroughly mixed to provide composite samples of Hamala and Budaiya soils for the pot experiments.

Three different organic amendments are principally used for agricultural soils in Bahrain. Farm manures such as cow and chicken manure are traditional materials used extensively over many years. As supplies of these materials have been insufficient to meet demand in recent years, more use has been made of sewage sludge materials to grow fodder crops. Fresh cow manure was collected from the Government farm at Muharraq, air dried at 35°C, ground to pass a 2 mm sieve and stored in polythene bags for use in the experiments. Fresh dried chicken manure was collected from the Hamala Poultry Company, and sieved prior to use. Anaerobically digested sewage sludge was obtained from the Tubli Sewage Treatment Works. This sewage is derived mainly from domestic sources. The digested sludge is dried on sand beds, collected and stockpiled. Samples were collected from the stockpile, sieved and stored for use in the experiments.

Irrigation waters in Bahrain are primarily derived from ground water sources and salinity varies from 2000 to 6000 mg/l. Two water sources were selected for the pot experiments. The water supply at the Hamala Agricultural farm was selected as representing low salinity water. Mean total dissolved solids in this water is approximately 2100 mg/l. Water from the Sitra water blending station with mean total dissolved solids of approximately 5000 mg/l was selected as representing high salinity irrigation water. Samples from both sources were collected in white polyethylene containers of 25 l capacity and used for the pot experiments. All the containers were checked for trace metal contamination by storage for six months filled with water. No increase in trace metal content were detected when the stored water was analysed at the end of this period.

Trace metal concentrations in stored water

	Cd	Pb	Cu	Zn (ug/l)
Before storage	0.4	3.1	4.2	10.1
After six months	0.3	3.0	4.8	11.0

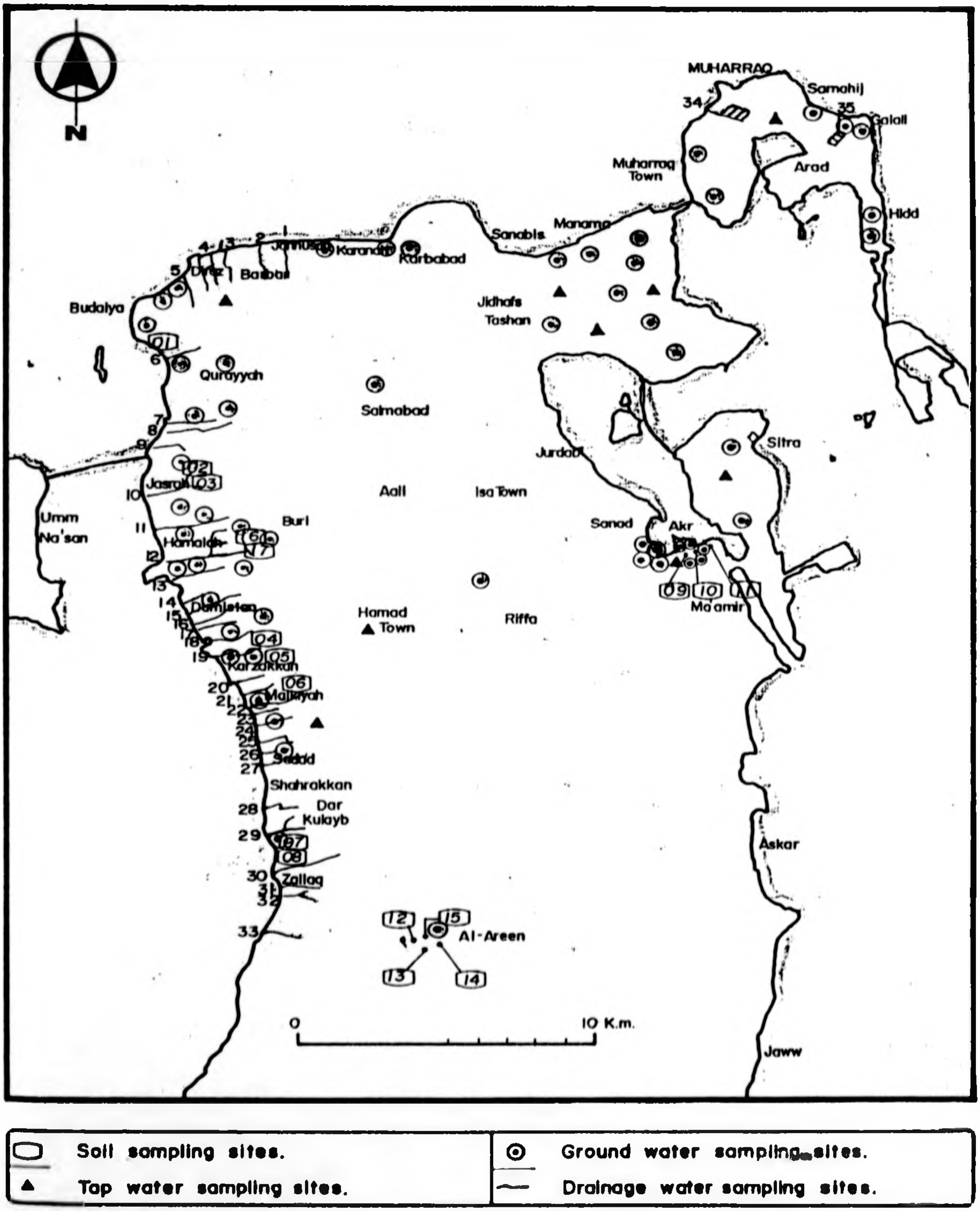


FIGURE: -4.1

SAMPLING SITES FOR SOIL, GROUND WATER, TAP WATER AND DRAINAGE WATER.

4.1.1.1 : Experimental details :

Polyethylene cylindrical pots of 9.4 cm diameter and 16 cm length (surface area 69.36 cm2), were used for the experiment. A small hole in the base of the pot, cemented to the polyethylene drainage tube was used to drain the pots. The leachate was collected in a polyethylene bottle below the pot (Figure-4.2).

Soils collected for pot experiments were air dried at 35°C, sieved to pass < 2 mm then 1500 g of the soil was weighed to pack the pots. Soils were packed uniformly into the pots using a wooden thistle to compress it in order to make the packing approximately equal to the field bulk density of 1.5 kg m^{-3} .

Additions of organic amendments were calculated from typical agricultural applications of manure, which in Bahrain are approximately 40 Mg ha^{-1} dry matter per crop. A 40 Mg ha^{-1} addition is equivalent to 28 g dry matter added to the pot surface of 69.36 cm2. the manure was added to the upper surface of the soil in the pot and thoroughly mixed in to the uppermost 5 cm of soil to simulate the effect of light surface cultivation which is typical of agricultural practice in Bahrain. The effects of different rates of application of the cow manure were also examined by adding the equivalent of 20

Mg ha^{-1} and 80 Mg ha^{-1} of this material. All organic amendment treatments were duplicated, and control pots with no organic amendment was used.

Pots were irrigated regularly with water from one of the two sources. 100 ml of water was added twice per week for the duration of the six month incubation period. A total of 5200 l water was thus added to each pot, equivalent to addition of 750 mm water to the soil surface during the six months. Irrigation water use in Bahrain are not always constant as it depends on the salinity of the soil. Water is applied to the soil for irrigation as well as for leaching purposes.

The experimental design was thus as follows.

Control)
20 Mg ha^{-1} cow manure)
40 Mg ha^{-1} cow manure)
80 Mg ha^{-1} cow manure) × 2 replicates, × 2 soils, 2 waters
40 Mg ha^{-1} chicken manure)
40 Mg ha^{-1} sewage sludge)

Full details of the pot experiment are shown diagramatically in Figure-4.3.

The pot experiments were carried out in a protected area from January to June 1988, (on low salinity water) and from January to June 1989, (on high salinity water). During the experiment mean daily air temperature ranged from 18.5 to 35 C, and daily maximum air-temperature ranged from 25.3 to 42 C. Relative humidity ranged from 58 to 80 %. These climatic conditions were typical of crop growing conditions in Bahrain.

Leachates drained in polythene containers of 1.2 l capacity kept beneath each pot during the experiment (Figure 4.2). After the experimental period the leachates were collected, transported to the lab and analysed immediately for nutrients and other physical and chemical properties.

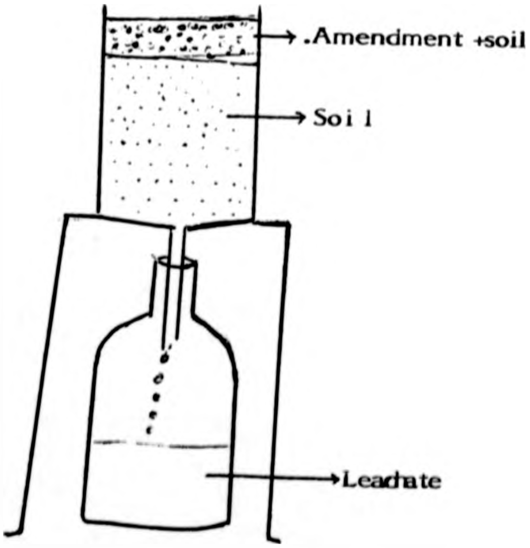
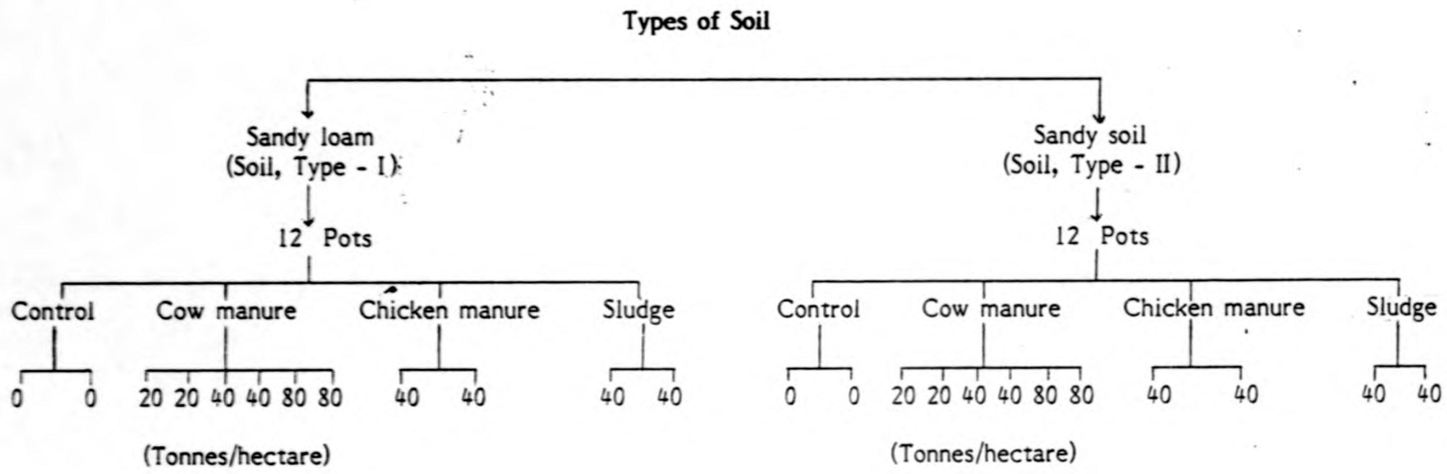


Fig.4.2. Pot experiment setup & Leachate collection system

FIGURE - 4.3

LAYOUT OF POTS IN POT EXPERIMENTS



For Water Type - I (Low salinity water) - 24 Pots
For Water Type - 2 (High salinity water) - 24 Pots
Total - 48 Pots

0 - 5 cm
48 Pots 96 samples
5 - 16 cm

4.1.2 : Physical and chemical analyses of the soil :

All soil analysis was carried out on air dried < 2 mm soil.

4.1.2.1 : Physical analyses :

4.1.2.1 a). Particle size analysis :

The particle size distribution of a soil expresses the proportions by weight of the different particle size classes.

The aim of the particle size analysis was to determine the percentage of soil material contained in each of the three particle size ranges. There are a number of different schemes for subdividing the particle size distribution. As previous work in Bahrain has used the U.S.Department of Agriculture scheme (BSMRS, 1976) this scheme is used here.

The term soil texture refers to the relative proportions of sand, silt and clay in the sample. The sand includes particles larger than 0.05 mm in diameter. This fraction provides physical support to plants and plays an important part in soil drainage and aeration. The fine soil material is made up of silt and clay particles smaller than 0.05 mm in diameter. It determines in large measure, the water holding capacity of the soil, soil aeration, supply of available nutrients and the cation exchange capacity (Wilde et al, 1978).

For judging the textural class of soil, a textural diagram is used as shown below in Figure-4.4.

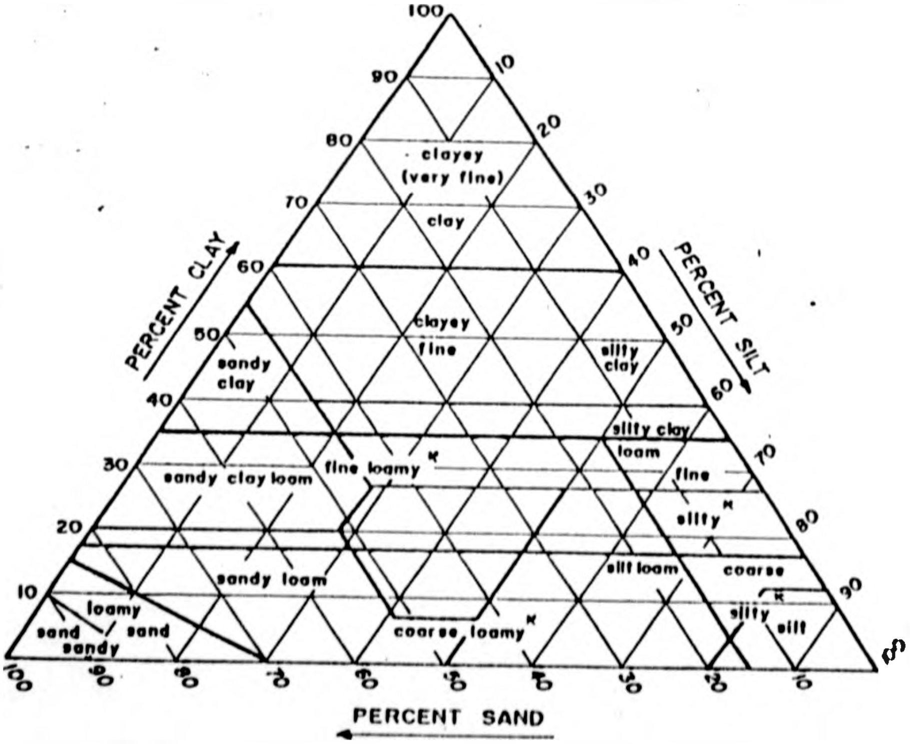


Fig.4.4 Texture chart showing percentages of particle sizes of soil separates and texture classes.

In surveys for the broader purposes of land utilization soils are classified into twelve or more textural classes, but a crop producer may be satisfied with less detailed subdivision, as exemplified by the following outline:

Soil class	Silt and clay per cent
Sand	< 7.00
Loamy sand	7.00 - 15.00
Sandy loam	16.00 - 25.00
Light loam	26.00 - 40.00
Heavy loam	> 40.00

Coarse textured or sandy soils usually have a low supply of moisture and nutrients and are well adapted only to trees of modest requirements. The importance of soil texture for plant growth is indirectly proportional to the content of silt and clay particles. But heavy clayey soils usually cause drainage problems. Textural analysis therefore, attain their greatest significance in soils with a fine fraction of less than 20 or 25 per cent. A content of fine separates exceeding 45 per cent seldom deserves consideration since the growth of plants on heavy soils is influenced by the structural make up of the soil profile and not by the content of dispersed colloids.

The usual methods of fractionation and particle size analysis require that particles are dispersed in an aqueous solution, i.e, that they are detached from one another and suspended in the liquid. However, soils which contain considerable amounts of readily soluble salts, (gypsum) or organic matter may not disperse adequately unless these components are removed first.

Mixtures of sodium metaphosphate ($NaPO_3$) and Na_2CO_3 have proved particularly effective, and have made it possible to disperse calcareous soils without the prior removal of alkaline earth carbonates (Tyner, 1940; Kilmer and Alexander, 1949). Removal of gypsum can be achieved by treating the soil with the above reagents, followed by filtration and washing with enough water to remove gypsum. The effectiveness of these dispersing agents depends upon the adsorption of sodium in exchange for other cations, and the resultant development of strong electrical repulsion forces between the soil particles (Day, 1965).

To about 150 g of the soil sample was added 10 ml of Calgon (10%) as a wetting agent, and the sample was transferred to an 250 ml glass bottle by means of a funnel. The volume was made to 250 ml and the bottle stoppered and shaken overnight on a shaker. The well dispersed sample was analysed by the pipette method. (Day, 1965).

4.1.2.1 b). Aggregate stability :

One of the important aspects of soil structure is the stability of the compound particles or aggregates towards dispersion under conditions of stress such as cultivation or raindrop impact (Grieve, 1979).

The physical structure of a soil reflects the nature of its component primary grains and the extent to which they have aggregated into larger particles. Soil physical structure determines pore-size distribution, which in turn affects water flow and erosion potential, microbial and faunal behaviour and organic matter dynamics (Strickland et al 1988).

Soil particles aggregate as a result of physical binding by roots and hyphae, glueing by bacterially produced polysaccharides and physico-chemical interactions between silicate clay surfaces and functional groups of partially decomposed organic matter. Aggregation may affect nutrient turnover by controlling microbial predation and by protecting organic matter from microbial degradation.

Aggregate stability is most commonly measured by a wet sieving test. In this test a sample of aggregates is wet and sieved under water. The proportion of the sample which retains on the sieve is used as the index of stability.

Although the test is subjective, it gives a useful first sorting of soils according to the observed coherence of their aggregates in water. In the context of irrigation it will be desirable to make the observations both in distilled water (equivalent to rain water) and in the relevant irrigation water or its synthetic equivalent, because the electrolyte content of the water influences the degree of dispersion (Loveday, 1972)

Soils were sieved gently to obtain > 2mm aggregates. 50 g of these samples were sieved under water on a 2 mm sieve for 2 minutes at 30 cycles per minute. The remaining aggregates on the sieve were dried at 35 C and weighed. This was reported as % of the original sample weight (Grieve, 1979).

4.1.2.1 c). Water holding capacity :

The amount of water (W) in a soil at any given time will depend upon the amount added by irrigation or rainfall (R) minus the amount lost by evaporation (E), plant traspiration (T) and drainage (D). This relationship can be expressed in a mathematical way using the sign a to indicate proportional to thus :

$$W \propto R - (E+T+D)$$

The most important soil characteristic is the water retention capacity. Water retention and availability of soil water depends upon pore space. The water may be held in a state available to plants in larger pores, but in smaller pores it may be held so tightly that plants cannot extract it (Courtney, 1984). The behaviour of water in a soil can be understood in terms of the forces acting upon it. Water is attracted to the solid soil particles by surface tension. Opposing this are the agents which exert forces away from the solid particles. These are the forces of gravity, the action of plant roots and evaporation.

Water Holding Capacity is the amount of water a given quantity of soil can retain when placed in a cylindrical vessel with a perforated bottom, saturated with water, and then allowed to drain freely (Wilde, et al 1978). A filter paper was placed at the bottom of a brass cylinder with a perforated base and weighed. The cylinder was then half filled with the soil, tapping it gently between additions. Then it was allowed to stand in a water container, in which water was about half the height of the soil. Soil was thus allowed to be saturated with water overnight. Afterwards the cylinder was allowed to drain overnight, wiped dry outside and weighed. The cylinder was then placed in an oven at 100 C, dried and weighed (Wilde, et al, 1978).

$$\% \text{ water holding capacity} = \frac{b-c-d}{c-a} \times 100$$

a = Wt of cylinder + dry filter paper

b = Wt of cylinder + saturated soil + saturated filter paper

c = Wt of cylinder + dry filter paper + dry soil.

d = Amount of water absorbed by the filter paper.

4.1.2.1 d). Average bulk density :

Bulk density is the weight of oven-dry material per unit volume. Hence, it reflects specific gravity and porosity of a physical body (Wilde, et al 1978).

Since the specific gravity of soil particles varies in most instances within the narrow limits of 2.60 and 2.70, bulk density of soils is rather closely correlated with porosity, and in turn, with the infiltration capacity and degree of aeration. Porosity of soils (P) expressed as percent by volume is calculated from the S.G of soil material (S) and bulk density of soil (D).

$$P = \frac{S - D}{S} \times 100$$

Assuming an approximate figure of 2.6 for S.G, and 1.4 for bulk density (D), porosity may be determined as

$$P = \frac{2.60 - 1.40}{2.6} \times 100 = 46.0\ \%$$

A cylindrical tin of 3.7 cm in diameter and 6.0 cm in height was used as a core sampler. The soil sample was taken by pressing the core cylinder downward by means of a tightly fitting outer iron jacket. The core cylinder together with the surrounding soil was removed by a spade, the surplus soil was cut away with a knife. The sample was expelled from the cylinder into a tared glass petri dish. The samples were dried in an oven at 110 C and weighed on a balance. Bulk density was calculated as

$$\frac{\text{Oven dry soil mass}}{\text{Volume of cylinder}} \quad \text{kg m}^{-3}.$$

4.1.2.2 Chemical analysis :

4.1.2.2 a). pH (Soil reaction)

The pH value of an aqueous solution is the negative logarithm of the hydrogen ion activity. Soil characteristics that are known to influence pH include the composition of the exchangeable cations, the nature of the cation exchange materials, the composition and concentration of soluble salts, and the presence or absence of gypsum and alkaline- earth carbonates. pH values of saturated soil paste of about 8.5 or greater invariably indicate an exchangeable- sodium- percentage of 15 or more and the presence of alkaline- earth carbonates. The exchangeable- sodium percentage of soils having pH values <8.5 may or may not exceed 15. soils having a pH of <7.5 almost always contain no alkaline earth carbonates and those having values of < 7.0 contain significant amounts of exchangeable hydrogen (U.S. Salinity Lab Staff, 1954). pH is regarded as a useful indicator of other soil properties and of the need or otherwise for amendment with lime. Some plants tolerate a wide range of pH, whereas some are sensitive to acidity and some to alkalinity. The availability of certain nutrient elements are affected by soil pH (Loveday, 1972).

Since it is the pH value of a soil-water system that is measured, the relative proportions of the components of this system will affect the results (Hesse, 1971). Although steps can be taken to standardize the variables of water content and salt concentration, the measurement of soil pH remains somewhat arbitrary. Different analysts have adopted different soil water ratios and as mentioned above pH of the saturation paste is generally preferred, as it is closest to the field conditions. Generally, the greater the proportion of water the greater the measured pH value will tend to be. Huberty and Haas (1940) quote one soil as rising from pH 6.45 at 6.3% moisture to 8.60 when a 1:5 suspension was measured.

Even though pH of the saturation paste is preferred for soil pH measurements, the method of preparing a saturation paste is tedious and time consuming. Generally in soil chemistry a quick and accurate judgement is obtained from a 1:5 solution of soil in water.

Measurement was made on a saturation extract and 1:5 (soil : distilled water) extract during the initial stages of pot experiments. After the incubation period and for the field experiments only the 1:5 pH measurement was made as sample numbers were too large.

pH was measured on a digital pH meter (Orion 901-Ionalyzer).

4.1.2.2 b). Soluble salts & Electrical conductivity.

The term soluble salts, as applied to soils, refers to major dissolved inorganic solutes. Soil salinity is calculated from the concentrations of soluble salts. The management and need for reclamation of saline soils are evaluated from measurements of such concentrations (U.S. Salinity Lab Staff, 1954).

Soluble salts in soils can be determined or estimated from measurements made

(1) on aqueous extracts of soil samples

(2) on samples of water obtained from the soil.

The appropriate method of measuring salinity must be selected for the specific condition and purpose. When determination of a particular solute is required Soil sample extracts give relative comparisons only, since the soils are adjusted to unnaturally high water contents during extraction (Rhoades, 1982).

The salt content of the soil can be estimated roughly from an electrical conductivity measurement on a saturated soil paste or more dilute suspension of soil in water. The conductivity of the saturation extract is recommended as a general method for appraising soil salinity in relation to plant growth.

The special advantage of the saturation extract method of measuring salinity lies in the fact that the saturation percentage is nearer to the field moisture content. For this reason the conductivity of the saturation extract (ECe) can be used directly for appraising the effect of soil salinity on plant growth. But since the saturation extract method is time consuming, salinity estimates based on the conductivity of 1:5 extract are also used, particularly if the amount of soil sample is limited or more soil samples are to be investigated (U.S. Salinity Lab Staff, 1954).

Soil salinity is determined from the conductivity of saturation extract (ECe) as :

0 - 4 mS or mmhos/cm = salt free
4 - 8 mS or ,, = slightly saline
8 -15 mS or ,, = moderate
\> 15 mS or ,, = strong.
Source : (U.S. Salinity Lab Staff, 1954).

Piper (1944) found the relationship for EC and salt content of 1:5 extract to be K25 x 336 = % total soluble salts. U.S. Salinity Lab Staff (1954) suggested another relationship between the electrical conductivities of saturation extracts and 1:5 extracts in non- gypsiferous soils as ECe = 6.4 x EC of 1:5

Soluble salts were determined in saturation extracts as well as in 1 : 5 extracts by chemical analyses. Saturation paste was prepared by adding distilled water to the soil sample which was then allowed to stand for 24 hours. A vacuum pump was used to draw off the saturated extract.

The electrical conductivity of the saturation extract ECe and of 1:5 soil water extract was measured by an Orion 101 conductivity meter. The reading was expressed in mmhos/cm. at 25°C which is same as dS m^{-1}. or mS cm^{-1} .

Individual ions in the extracts were determined by flame photometry (Na and K), complexometric titration (Ca and Mg), acidimetric titration for CO_3 and HCO_3, argentometric titration for Cl and a gravimetric method for SO (Standard Methods, 1987).

4.1.2.2 c). Organic carbon :

The carbon in soils is the sum of both organic and inorganic carbon. Most organic carbon is present in the soil organic matter fraction, whereas inorganic carbon is largely found in carbonate minerals. Soil organic matter is estimated routine by from measurement of its organic carbon content. In soil organic matter C is 48-58% by weight. Organic matter content of soil can be estimated by multiplying organic carbon value by a factor of 1.724 (Hesse, 1971)

Organic matter contributes to the physical condition of a soil by holding moisture and by affecting structure and stability. (Hesse, 1971). It is a direct source of plant nutrient elements, the release of which depends upon microbial activity and by affecting the CEC, organic matter is directly involved in the availability of nutrient elements. The ratio of C to N is calculated by simple division of the percentage of C content by the per cent of the total nitrogen content.

In Bahrain as the soils are formed from calcareous parent materials, under arid conditions, inorganic carbon concentration often exceeds the amount of organic carbon present. In calcareous soils, determination of OC is simply made by analysis for total Carbon using either wet or dry combustion techniques. Where wet oxidation with potassium dichromate is followed, by titration with ferrous sulphate or ferrous ammonium sulphate, errors of overestimation can be introduced if other oxidizable compounds are present such as sulphides. For calcareous soils organic carbon is calculated to be the difference between total carbon and carbonate carbon determined by any of the methods. Alternatively CO3- C can be removed by treating with H2SO4 containing FeSO4 or HgSO4 prior to wet combustion or with H2SO3 prior to dry combustion of the organic carbon. This has some difficulties as some of the organic carbon may be oxidised during this process (Nelson and Sommers, 1982).

The organic carbon is usually determined by the modified Walkley-Black procedure (Hesse, 1971). Here organic carbon is oxidised by an excess of hot chromic acid. The remaining chromic acid not used in oxidation of the organic carbon is determined by titration with ferrous ammonium sulphate (Chapman and Pratt, 1978). Chloride , ferrous iron and higher oxides of manganese can undergo oxidation reduction reactions in chromic acid mixtures leading to over estimation. Chloride forms chromyl chloride as follows:

$6\ H_2SO_4 + K_2Cr_2O_7 + 4\ KCl = 2\ CrO_2Cl_2 + 6\ KHSO_4 + 3H_2O.$

Red CrO_2Cl_2 decomposes at 190° C, releasing free chlorine. Chloride can be eliminated by washing the soil free of chloride before analysis or precipitating chloride as AgCl by addition of Ag2SO4 to the digestion acid.

Walkley & Black method value x 1.3 gives organic carbon of 73-119% of wet combustion methods (Hesse, 1971).

% Organic matter = 0.35 + 1.8 x % Organic carbon.

The soil sample was dried in an oven at 105° C for 24 hours. The dried sample was ground in an agate mortar and then passed through a 0.2 mm sieve. A weighed amount of the powdered sample was placed in a 500 ml conical flask. Chloride interference was eliminated by adding 5 ml of conc. Sulphuric acid containing AgCl which also allowed the inorganic carbonates to escape as CO_2. Using a pipette 10 ml of the I N Potassium dichromate solution was added and mixed carefully by swirling. Then 20 ml of concentrated sulphuric acid was added and mixed gently for one minute. The flask was placed in a fume cupboard for 30 minutes. Afterwards 200 ml of distilled water, 10 ml of concentrated phosphoric acid and 2 ml ferroin indicator were added and the solution titrated with 0.4 N ferrous ammonium sulphate to a bright green end point. A reagent blank was also carried out.

% Organic Carbon = (Blank - Titre)x N ferrous Ammonium Sulphate x 0.003 x 100 /Wt.

4.1.2.2 d). Extractable Phosphorus : (Available phosphorus)

The availability of soil phosphorus to plants varies greatly depending on reaction, mineralogical composition, type of colloids present, and content of organic matter of the soil. In many instances phosphorus occurs in the soil in the form of sparingly soluble compounds such as iron and aluminium phosphate, tricalcium phosphate, and organic phosphorus . These compounds are only slowly or partially available to plants. As a rule, analyses showing a plentiful supply of available phosphorus need not be questioned. On the other hand tests showing a critical deficiency of phosphorus should be regarded with caution (Wilde, 1978).

The amount of plant available P is determined by analysing the amount of P removed from soil by a particular extractant (EPA, 1983). Acidic solutions are unsuitable as extractants for calcareous soils (Hesse, 1971) which are more reliably extracted with alkaline solutions. Olsen et. al (1954), used 0.5 M sodium bicarbonate solution at pH 8.5, an extractant which controls the removal of calcium phosphate.

Phosphorus was extracted from soil with a sodium bicarbonate solution of pH 8.5 (0.5 M) at 1:20 soil extractant ratio. The concentration of the blue complex produced by the reduction with ascorbic acid of the phosphomolybdate formed when acid ammonium molybdate reacts with phosphate was measured spectrophotometrically at 880 nm. A Bauch & Lomb Spectronic 20 UVD spectrophotometer was used (HMSO.1986)

4.1.2.2 e). Cation exchange capacity (CEC)

The ability of clays and humus to retain cations for plant use is called the Cation Exchange Capacity (CEC). CEC is measured in meq 100 g^{-1} soil. A milli-equivalent is a measure of the ratio in which the element combines with or displaces hydrogen ion (Courtney et al, 1984) and is calculated by :

$$\frac{\text{molecular weight}}{\text{valency} \times 1000}\ g \qquad \text{eg. 1 milliequivalent of calcium} = \frac{40.08}{2 \times 1000} = 0.02004\ g$$

The CEC is a measure of its negative charge or the amount of positive charged cation it can hold against leaching. Soils with a low CEC have little cation holding ability. They are also likely to have poor natural fertility, due to their low content of humus and clay. Soils with the same texture can vary greatly in exchange capacity because of differences in the amount of organic matter and type of clay they contain (Leonard 1976).

The conventional method for determining CEC is by saturating the soil complex with an index cation, washing out the excess and determining the amount of cation retained. It has been found that in general, barium, strontium, calcium and magnesium used as index cations result in higher values of cation exchange capacity than when ammonium or sodium are used and that pH also affects the results. Hesse, (1971); and Mehlich, (1942) reported that the cation exchange capacity of a soil is constant between pH 8 and pH 9 and consequently recommended a barium chloride-triethanolamine buffer solution at pH 8.2. Bascomb (1974), utilized the phenomenon of compulsive exchange which occurs between a barium soil and magnesium sulphate solution and during which barium ions are removed by precipitation as sulphate. An EDTA, titration is used to measure the amount of magnesium exchanged from a standard solution by a barium soil and the cation exchange capacity of the soil calculated. This method is used in the case of calcareous soils. It has a further advantage of speed, constant pH conditions, avoidance of excessive washing and complete replacement of saturating cation in one operation.

As the soils in Bahrain were calcareous, the method using barium as index ion was used. A weighed amount of the soil was treated with buffered barium chloride solution several times, centrifuged and the liquid was discarded. Then the sample was shaken with distilled water and discarded the washing. Standard magnesium sulphate was added and shaken for 2 hours. An aliquot of the centrifuged extract was titrated with standard EDTA, using Eriochrome Black T as indicator. CEC was then calculated.

4.1.2.2 f). Total Nitrogen (H M S O. 1986)

The compounds of nitrogen are of interest because of the importance of nitrogen in the life processes of all plants and animals. The chemistry of nitrogen is so complex because of the several forms that nitrogen can assume. Ammonia, organic, nitrate and nitrite are the most important forms of nitrogen involved in considering total nitrogen. The term Kjeldahl nitrogen refers to organic plus ammonia nitrogen. Organic nitrogen compounds occur in the environment as animal and vegetable proteins and as decomposition products of proteins, such as amino acids and polypeptides.

Organic nitrogen added to the soil is converted to ammonia which is then converted by nitrification to nitrate. Protein decomposes by biological action to amino acids and then to ammonia which is converted by nitrification to nitrites and nitrates. Synthesis of plant and animal protein, on the other hand, proceeds with uptake of nitrates and nitrites (Baush & Lomb, 1974).

Nitrogen in the soil was converted to ammonium-nitrogen by digestion with sulphuric acid and sodium sulphate with a Copper-selenium catalyst. The ammonia liberated with sodium hydroxide was removed by steam distillation and determined titrimetically (Standard Methods, 1987).

4.1.2.2.g). Exchangeable ± soluble Cations & anions (Hesse,1971)

Exchangeable cations are those that can be exchanged by a cation of an added salt solution. In many cases, the definition of an exchangeable cation is entirely straight forward, that is, any added cation will exchange with the soil cation. The exchangeable cations Ca, Mg, K and Na are often called the exchangeable bases, and these depend to a large extent on the chemical and mineralogical makeup of the soil (Thomas, 1982).

As far as extraction and determination of the individual exchangeable cations are concerned, ammonium acetate (1N) is to be preferred over all other extractants, mainly for analytical convenience, although it has the further advantage of ammonium ions usually being present naturally in soil in small amount. The ammonium acetate leachate is easily worked up for subsequent measurement of cations by digestion with nitric acid and hydrochloric acids to destroy organic matter. However, in the case of soils containing free $CaCO_3$ and gypsum ($CaSO_4.2H_2O$) this method is not recommended even though no other method is satisfactory either (Thomas, 1982).

5.0 g of soil was leached with I M Ammonium Acetate and collected 100 ml leachate in a volumetric flask. The ammonium acetate extract was examined for exchangeable cations namely Calcium, Magnesium, Sodium and Potassium. Calcium and Magnesium were analysed by EDTA titration, whereas Sodium and Potassium by flame photometry using Pye-Unicam SP-9-800 Atomic Absorption spectrophotometer.

The following methods were used to analyse both exchangeable and soluble ions (1:5)

Calcium: Calcium ion was sequestered upon the addition of disodium dihydrogen ethylenediamine tetraacetic acid (EDTA). The titration end point was detected by means of hydroxy naphthol blue indicator, which combines with calcium only (EPA 1983). The results are expressed as milligrams per litre (mg/l) and coverted to meq kg^{-1} soil.

Magnesium: Calcium and magnesium ions in the sample were sequestered upon the addition of disodium ethylenediamine tetraacetate(EDTA). The end point of the reaction was detected by means of Eriochrome Black T indicator, which has a red colour in the presence of calcium and magnesium and a blue colour when the cations are sequestered. Calcium value was subtracted from the above value to get magnesium concentration. The results are expressed as milligrams per litre (mg/l) and converted to meq kg^{-1}.

Sodium: Sodium was determined using flame emission mode of the Atomic Absorption Spectophotometer (Pye-Unicam SP-9 800). Results are expressed as milligrams per litre (mg/l) and converted to meq kg^{-1}.

Potassium: Potassium was determined using flame emission mode of the Atomic Absorption Spectrophotometer (Pye-Unicam, SP-9-800). Results are expressed as milligrams per litre (mg/l) and converted to meq kg^{-1}.

Sulphate : Sulphate was precipitated as barium sulphate in a hydrochloric acid medium by the addition of barium chloride. After a period of digestion, the precipitate was filtered, washed with hot water until free of chloride, ignited and weighed as barium sulphate.

Results are expressed as milligrams per litre (mg/l) and converted to meq kg^{-1}.

Chloride: An aliquot of the sample was titrated with standard silver nitrate solution in the presence of potassium chromate as indicator. Results are expressed as milligrams per litre (mg/l) and converted to meq kg^{-1}.

Carbonate and Bicarbonate :

Bicarbonate is a normal constituent of saline and sodic soil extracts, whereas CO3 is often present in sodic soil extracts. Both CO3 and HCO3 have a tendency to precipitate the divalent cations Ca and Mg, resulting in an increase in the ratio of Na to (Ca + Mg) in the soil solution. This favours the adsorption of Na by the exchange complex of the soil and the development of undesirable sodic soil conditions. If CO_3 is present in a soil water extract in titratable amounts, the pH of the extract must be > 8.5.

The usual method of determination in soil extracts is by titration with dilute acid, first to the HCO_3 stage or CO_3 end point (pH 8.5), then using the same aliquot to the carbonate stage or bicarbonate end point (pH 4.5) (Vogel, 1962).

$$CO_3 + H - HCO_3 \text{ (first stage)}$$
$$HCO_3 + H - H_2CO_3 - CO_2 + H_2O. \text{(second stage)}$$

5 ml of 1 : 5 soil water extract was pipetted into a beaker. The solution was titrated using the standard 0.02 N H_2SO_4 first to pH 8.5, for CO_3 and then continued to pH 4.5 for HCO_3, recording the CO_3 titre and the total titre.

4.1.2.2. h): Extractable trace metals :

Sewage sludge or other organic amendments contain higher concentrations of various metals than most agricultural soils and when sludge is applied to the land, the metals tend to accumulate in the cultivated layer. It is essential that metal concentrations in sludge treated soils are not allowed to reach levels which could deleteriously affect soil fertility or animal and human food chains. For this reason limit values for maximum permissible metal concentrations in sludge treated soils are established. These limits usually apply to the total content (often strong acid extractable concentration) of metal in the soil. For regulatory purposes this approach is both convenient and cautious since only a small proportion of the metal content of metal is likely to be environmentally active in terms of its availability for crop uptake or for leaching to groundwater. Nevertheless, the total content of metals present in soil is in most cases of minor importance for calculating the extent of crop uptake and consequent phytotoxicity and entry of metals into the food chain. Also, the different forms of binding of the metals and how these are influenced by soil chemistry, plant type and climatic and environmental conditions are of major importance in the assessment of potential pollution (Leschber et al.; 1981).

Since adsorption of pollutants onto airbone and waterborne particles is a primary factor in determining the transport, deposition, reactivity and potential toxicity of these metals, analytical methods should be related to the chemistry of the particle surface and / or to the metal species highly enriched on the surface. Basically there are three methodological concepts for determining the distribution of an element within or among small particles as follows.

(1) Analysis of single particles by X- ray fluorescence using a scanning electron microscope.

(2) The surface of the particles can be studied directly by the use of electron microprobe X - ray emission spectrometry.

(3). Solvent leaching - apart from the characterization of the reactivity of specific metals - can provide information on the behaviour of metal pollutants under typical environmental conditions. For common single reagent leachate tests, e.g U.S.EPA, ASTM, IAEA, ICES and German Water Chemistry Group use either distilled water or acetic acid (Leschber et al.; 1981)

In environmentally relevant investigations possibility of release of metals into solutions are of prime importance. The uptake of trace elements by plants is the obvious criterion of their availability. But no two species of plants growing in the same soil remove identical quantities of the various trace elements, and the relative amounts taken up by different species vary from soil to soil because of such factors as composition, pH, moisture status, fertility level. and the content of the element being considered. For instance, at low soil-Cu levels, grasses contain more copper than clovers, while at high levels position is reversed. The availability of a trace element in a soil as shown by the capacity of a plant to take it up, is in fact as much a function of the plant as of the soil. It is therefore desirable to be able to make some arbitrary assessment of availability by an extraction technique.

For the determination of adsorbed cations, the choice of extractant must be guided by the degree of displacement which is required. This can be illustrated by comparing the effectiveness of ammonium acetate of pH 7 and acetic acid at pH 2.5. The amounts of trace elements extracted by ammonium acetate are generally quite small. Considerably large amounts of such elements as Co, Ni, Pb, Zn, Cu, Mn, Ti, V and Cr are extracted by acetic acid. For the most readily displaced elements the amounts removed by all these extractants are similar. For the cations of the heavy metals, factors including ionic potential hydration and size of ions produce much stronger binding. The amounts of trace elements normally extracted from surface layers of arable Scottish soils by 2.5 % acetic acid at pH 2.5 in most instances did not differ greatly from the amounts obtained by extractants like 0.05 M EDTA (Mitchell, 1964).

To release metal ions weakly bound to specific inorganic sites (e.g.,carbonates) extraction with 0.4 M Acetic acid has been recommended (Pickering , 1981). The reason is that at soil pH values lower than 6, Cd and Zn are predominantly bound unspecifically. Extractants with pH values lower than 6 are, therefore, of little use to assess the bioavilability of metals in soil (Hani and Gupta,; 1985). However a single extraction only reflects the situation at a given moment and does not provide information about the effects to be expected over a longer lapse of time.

5 gm air dry soil was shaken with 100 cc of 2.5 % acetic acid for several hours, preferably overnight and filtered. The filtrate was tranferred to a beaker, and evaporated to dryness with 10 ml H_2O_2 (30 %). The residue was dissolved in dilute hydrochloric acid and trace metals determined using Pye-Unicam SP-9-800 Atomic Absorption Spectrophotometer (Hanna, 1964).

4.1.2.2 i) : Total trace metals : (MOOPAM, 1983).

About 1 .0 g of dried soil was weighed into a teflon beaker, added 2 ml of concentrated nitric acid and evaporated to dryness at 80 C. 5 ml of a mixture of concentrated nitric acid, perchloric acid and hydrofluoric acid (3: 2: 1) was added and again evaporated to dryness. The temperature of the hot plate was raised to 150°C to remove the perchloric acid. The beaker was cooled to room temperature and the residue dissolved in 1 ml of concentrated nitric acid, transferred to a 50 ml volumetric flask and diluted to the mark with distilled water. The trace metals Cd, Cu, Zn and Pb were analysed using a Pye- Unicam SP-9 Atomic Absorption Spectrophotometer with graphite furnace for Cd and Pb and flame for zinc and copper. Some of the furnace programmes used are shown in Table- 4.1.

4.1.3 Chemical analysis of organic amendments :

Samples of air dried cow manure, chicken manure and sewage sludge were analysed for Cd, Cu, Zn and Pb by the method used for total trace metals in the soil.

Table-4.1

VIDEO FURNACE PROGRAM

1. **LEAD:**

	STAGE	TEMP C	TIME(S)	RAMP	OTHER CONDITIONS
1.	Dry	120	30	4	–
2.	Ash	600	30	3	–
3.	Atomise	2000	3	0	T.C, A.2, P.T, R.C
4.	Clean	2800	2	1	–

Sample Volume	10 ul	Lamp current 5 mA
Wave Length	217.0 nm	Uncoated Tube
Band Pass	0.5 nm	B.C. on

2. **CADMIUM:**

	STAGE	TEMP C	TIME(S)	RAMP	OTHER CONDITIONS
1.	Dry	120	30	4	–
2.	Ash	350	30	3	–
3.	Atomise	2000	3	0	T.C, A.2, P.T, R.C
4.	Clean	2800	2	1	–

Sample Volume	10 ul	Lamp current 5 mA
Wave Length	228.8 nm	Uncoated Tube
Band Pass	0.5 nm	B.C. on

6. **COPPER:**

	STAGE	TEMP C	TIME(S)	RAMP	OTHER CONDITIONS
1.	Dry	125	30	4	–
2.	Ash	900	30	3	–
3.	Atomise	2700	10	0	T.C, A.2, P.T, R.C
4.	Clean	2800	3	1	–

Sample Volume	10 ul	Lamp current 4 mA
Wave Length	324.8 nm	Uncoated Tube
Band Pass	0.5 nm	B.C. on

11. **ZINC:**

	STAGE	TEMP C	TIME(S)	RAMP	OTHER CONDITIONS
1.	Dry	125	30	4	–
2.	Ash	400	30	3	–
3.	Atomise	2500	3	0	T.C, A.2, P.T, R.C
4.	Clean	2700	3	1	–

Sample Volume	10 ul	Lamp current 8 mA
Wave Length	213.9 nm	Uncoated Tube
Band Pass	0.5 nm	B.C. on.

4.1.4 Physical and chemical analysis of water and leachate in pot experiments :

Irrigation waters and leachates from the pot experiments were analysed by Standard methods (1987).

4.1.4.1 Physical analysis:

4.1.4.1.a). Total Dissolved Solids (TDS).

TDS refers to material that is left in the container after evaporation of a sample at 180 C. TDS and salinity are almost same. Salinity is the total content of solids expressed as g/kg when bicarbonates and carbonates are converted to oxides and chlorides are substituted for bromides and iodides. By definition, salinity is always slightly less than the weight of the salts actually dissolved. The results are expressed as mg/l (Standard Methods, 1987).

4.1.4.1 b). Electrical Conductivity at 25 C.

Conductance is the ability of a material to carry current. A simple and convenient way to determine the total ionic content of a solution is to measure its ability to conduct electricity. The conductivity is defined as the reciprocal of the resistance and the unit of conductivity is the siemens or mho and its multiples. Specific conductivity is linked to measured conductivity by the d/a ratio (ie, distance between the electrodes and electrode area), which is termed as cell constant. Conductivity depends on the total concentration of the minerals dissolved in the sample (TDS) and the temperature. Concuctance increases with temperature.

Conductivity of the water was measured using a conductivity meter (Orion Model-101) and reported as mmhos/cm (dS m^{-1})

4.1.4.2 : Chemical Analysis:

Chemical parameters such as calcium, magnesium, sodium, potassium, bicarbonate, sulphate, and chloride were analysed using the instrumental methods specified for the chemical analysis of soils , but results are expressed as mg l^{-1} .

4.1.4.2 a). pH : pH is an expression of the intensity of the alkaline or acid condition of a water. pH was measured using pH mode of the Orion 901 Ionalyzer.

4.1.4.2 b). Ammonia-nitrogen:

The filtered sample was treated in an alkaline citrate medium with sodium hypochlorite and phenol in the presence of sodium nitroprusside which acts as a catalyst. Citrate added helps to prevent precipitation of magnesium hydroxide. The reaction is for total ammonia nitrogen. This includes NH_4 ions and the unionised NH_3. The absorbance (blue colour) was measured at 640 nm using Bauch and Lomb Specronic 21-UVD Spectrophotometer. Concentrations were calculated using a calibration factor derived from calibration curves.

The results are reported as micrograms of ammonia nitrogen per litre (ug NH3-N/l). (Strickland and Parsons, 1972).

4.1.4.2 c). Nitrite-nitrogen:

Nitrite-nitrogen was determined by diazotizing with sulphanilamide and coupling with N (1-naphthyl) ethylenediamine to form a highly coloured azo-dye whose absorbance was measured at 543 nm. Concentrations were calculated using calibration factors derived from calibration curves. Results are expressed as micrograms of nitrite nitrogen per litre (ug NO2-N/l) (Strickland and Parsons 1972).

4.1.4.2 d). Nitrate:

Nitrate was reduced to nitrite by passing through a column containing cadmium filings coated with metallic copper. The nitrite produced was measured by the method given above.

Results are expressed as milligrams of nitrate nitrogen per litre (mg NO3-N/l).

4.1.4.2 e).Phosphate-phosphorus:(PO4-P)

The water sample was allowed to react with a composite reagent containing ammonium molybdate and potassium antimonyl tartrate to form a heteropoly acid-phosphomolybdic acid which was reduced to the intensely coloured molybdenum blue by ascorbic acid. The absorbance was measured at 885 nm. Concentrations were calculated from calibration factors derived from calibration curves. The results are reported as micrograms of phosphate-phosphorus per litre (ug PO4-P/l).

4.1.4.2 f) Total Kjeldahl Nitrogen (TKN).

Total nitrogen (Organic nitrogen and ammonia) were converted to ammonium sulphate by digestion with sulphuric acid and potassium sulphate with a copper-selenium catalyst. The ammonia liberated with sodium hydroxide was removed by steam distillation and absorbed by passing the distillate into a boric acid solution in the receiver. The ammonia was then titrated with standard sulphuric acid solution (Standard Methods, 1987).

4.1.4.2 g). Trace metals (Cd, Cu, Zn and Pb).

100 ml sample was digested with 1 ml concentrated nitric acid then evaporated to near dryness. Finally the remaining residue was dissolved by warming and filtered. The filtrate was transferred to a 100 ml volumetric flask, cooled, diluted to the mark with 0.1 N nitric acid (Standard Methods, 1987).

Metals were measured using graphite furnace Atomic Absorption Spectrophotometer (Pye-Unicam SP-9-800).

4.2 Field experiments :

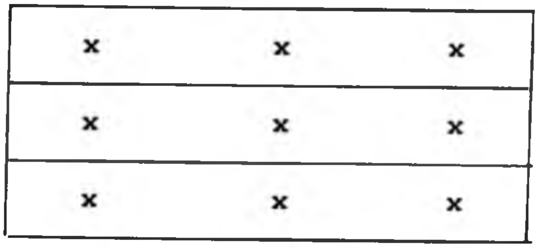
In order to check the validity of the results of the pot experiments in the field, soils, ground water, runoff water and land drainage from farms using the organic amendments studied were sampled and analysed. A total of 17 farms were selected and categorised into three groups according to their manuring history.

Sampling sites are shown in Figure-4.1, and site characteristics in Table-4.2. Farms 1-6 used mainly chicken manure, farms 7-11 used mainly cow manure, together with chemical fertilizers. Farms 12, 13, 14 and 15 had used sewage sludge for 5 years, 2 years, 1 year and 6 months respectively. Farms 16 and 17 had used sewage sludge for the last 5 years and 3 years respectively. These farms were all sited on the agricultural area in Bahrain from the north to the west coasts of the main island.

4.2.1. Soil sampling at farms selected:

In each farm, a large plot was selected (approximately 500 m^2 area) on recently cropped land. The plot was divided into segments as shown in Figure-4.5 below. Soil samples were taken from depths of 0-5, 5 -25 and 25-50 cm at each point shown. A soil auger was used for sample collection. From each site, soil samples from the same depth were mixed together and a composite sample was collected for three depths.

Figure-4.5 Field soil sampling method.



A total of 17 x 3 = 51 samples were collected. Three soil samples were also sampled similarly from virgin control fields namely at Hamala, Al-Areen and Al-Marooze. Most of the fields were cultivated for alfalfa, sudan grass, and vegetables. Normal recommended crop management practices were followed for this area, with respect to fertilizer applications tillage and irrigation strategies.

Table-4.2

FIELD EXPERIMENT
SITE CHARACTERISTICS OF FARMS STUDIED

NO	FARM NAME	CROPS GROWN	IRRIGATION TYPE	APPROX. YEARS AMENDMENT	APPLICATION PER YEAR	APPROX TOTAL AMENDMENT Mg ha^{-1}	AREA UNDER CULTIVATION ha	AMENDMENT USED
1	YATEEM GARDEN	ALFALFA TOMATO	FLOOD	30	2	40	8	CHICKEN MANURE
2	MOHAMED DAIF	TOMATO VEGETABLES	DRIP	2	2	40	4	CHICKEN MANURE
3	EBRAHIM YOUSIF SALEH	TOMATO VEGETABLES	DRIP	5	2	40	4	CHICKEN MANURE
4	EBRAHIM HASSAN AL-MAJID	TOMATO VEGETABLES	DRIP	7	2	40	6	CHICKEN MANURE
5	HASSAN MAKKI ASOOR	TOMATO VEGETABLES	DRIP	5	2	40	4	CHICKEN MANURE
6	ALI YOUSIF AL-MALAH	ALFALFA VEGETABLES	FLOOD	20	2	40	4	CHICKEN MANURE
7	AL-MAROOGE	ALFALFA	FLOOD	20	2	40	10	COW MANURE
8	AL-MAROOGE	ALFALFA	FLOOD	20	2	40	10	COW MANURE
9	AL-AKR NEAR WELL 1/134	DATES VEGETABLES	FLOOD	10	2	40	1	COW MANURE
10	AL-AKR NEAR WELL 1/137	TOMATO VEGETABLES	FLOOD	10	2	40	1	COW MANURE
11	AL-AKR NEAR WELL 1/135	TOMATO VEGETABLES	FLOOD	10	2	40	1	COW MANURE
12	AL-AREEN YEARS	ALFALFA RHODES GRASS	FLOOD	5	1	76	2.53	SEWAGE SLUDGE
13	AL-AREEN YEARS	RHODES GRASS	SPRINKLER	2	1	76	2.25	SEWAGE SLUDGE
14	AL-AREEN YEAR	RHODES GRASS	SPRINGLER	1	1	76	2.20	SEWAGE SLUDGE
15	AL-AREEN MONTHS	0	SPRINGLER	0.5	1	76	1.85	SEWAGE SLUDGE
16	HAMALA EXPERIMENTAL	RYE GRASS	SPRINGLER	5	1	76	1.40	SEWAGE SLUDGE
17	"	RHODES GRASS	SPRINGLER	3	1	40	1	SEWAGE SLUDGE

4.2.2 Ground water sampling :

The aim of the water quality check was to investigate the state and quality of ground water in Bahrain by measuring a total of 14 chemical and physical parameters.

Samples were collected in clean polyethylene bottles from 57 wells throughout Bahrain as shown in Figure-4.1.

4.2.3. Drainage water sampling :

The traditional flood irrigation method employed in Bahrain necessitated the construction of an adequate drainage system. This need was accounted for by excavating 35 main drains for an area of approximately 44 km2. The effluent from the drainage channels is discharged directly to the shallow sea coast.

Amoung the other sources of marine pollution (Madany and Zainal, 1987), drainage water might be considered as a potential source, depending on its quantity, quality and location of disposition. No data are available regarding the chemical characteristics of the drainage water in Bahrain. The aim of the present study was to investigate the following.

a. The quality of drainage water by measuring a total of 16 physical and chemical parameters.

b. To determine pollution loads from discharging drainage water into sea.

c. To correlate the fertilizer and amendment addition with the chemical properties of drainage water.

Samples were collected in polyethylene bottles from 35 drains throughout Bahrain. Figure-4.1, shows the location of the sampled drainage water.

4.2.4 Run-off water sampling :

Run-off water samples from the farms used in the field experiments were collected, immediately after the first rains, in clean polyethylene bottles, for determination of nitrogen, phosphorus potassium and trace metals.

4.2.5 Agricultural crop sampling :

Rye grass (*Lolium multiflorum*), Rhodes grass (*Chloris gayana*), Sudan grass (*Sorghum sudanensis*) and Alfalfa (*Medicago Sativa.L*) were sampled concurrently with the soils where sewage sludge had been used. The samples were air dried and ground to pass a 60 mesh screen.

4.2.6 Physical and chemical analysis of soils from 17 Farms :

Soil samples from 17 farms and three control sites , amounting to 54 samples, were air dried and passed through a 2 mm sieve. The sieved samples were analysed for the following :
Particle size, pH, Water holding capacity, Soluble salts and Electrical conductivity, Total organic carbon, Extractable phosphorus , Cation exchange capacity, Total kjeldahl nitrogen, Exchangeable cations, Carbonate and bicarbonate (1:5 solution), Extractable trace metals, and Total trace metals. Average bulk density was measured on the sample collected in the field. Aggregate stability was determined on a surface (0-5cm layer) sample, collected seperately for the purpose.

Analytical methods used were the same as those used for the soils from the pot experiments (section 4.1.2).

4.2.7 Physical and chemical analysis of ground waters and drainage water and run-off water .

The samples collected as described in section 4.2.1.5 were analysed for most of the parameters within 24 hours of collection. Standard methods were used for the determination of the chemical and physical characteristics of the water (Standard Methods, 1987).

The following parameters were analysed:
pH, salinity, conductivity, bicarbonate, calcium, magnesium, sodium, potassium, sulphate, chloride, nitrite, ammonia, nitrate, phosphate, fluoride and boron.

Analytical methods used were the same as those used for the water analysis in section 4.1.4.

4.2.8 Chemical analysis of agricultural crop :

4.2.8.1 Total trace metals in plants.

Total trace metals in agricultural products were analysed according to procedures outlined in HMSO (1986). 5 g of dried and ground sample was digested with 60 ml of digestion acid (Perchloric acid 60% and Nitric acid 70 % in the ratio 1:4 vol) on a hot plate maintained at 100 C, till oxidation was complete. The excess nitric acid was removed by evaporating the solution at 200 C to approximately 5 ml. The clear solution obtained was evaporated to dryness and the beaker cooled. To the cooled residue 5 ml of 6 M hydrochloric acid was added and boiled. The solution was further diluted with 25 ml of distilled water and filtered into a 50 ml volumetric flask and made up to the volume. Trace metals in this solution was determined by Pye-Unicam SP-9-800 Atomic absorption spectrophotometer.

CHAPTER-5

RESULTS

5.1 Pot experiments

5.1.1 Properties of soils, organic amendments and irrigation waters used in the pot experiments.

5.1.1.1 Soils.

Two soils representing the major agricultural soils of Bahrain were used in the pot experiments. Soil profile descriptions of the two soils are given in Table. 5.1. Both soils were uncultivated at the time of sampling, although the Budaiya (type-2) soil has been regularly cropped with vegetables. The principal contrasts between the soils were in their textures and stone content. The Hamala (type-1) soil was shallow (25 cm) and developed from limestone rock, with abundant rock fragments throughout the profile. The Budaiya soil was essentially stoneless throughout the profile and was developed in a parent material of sand. Textures of both soils were therefore light, sandy loam in the case of the Hamala soil and sand in the case of Budaiya soil.

Table-5.1.

Charecteristics of soils used in pot experiments

	Hamala Type-1 soil	Budaiya Type-2 soil
Location :	Figure 4.1	Figure 4.1
Vegetation :	No vegetation, bare, never cultivated .	No vegetation. fallow at the time of sampling. Vegetable crops were grown in this soil in previous season.
Parent material :	Sandy with rocks.	Sandy.
Drainage :	poor	Poor.
Surface :	Nearly level with stones 1 - 10 cm size.	level and sandy
Classification :	Sandy loam.	Sandy
FAO classification :	Raw mineral soils D3 Gravelly soils with stones.	C2b Beach sands with shells
Depth		
0 - 5cm :	Pale brown, dry sandy loam, stones 1- 10 cm diameter, no clear boundary	Yellowish brown, slightly sticky, moist sand, loose single grain.
5 - 25cm :	Yellowish brown, 50% limestone fragments.	Yellowish brown, slightly sticky, moist sand .
25 - 50cm :	Limestone rock.	Yellowish brown, slightly sticky, moist sand.

TABLE..5.2.

Analysis results of soils used in pot experiments

Properties	Hamala soil			Budaiya soil		
	0-5cm	5-25cm	25-50cm	0-5cm	5-25cm	25-50cm
1. Bulk density kg m^{-3}	1460	1480	1430	1430	1440	1440
2. Particle size. sand %	70.4	53.9	60.9	91.2	95.0	93.7
silt %	28.8	45.4	38.6	8.3	3.9	5.5
clay %	0.8	0.7	0.5	0.5	1.1	0.8
gravel %	50.0	60.0	60.0	nil	nil	nil
3. pH (1:5, soil: water)	8.08	7.67	7.20	7.80	7.66	7.60
4. Total Organic Carbon (TOC) %	0.62	0.82	0.92	0.68	0.63	0.63
5. Extractable Phosphorus (mg kg^{-1})	11.74	1.91	3.08	72.22	3.67	2.92
6. CEC meq 100 g^{-1}	2.62	1.86	0.50	1.80	2.60	0.90
7. Total Kjeldahl Nitrogen (TKN) mg kg^{-1}	910	140	70	600	140	250
8. Exchangeable cations (meq kg^{-1})						
Ca	2267.5	838.3	998.0	1596.8	447.1	439.1
Mg	144.0	88.0	112.0	144.0	16.0	16.0
Na	342.3	121.9	150.3	300.3	25.1	13.5
K	23.3	9.8	13.9	56.3	2.2	0.8
9. Soluble salts in (1:5) solution (meq kg^{-1})						
Conductivity at 25 C (S m^{-1})	0.80	0.55	0.61	0.81	0.18	0.15
Soluble salts % in (1:5) solution.	0.67	0.39	0.44	0.61	0.14	0.11
Ca (meq kg^{-1})	190	110	190	130	100	90
Mg (meq kg^{-1})	60	90	10	130	0.4	0.4
Na (meq kg^{-1})	260	101	150	220	21	9
K (meq kg^{-1})	15	7	7	15	3	0.2
SO_4 (meq kg^{-1})	240	171	150	186	55	40
Cl (meq kg^{-1})	282	128	199	300	50	50

TABLE..5.2(continued)

Properties	Hamala soil			Budaiya soil		
	0-5cm	5-25cm	25-50cm	0-5cm	5-25cm	25-50cm
10. Soluble salts in sat.extract						
Ca (meq kg -1)	35	21	18	88	32	23
Mg (meq kg -1)	49	17	18	269	8	7
Na (meq kg -1)	303	81	82	851	50	24
K (meq kg -1)	18	4	3	177	5	4
SO4 (meq kg -1)	34	21	20	114	25	21
Cl (meq kg -1)	371	100	101	1269	68	35
HCO3 (meq kg -1)	1	1	1	1	1	1
ECe S m -1	6.68	3.22	3.65	14.50	1.50	1.02
Soluble salts % in sat extract.	4.28	2.06	2.33	9.28	0.96	0.65
SP (sat percentage)	29.13	37.04	39.60	17.07	22.00	23.26
11. Acetic acid (2.5 %) extractable trace metals						
Cd (mg kg -1)	0.03	0.03	0.03	0.03	0.02	0.02
Pb (mg kg -1)	0.27	0.36	0.36	0.36	0.18	0.36
Zn (mg kg -1)	0.85	0.68	1.00	1.12	1.20	1.00
Cu (mg kg -1)	1.00	1.04	1.10	0.38	0.50	0.20
12. Total trace metals						
Cd (mg kg -1)	0.20	0.20	0.20	0.20	0.20	0.20
Pb (mg kg -1)	1.05	1.10	1.10	1.40	1.40	1.40
Zn (mg kg -1)	12.20	12.50	11.80	15.20	15.80	16.10
Cu (mg kg -1)	7.50	7.60	8.10	8.00	7.90	8.50

Properties of the two soils determined on samples from three depths are shown in Table 5.2. The principal contrast in physical properties between the two soils was in their particle size distributions. Both soils had very small clay contents (1% or less), but the sand content of the Budaiya soil was much greater (> 90 %) than that of the Hamala soil (54-70 %). The differences in field textures of the two soils was thus confirmed by the laboratory determination of particle size distribution. Bulk densities in both soils were similar and uniform throughout the profiles (1430-1480 kg m^{-3}). Organic carbon content, extractable phosphorus and Kjeldahl nitrogen were all very low. Carbon content was always less than 1 % and varied little with depth in the soil. P and N decreased with depth in both soils and the extractable phosphorus content of the surface 5 cm of the Budaiya soil was some 7 times that of the Hamala soil. Otherwise C, P and N were similar in both soils. CEC was also very small, reflecting the small clay and organic C content in both soils. The decrease in CEC with depth in both soils was unrelated to variations in organic carbon content.

Both soils were highly saline as evident from the average EC of the saturation extracts (Table- 5.2), 4.5 S m^{-1} for Hamala soil and 5.7 S m^{-1} for Budaiya soil.

The sum of the extractable cations extracted by ammonium acetate solution was clearly much greater than the measured CEC for all samples. Exchangeable cations were dominated in all cases by Ca^{2+} and to a lesser extent by Na^{+}.

Total trace metal concentration in the unamended soils were small. In the Hamala soil, Zinc and Copper were dominant with mean concentrations of 12.2 and 7.7 mg kg^{-1}, respectively. In the Budaiya soil, Zn and Cu concentrations averaged 15.7 and 8.1 respectively. Acetic acid extractable metals concentration generally ranged between 10-20 % of total metal concentrations for both the soils.

5.1.1.2 Organic amendments and irrigation waters.

Analyses of the three different organic amendments (cow manure, chicken manure and sewage sludge) used in the pot experiments are given in Table .5.3. The three materials varied significantly in most of the properties determined. Cow manure had the greatest ash content and C:N ratio. Concentrations of the three major plant nutrients, N, P and K were smaller than those in chicken manure. Sewage sludge and chicken manure had similar ash, C:N ratio and concentrations of nitrogen and phosphorus, but the potassium concentration in sewage sludge was much smaller than that in either of the two farm manures.

Trace metal concentrations were invariably greatest in the sewage sludge, despite its principally domestic origin. Cd, Pb, Cu, Cr and Hg concentrations were all at least ten times greater in sewage sludge than in farm manures. Differences between the farm manures and the sewage sludge were less pronounced in the case of Zn and Ni, and chicken manure in particular had significant concentrations of these two metals, 460 mg kg^{-1} and 71 mg kg^{-1}, respectively.

TABLE- 5.3

COMPOSITION OF ORGANIC AMENDMENTS STUDIED

Constituents	unit	cow manure	chicken manure	sewage sludge
Moisture	%	8.99	25.24	14.37
Dry matter	%	91.01	74.76	85.63
Ash	%	63.30	22.39	33.23
Volatile solids	%	27.71	52.37	52.40
pH (1:5)		8.30	8.00	7.10
Chloride (1:5)	mg/kg	1597.50	2130.00	2662.50
Total soluble salts (1:5)	%	0.70	2.00	1.30
TKN	%	0.62	3.50	4.75
P (total)	%	0.46	1.78	1.52
K (total)	%	0.69	2.66	0.42
Organic Carbon	%	20.39	43.12	37.09
C/N		33:1	12:1	8:1
Cadmium (Cd)	mg/kg	0.13	0.295	4.83
Lead (Pb)	mg/kg	5.60	5.65	171.33
Zinc (Zn)	mg/kg	71.50	460.00	733.33
Copper (Cu)	mg/kg	20.00	30.00	505.00
Chromium(Cr)	mg/kg	6.05	4.25	53.30
Mercury (Hg)	mg/kg	0.03	0.03	0.19
Nickel (Ni)	mg/kg	30.00	71.00	100.00

Chemical composition of the two water types used in the experiment, are given in Table. 5.4. The Hamala water (WT1) was a typical low salinity water and the salinity of the Sitra water (WT2) was the highest normally used for agriculture. pH of both waters was similar, and as expected total dissolved solids and electrical conductivity of the Sitra water was 2.5 times greater than that of the Hamala water. Most of the differences between the TDS of the two water sources can be explained by the larger Na and Cl concentrations in the Sitra water. Na and Cl concentrations in the Sitra water were approximately twice those of the Hamala water, while the other major anions and cations were present in both water sources at very similar concentrations. Trace metal concentrations (Cu, Zn, Pb and Cd) in both water types were also very similar and were present at very small concentrations.

TABLE-5.4

Results of water used for pot test

		Hamala Ground water		Sitra Ground water	
Conductivity S m^{-1}		0.34		0.77	
pH		7.60		7.30	
Total Dissolved solids mg L		2100.00		5050.00	
CATIONS :					
			meq L^{-1}		meq L^{-1}
Ca	mg L^{-1}	232.00	11.58	282.00	14.07
Mg	mg L^{-1}	92.00	7.57	144.70	11.90
Na	mg L^{-1}	500.00	21.74	1205.00	52.39
K	mg L^{-1}	30.00	0.77	52.60	1.35
ANIONS :					
HCO3	mg L^{-1}	234.20	3.84	158.00	2.59
SO4	mg L^{-1}	524.40	10.89	561.30	11.69
Cl	mg L^{-1}	887.50	25.03	2307.50	65.07
NO3	mg L^{-1}	12.30	0.19	12.90	0.20
TRACE METALS :					
Cu	ug L^{-1}	4.00		3.25	
Zn	ug L^{-1}	10.50		8.90	
Pb	ug L^{-1}	3.85		3.28	
Cd	ug L^{-1}	0.65		0.62	

Total metal loadings added to the soil by the different treatments are given in Table.5.5. Organic amendment metal additions were calculated as the product of total mass added during the experiment and the metal concentration. Leaching water metal additions were calculated as the product of total volume added and concentration.

From the values indicated in Table- 5.5 it is clear that the major source of added metals in the pot experiments was the organic amendments. In relative terms the copper, lead and zinc added in 5000 ml of irrigation water represented less than 10% of that added in 28 g of the farm manures. Cadmium additions in water and farm manures were, however, similar. As expected the greatest amounts of metals added were in the 28 g sewage sludge treatments. Metals added in sewage sludge as Cu, Zn, Pb and Cd were respectively 800, 450, 250 and 45 times more than that added in water.

TABLE-5.5

Metals added in pot experiments (ug)

	Added in 28 g amendment (equivalent to 40 Mg ha^{-1})			Added in 5000 ml water (5 litres water)	
	Cow	chicken	sludge	Hamala (WT1)	Sitra (WT2)
Cu	560.00	840.00	14140.00	20.00	16.25
Zn	2002.00	12880.00	20532.40	52.50	44.50
Pb	156.80	158.20	4797.24	19.25	16.40
Cd	3.64	8.26	135.24	3.10	3.25

5.1.2 Soil differences following treatment with 40 Mg ha^{-1} cow manure, chicken manure and sewage sludge.

40 Mg ha^{-1} equivalent of cow manure, chicken manure and sewage sludge were added to pots filled with each soil type. Pots were leached with the low and high salinity waters. All treatments were duplicated. At the end of the six month experiment, soil samples from 0-5 cm, and 5-16 cm depths were analysed.

Soil differences following the treatments were tested for statistical significance using two-way analysis of variance, using the SPSS-PC software package. Separate analyses were carried out for each soil type and soil depth.

Each analysis of variance compared four organic treatments (control vs cow vs chicken vs sludge) by two water treatments (low vs high salinity).

Results of the Analysis of variance are given in Table 5.6 for the 0-5 cm layer, and in table. 5.7 for 5-16 cm. The more significant differences among treatments are also shown graphically in figures 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, and 5.7. Mean values for each soil treatment are listed in the appendix (Tables. 1 to 8).

5.1.2.1 Organic carbon, nitrogen and phosphorus.

Only total nitrogen differed significantly among treatments at the 5-16 cm soil depth. For both soils organic C,N and P were significantly different at the 0-5 soil depth. Figures 5.1, 5.2 and 5.3 shows the pattern of difference among the four treatments for the two soils and waters. All three organic amendments significantly increased C,N and P contents in the soil when compared with the control.

Greatest C and N contents were found following the sludge treatment of both soils. Organic Carbon increased approximately 2 fold when the sludge treatment was compared with the control (0.7 to 1.85 %). Nitrogen increases in the 0-5cm layer were 2, 8 and 10 fold for cow manure, chicken manure and sewage sludge respectively (220 to 480, 1650, 2186 mg kg^{-1} respectively). P concentrations were variable after the treatments, but the highest concentrations were noted in the case of the chicken manure treatment (335 mg kg^{-1}, Table-1 & 2).

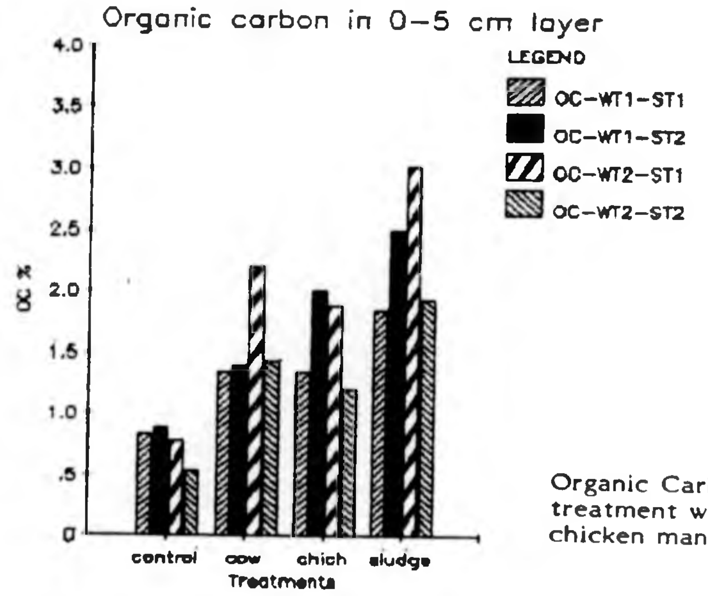


Figure - 5.1

Organic Carbon in the 0.5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & sewage sludge.

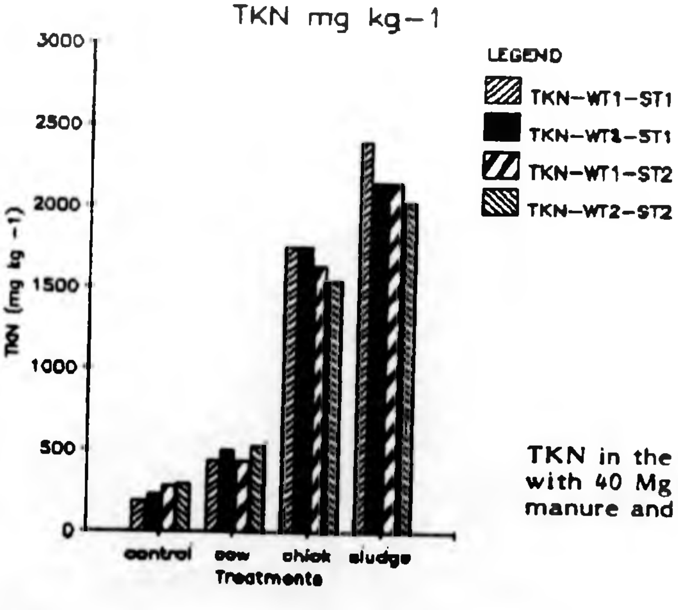


Figure - 5.2

TKN in the 0-5 cm layer, after treatment with 40 Mg ha^{-1} cow manure, chicken manure and sewage sludge.

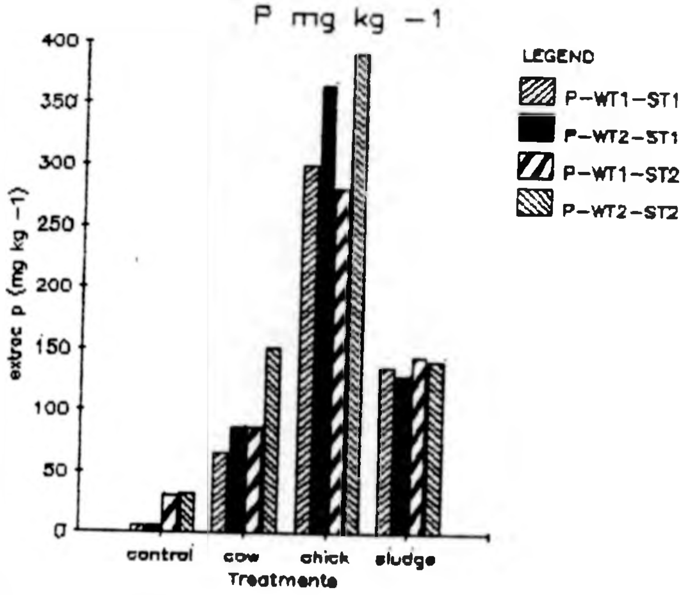


FIGURE - 5.3

Extractable - P, in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure and sludge treatments.

5.1.2.2 Aggregate stability and Water Holding Capacity.(WHC).

Aggregate stability generally increased with the addition of various amendments, using water of low salinity (1 to 8% in ST1, 1-16 % in ST2). In the case where water of high salinity was used, there was no significant improvement in aggregate stability (1 to 2%) (See Table 1&2 in the appendix). Sewage sludge at 40 Mg ha-1 gave the highest value in both the soils. When water of low salinity (WT1) was used, average aggregate stability were 6.05, 5.70 and 8.3 % for the Hamala soil and 8.5, 11.35 and 16.65 % for the Budaiya soil with 40 Mg ha-1 cow manure, chicken manure and sludge respectively. Control soils had 1% aggregate stability

Water holding capacity (WHC) had a very minor improvement after treatment with organic amendments. Average water holding capacity varied from 10.5% to 12.35% for the Hamala soil and from 11.5% to 12.4 % for the Budaiya soil after the treatments and using water of low salinity. Generally greatest improvements were noticed in the sludge treatment in all soils. Treatments with water of high salinity gave very similar results. The highest value in the Hamala soil was obtained using chicken manure and in the Budaiya soil using sewage sludge when low salinity water was used.

5.1.2.3 Cation Exchange Capacity (CEC) and exchangeable cations.

CEC significantly increased in the surface layer after different organic amendment use (Table.5.6). In the 0-5 cm layer, sewage sludge at 40 Mg ha^{-1} gave the highest value, 4.9 meq 100 g^{-1} in Hamala soil and 5.6 meq 100 g^{-1} in Budaiya soil using water of low salinity, compared to control values of 1.3 meq 100 g^{-1} and 1.4 meq 100 g^{-1} respectively. When water of low salinity was used, average CEC were 1.90, 2.55 and 4.9 meq 100 g^{-1} for the Hamala soil, 1.85, 2.0 and 5.6 meq 100 g^{-1} for the Budaiya soil, with 40 Mg ha^{-1} cow manure, chicken manure and sludge treatment respectively. Treatments with water of high salinity gave nearly the same values. Exchangeable cations were variable and comparison of the organic amendment treatments with the control did not show statistically significant differences. Exchangeable calcium concentrations were, however, significantly different between the two water types. Calcium concentrations were larger when low salinity water was used (See, appendix. Table 1 & 2). High salinity water also resulted in significant increase in exchangeable sodium concentrations in the upper layer of both soils.

5.1.2.4 Salinity and soluble salts.

Salinity, represented by the conductivity of 1:5 soil water solution were 3.74, 4.93 and 4.37 mS cm^{-1} for the Hamala soil and 4.1, 4.55 and 4.31 mS cm^{-1} for the Budaiya soil respectively, when treated with 40 Mg ha^{-1} cow manure, chicken manure and sludge and using water of low salinity, showing that the chicken manure treatment has a slightly greater tendency to increase the salinity of soil. High salinity water increased the soluble salts content of the surface layer but there was no noticeable change in the salts in the lower 5-16 cm soil depth (Tables-3 & 4, in Appendix). Sodium and chloride concentration in the 0-5 cm layer were higher when water of high salinity was used. Concentrations of Ca, Mg, Na, K, SO4 and Cl in the 1:5 solution did not vary significantly from the control values after the various treatments.

5.1.2.5 Extractable and total metals

Organic amendments had a significant effect on both acetic acid extractable metal and total metal contents in the 0-5 cm layer. Figures 5.4, 5.5, 5.6 and 5.7 shows the pattern of the differences in extractable metal concentrations and Figures, 5.8, 5.9, 5.10, and 5.11, in total metal concentrations.

In the Hamala soil average extractable metal concentration varied from 0.02-0.04 mg kg^{-1} for Cd, 0.45-5.35 mg kg^{-1} for Cu, 1.2-32.1 mg kg^{-1} for Zn and 0.2-0.45 mg kg^{-1} for Pb in the surface layer using water of low salinity. In the Budaiya soil, values ranged from 0.02-0.03 mg kg^{-1} for Cd, 1.2-3.5 mg kg^{-1} for Cu, 1.35-35.5 mg kg^{-1} for Zn and 0.2-0.45 mg kg^{-1} for Pb. There was a slight tendency for more extractable Pb and Zn following use of high salinity water.

Extractable Cd, Pb and Cu showed an increase only in the sludge treated soil. Extractable zinc concentrations generally increased in all the soils after various amendment use. Extractable Zn was the highest metal obtained after the sludge treatment approximately showing a 30 fold increase.

In the Hamala soil, average total metal concentrations varied from 0.2-0.5 mg kg^{-1} for Cd, 7.5-35.65 mg kg^{-1} for Cu, 12.3-54.6 mg kg^{-1} for Zn and 1.1-10.3 mg kg^{-1} for Pb in the surface layer, using water of low salinity. In the Budaiya soil values ranged from 0.2-0.5 mg kg^{-1} for Cd, 7.9-36.1 mg kg^{-1} for Cu, 15.3-55.75 mg kg^{-1} for Zn and 1.4-10.9 mg kg^{-1} for Pb respectively. Water of high salinity also gave similar results.Clearly the major factor influencing metal concentration was the use of sewage sludge. In the 0-5 cm layer, Cd, Pb and Cu concentrations were not much different from the control soil after the treatments with cow and chicken manure. With the sewage sludge treatment concentrations of these metals in the soil were increased by a factor of 2-5 times (Tables, 5 & 6 in Appendix). Total zinc concentrations after the chicken manure and sludge treatments were 2 to 3 times greater than after the cow manure treatment. Metal concentrations did not vary significantly between the water types. Among the metals investigated, zinc was the only metal showing a tendency to leach to the lower layers and zinc concentrations were significantly different among the amendments in the 5-16 cm layer. Other metals were not significantly different here. Water salinity did not affect the metals after various treatments.

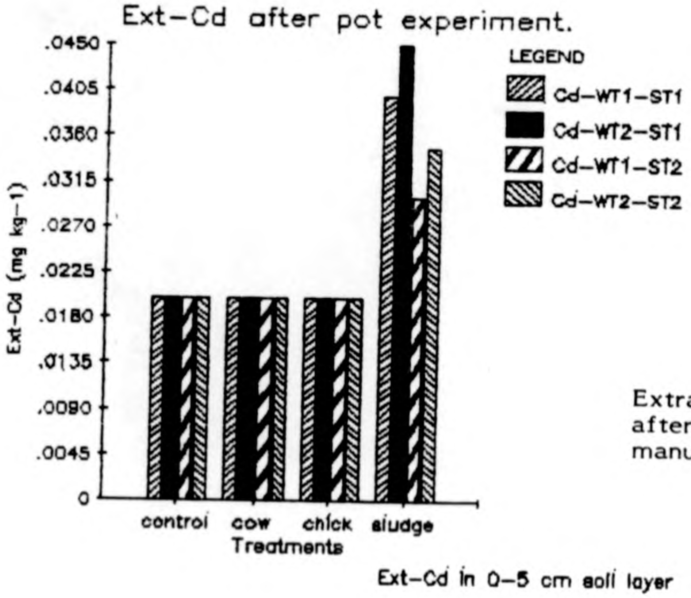


FIGURE - 5.4

Extractable - Cd in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & sludge.

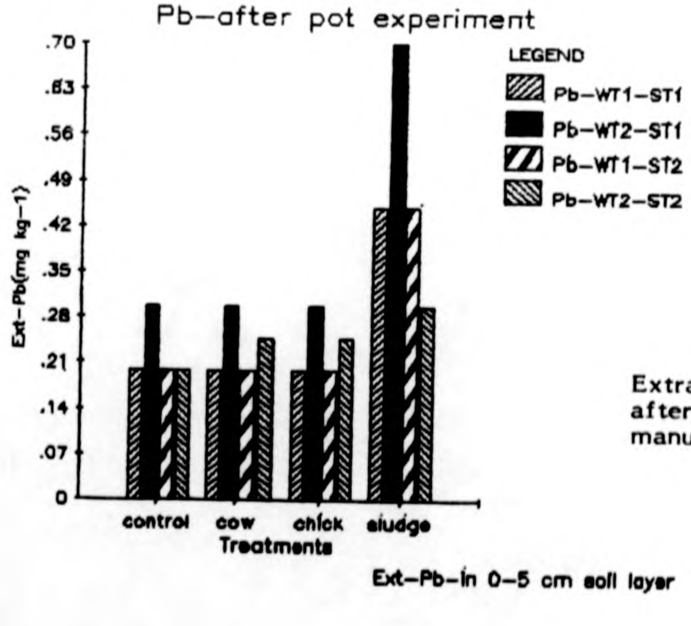
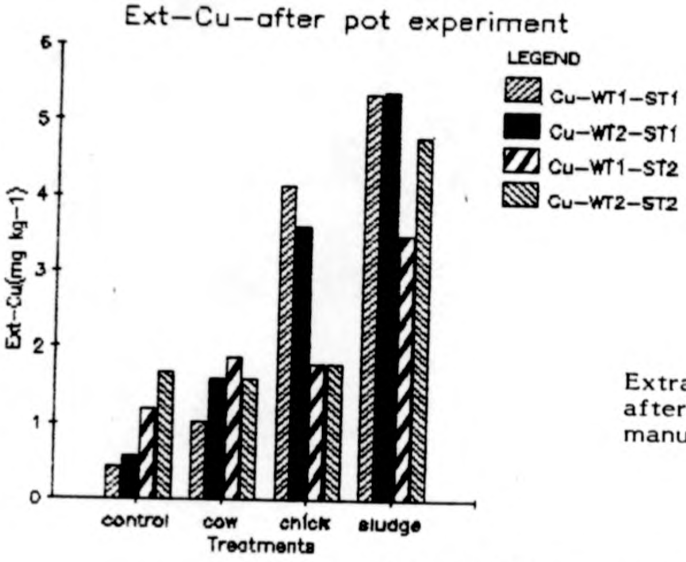


FIGURE - 5.5

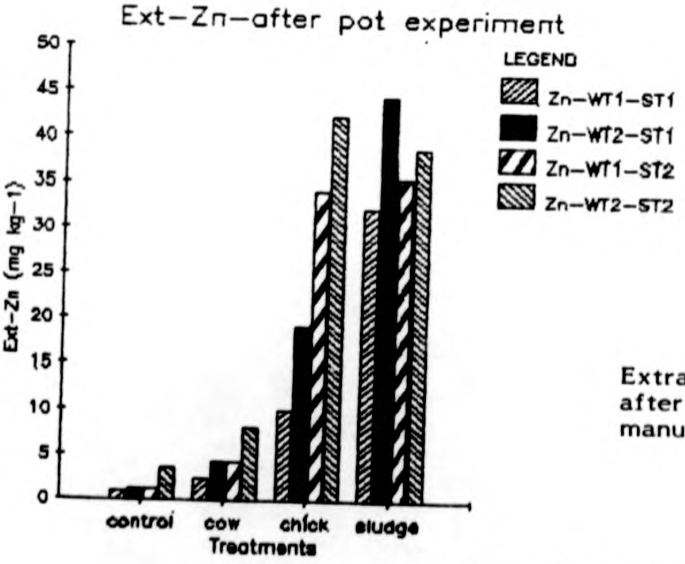
Extractable - Pb in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.



Ext-Pb-In 0-5 cm soil layer

FIGURE - 5.6

Extractable - Cu in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.



Ext-Zn In 0-5 cm layer

FIGURE - 5.7

Extractable - Zn in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.

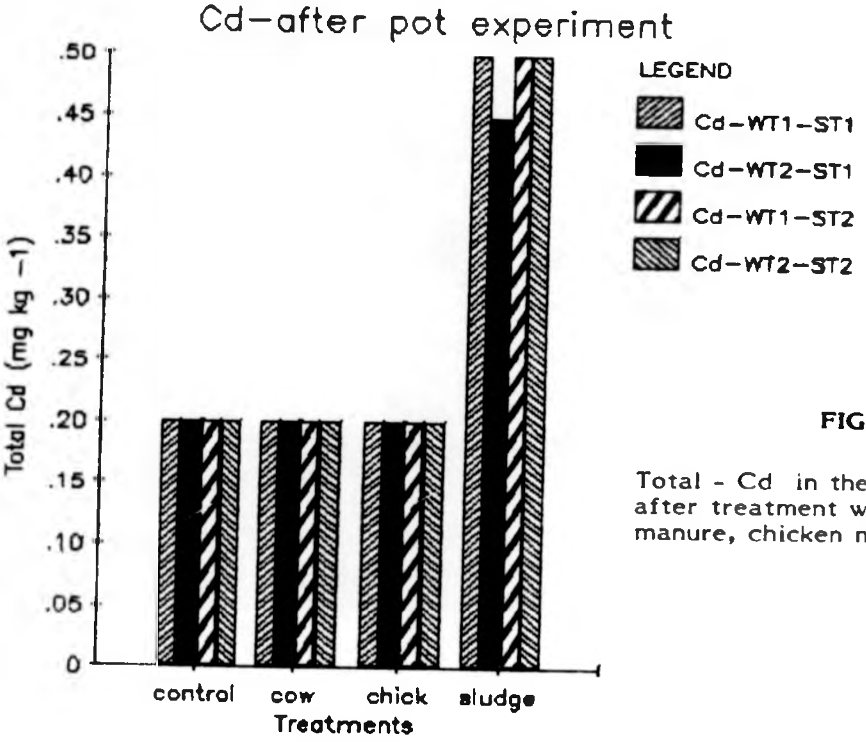


FIGURE - 5.8

Total - Cd in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.

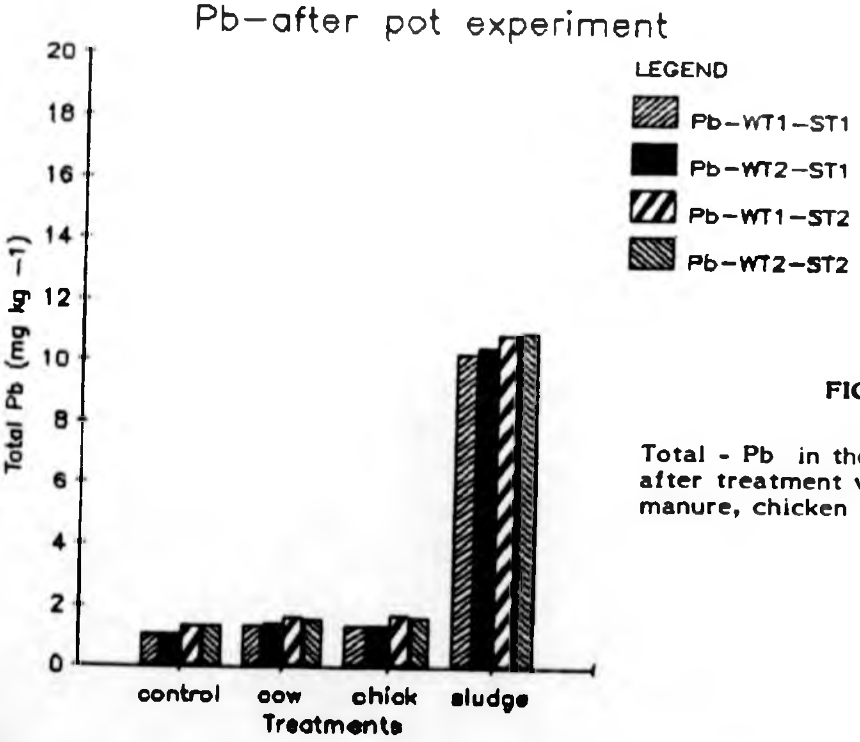


FIGURE - 5.9

Total - Pb in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.

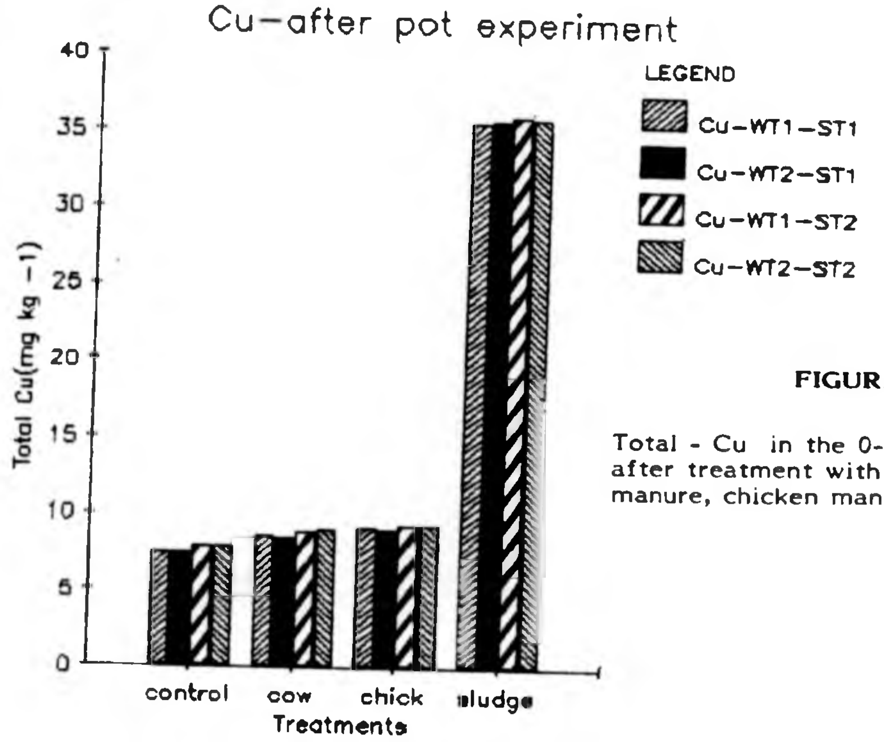


FIGURE - 5.10

Total - Cu in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.

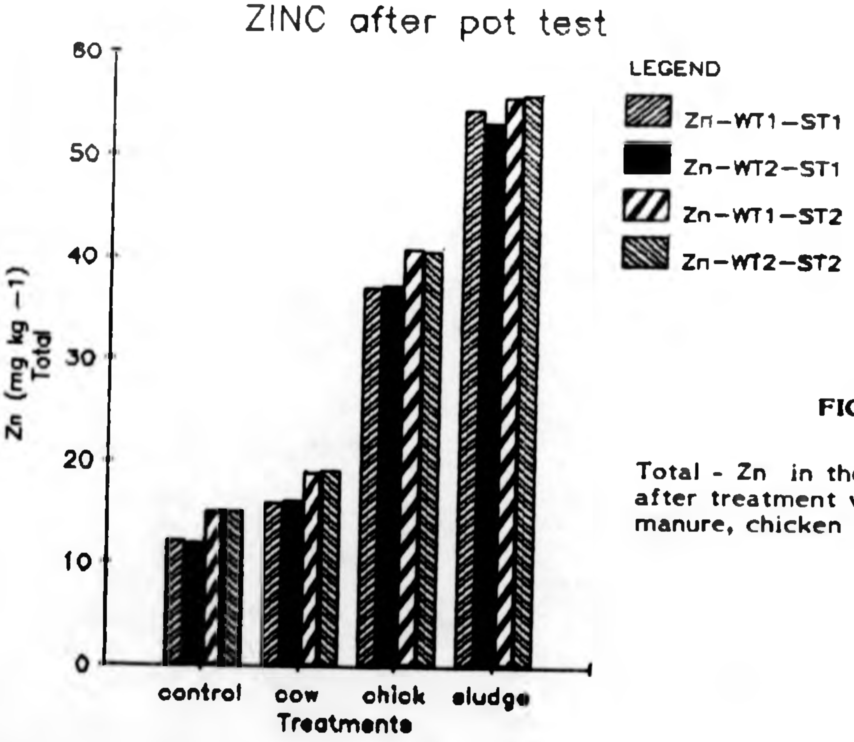


FIGURE - 5.11

Total - Zn in the 0-5 cm layer after treatment with 40 Mg ha^{-1} cow manure, chicken manure & Sludge.

TABLE- 5.6

POT EXPERIMENTAL DATA

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2
Layer 1 (0-5cm)

Cow manure, chicken manure & sewage sludge at 40 Mg ha^{-1}

Soil Property	significance of organic amendment		significance of water type use	
	soil 1	soil 2	soil 1	soil 2
WHC	* * *	*	NS	NS
Aggr stability	* *	*	* * *	* *
TOC	* * *	* * *	* *	*
PO4	* * *	* * *	NS	NS
TKN	* * *	* * *	NS	NS
CEC	* * *	* * *	NS	NS
Exchan. Ca	NS	NS	* * *	*
Exchan. Mg	*	NS	* *	NS
Exchan. Na	NS	NS	* * *	* * *
Exchan. K	NS	*	NS	*
Soluble salts	* * *	* * *	* * *	* * *
Soluble Ca	*	NS	NS	NS
Soluble Mg	NS	NS	* *	*
Soluble Na	* *	*	* * *	* * *
Soluble K	* * *	*	NS	NS
Soluble SO4	* *	*	NS	NS
Soluble Cl	NS	NS	* * *	* * *
Conductivity	* *	* *	* * *	* * *
Extrac. Cd	* * *	* * *	NS	NS
Extrac. Pb	* * *	* *	* * *	NS
Extrac. Zn	* * *	* * *	* *	*
Extrac. Cu	* * *	* * *	NS	NS
Total . Cd	* * *	NS	NS	NS
Total . Pb	* * *	* * *	NS	NS
Total . Zn	* * *	* * *	NS	NS
Total . Cu	* * *	* * *	NS	NS
pH	NS	NS	NS	* * *

p = 0.05 - 0.01 *
p = 0.01 - < 0.001 * *
p = < 0.001 * * *
NS = not significant

TABLE- 5.7

POT EXPERIMENTAL DATA

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2
Layer 2 (5-16 cm)

Cow manure, chicken manure & sewage sludge at 40 Mg ha^{-1}

Soil Property	significance of organic amendment soil 1	 soil 2	significance of water type use soil 1	 soil 2
WHC	NOT DONE		NOT DONE	
Aggr stability	NOT DONE		NOT DONE	
TOC	NS	NS	NS	NS
PO4	NS	NS	NS	NS
TKN	* * *	* * *	NS	NS
CEC	*	NS	NS	NS
Exchan. Ca	NS	NS	* *	* *
Exchan. Mg	NS	NS	NS	NS
Exchan. Na	NS	NS	NS	NS
Exchan. K	*	NS	NS	*
Soluble salts	NS	NS	* *	NS
Soluble Ca	NS	NS	* * *	NS
Soluble Mg	NS	NS	NS	*
Soluble Na	NS	NS	* * *	NS
Soluble K	*	NS	*	NS
Soluble SO4	*	NS	NS	* *
Soluble Cl	NS	NS	* * *	NS
Conductivity	NS	NS	NS	*
Extrac. Cd	NS	NS	* *	* *
Extrac. Pb	NS	NS	NS	* * *
Extrac. Zn	* * *	* *	NS	NS
Extrac. Cu	NS	*	* * *	*
Total . Cd	NS	NS	NS	NS
Total . Pb	* * *	NS	NS	NS
Total . Zn	* *	* *	NS	NS
Total . Cu	NS	*	NS	NS
pH	*	NS	* *	NS

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

5.1.3 Soil differences following different rates of addition of cow manure .

Effects of 20, 40 and 80 Mg ha^{-1} addition of cow manure were compared in a second series of pot experiments. Data analysis and graphs are presented in the same way as in section 5.1.2.

5.1.3.1 Organic carbon, nitrogen and phosphorus.

Cow manure additions significantly increased the C, N and P concentrations in the 0-5 cm soil layer. Figures 5.12, 5.13 & 5.14, shows the pattern of differences among the four treatments for the two soils and waters. Organic Carbon increased only 2.5 fold (0.8-2.6%) after the 80 Mg ha^{-1} cow manure treatments. However, increases were proportional to addition in amendments. TKN approximately showed a proportional increase at different rates in the 0-5cm layer (200 to 800 mg kg^{-1}). In both types of soils, phosphorus content was highly variable and showed the greatest concentration in all treatments using water of high salinity (WT2). Highest average concentration showed was 406 mg kg-1 for an addition of 80 Mg ha^{-1} in the case of Budaiya soil using high salinity water (WT2),and lowest 52.1 mg kg using 20 Mg ha^{-1} using water of low salinity (WT1). Additions of C, N and P at 20, 40 and 80 Mg ha^{-1} in two soils using two water types conducted in duplicates (2x2x2= n= 8) showed the average concentration 1.36, 1.60 and 2.20 % for C, 344, 486 and 835 mg kg for TKN, 66.8, 98.5 and 302 mg kg^{-1} for P respectively. The increase in C, and P with increase in additions were not so pronounced in the experiments and was not proportional to the addition showing a non-linear response. There was a significant difference in water type and C and P concentrations in the 5-16 cm layer.

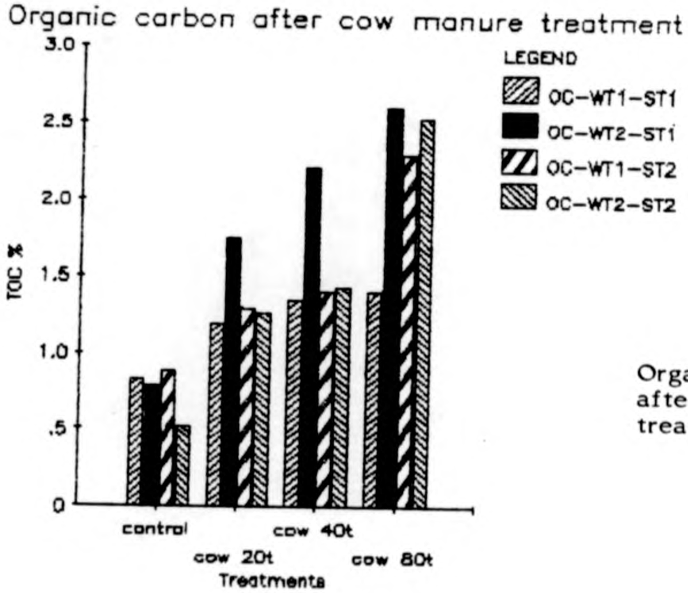


FIGURE - 5.12

Organic Carbon in the 0-5 cm layer after different rates of cow manure treatment.

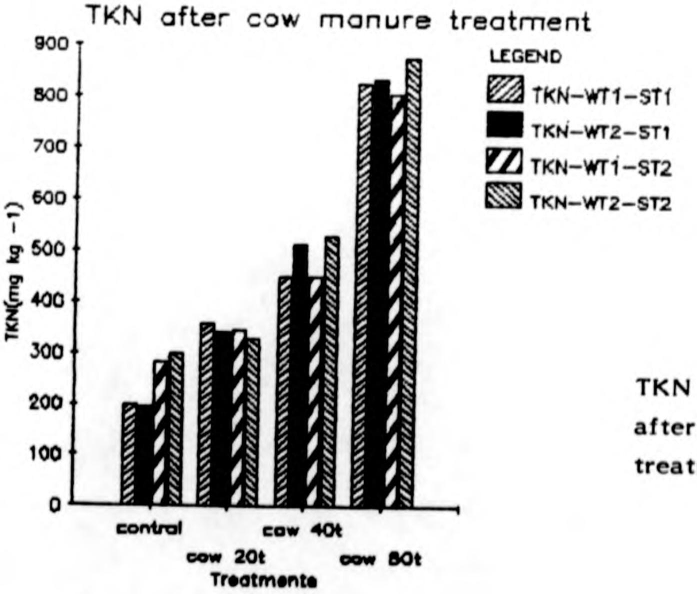


FIGURE - 5.13

TKN in the 0-5 cm layer after after different rates of cow manure treatment.

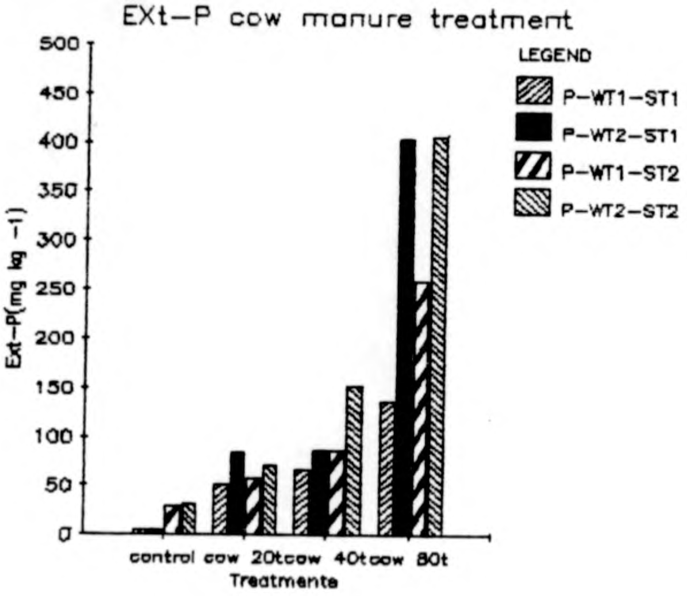


FIGURE - 5.14

Extractable - P in the 0-5 cm layer after different rates of cow manure treatment.

5.1.3.2 Aggregate stability and Water Holding Capacity.

Aggregate stability of Hamala soil generally increased with the addition of cow manure (max 6%), and in Budaiya soil (max 8.5%) (Table-1&2 in Appendix) using water of low salinity. In the case where water of high salinity was used, there was no significant improvement in aggregate stability (max 2%) in both soils. WHC had a very minor improvement after treatment with cow manure at different rates.

5.1.3.3 Cation Exchange Capacity (CEC) and exchangeable cations.

CEC, showed a very slight increase (max 2.3 meq 100 g^{-1}.) in the surface layer of soils after different treatments (Tables 1 & 2 in the appendix). Exchangeable cations were variable and comparison of the organic amendment treatments with the control did not show statistically significant differences. Calcium concentrations were, however, significantly different between the water types. Exchangeable calcium concentrations were larger when low salinity water was used. Higher salinity water increased sodium concentration in the surface layer.

5.1.3.4.Salinity and soluble salts.

High salinity water increased the soluble salts content of the surface layer and there was no noticeable change in the salts in the lower 5-16 cm soil depth (tables -3 & 4, in appendix). Sodium and chloride concentration in the 0-5 cm layer were higher when water of high salinity was used. Treatment did not have significant influence on the soluble salts in both types of soils.

5.1.3.5 Extractable and total metals

Leaving the case of Cd and Pb, organic amendments had a significant effect on both acetic acid extractable metal and total metal contents in the 0-5 cm layer. Figures 5.15, 5.16, 5.17 and 5.18 shows extractable metal concentrations and figures - 5.19, 5.20, 5.21 and 5.22 shows the pattern of the differences in total metal concentrations.

In the Hamala soil average extractable metal concentration varied from 0.45-1.25 mg kg^{-1} for Cu and 1.20-3.45 mg kg^{-1} for Zn in the surface layer using water of low salinity. In the Budaiya soil, values ranged from 1.2-1.6 mg kg^{-1} for Cu and 1.35-10.40 mg kg^{-1} for Zn. A slight tendency of extracting more Pb and Zn was seen in the case of high salinity water use. Extractable zinc concentrations generally increased in all the soils after cow manure use.

In the case of acetic acid extractable Cd and Pb did not show statistically significant difference in the

0-5 cm layers after different cow manure treatments (Table-5-8). None of the results were statistically significant for the 5-16 cm layer (Table-5-9). Again Zn was the only metal which showed a tendency to leach to the lower layer. Highest concentration of extractable metal found was in the case of Zn at 80 Mg ha cow manure treatment (Figure- 5.18).

In the Hamala soil, average total metal concentrations varied from 7.50-9.65 mg kg^{-1} for Cu, 12.3-19.45 mg kg^{-1} for Zn and 1.1-1.6 mg kg^{-1} for Pb in the surface layer, using water of low salinity. In the Budaiya soil values ranged from 7.9-10.1 mg kg^{-1} for Cu, 15.3-22.9 mg kg^{-1} for Zn and 1.4-1.75 mg kg^{-1} for Pb respectively. Water of high salinity also gave similar results. In the 0-5 cm layer, Cd, concentrations were not much different from the control soil after the treatments with cow manure. Water salinity did not affect the metals concentrations after various treatments.

Total concentration of zinc was found to be significantly different in the case of high salinity water use (WT2) and in all other cases metal response was linear. In all cases metal abundance at the surface layer was proportional to the addition in amendments.

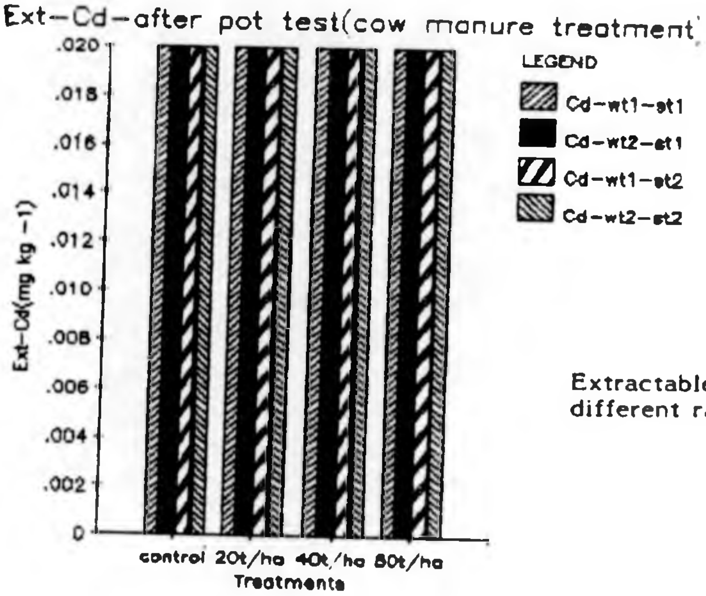


FIGURE - 5.15

Extractable -Cd in the 0-5 cm layer after different rates of cow manure treatment.

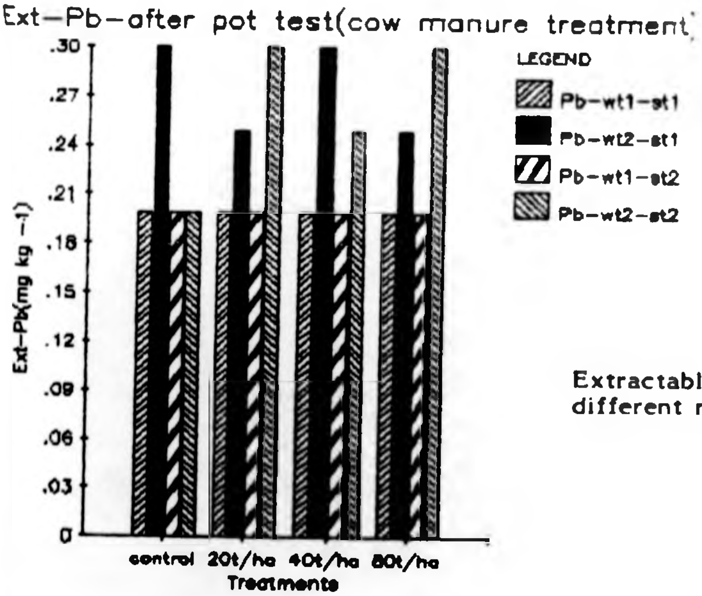


FIGURE - 5.16

Extractable - Pb in the 0-5 cm layer after different rates of cow manure treatment.

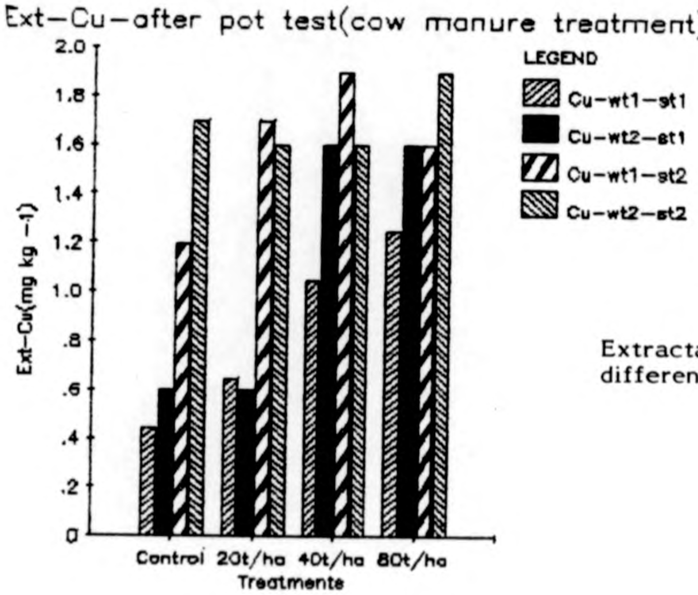


FIGURE - 5.17

Extractable - Cu in the 0-5 cm layer after different rates of cow manure treatment.

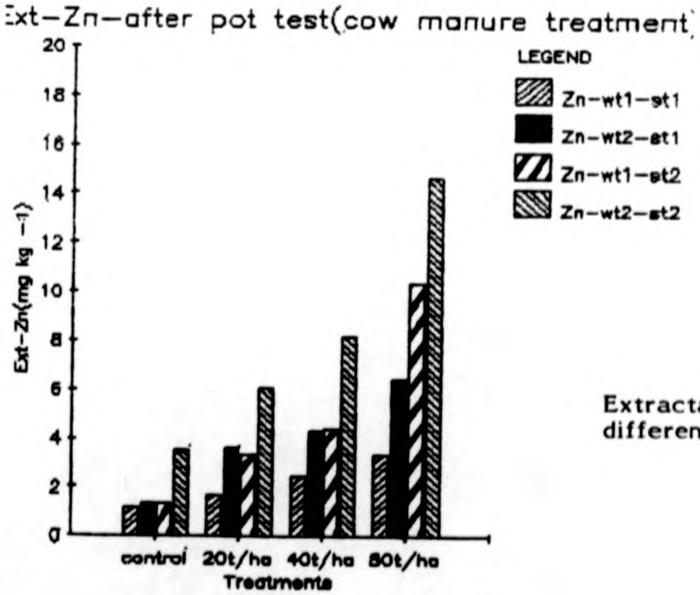


FIGURE - 5.18

Extractable - Zn in the 0-5 cm layer after different rates of cow manure treatment.

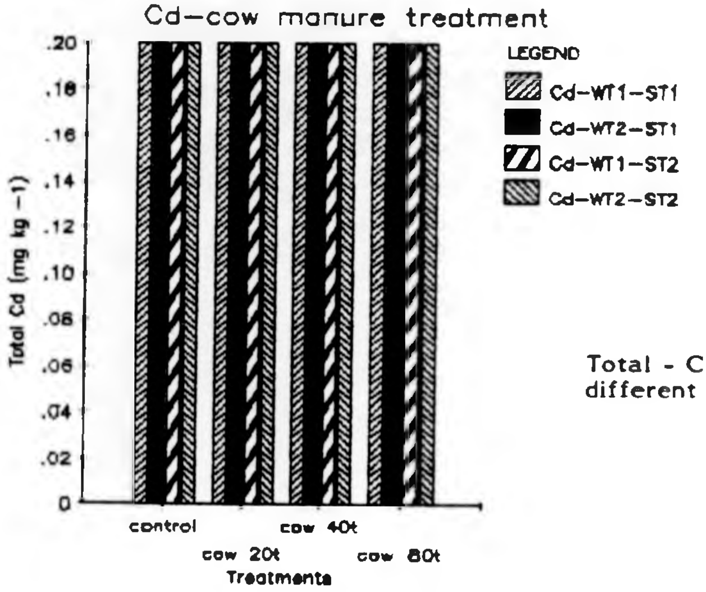


FIGURE - 5.19

Total - Cd in the 0-5 cm layer after different rates of cow manure treatment.

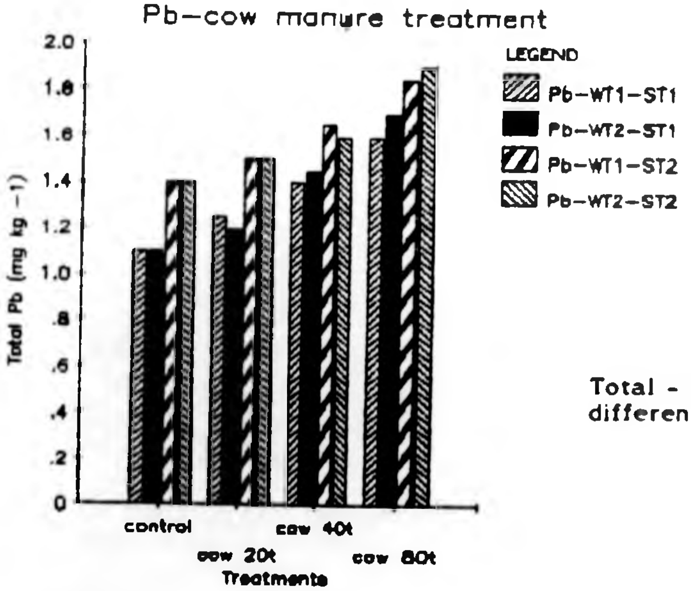


FIGURE - 5.20

Total - Pb in the 0-5 cm layer after different rates of cow manure treatment.

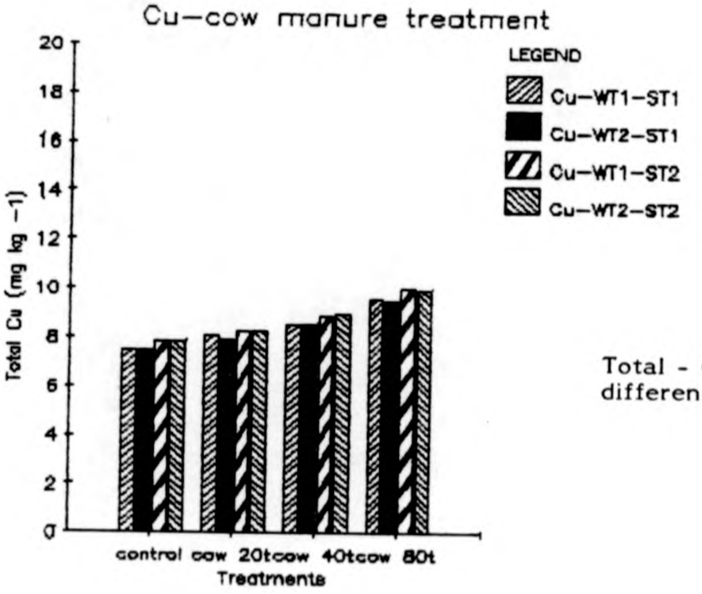


FIGURE - 5.21

Total - Cu in the 0-5 cm layer after different rates of cow manure treatment.

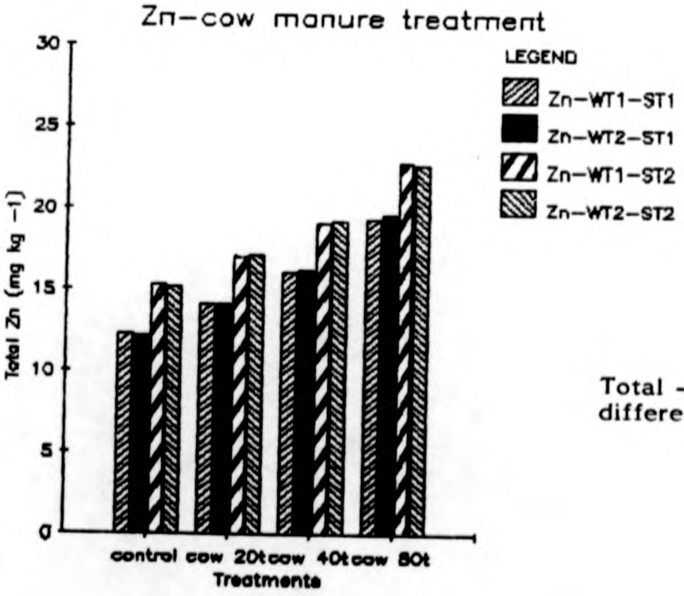


FIGURE - 5.22

Total - Zn in the 0-5 cm layer after different rates of cow manure treatment.

TABLE- 5.8

POT EXPERIMENTAL DATA

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2
Layer 1 (0-5cm)

Cow manure treatment at 20, 40, & 80 Mg ha^{-1}

Soil Property	significance of organic amendment		significance of water type use	
	soil 1	soil 2	soil 1	soil 2
WHC	NS	NS	NS	NS
Aggr stability	*	NS	* *	* *
TOC	* *	* * *	* *	NS
PO4	* *	* * *	*	NS
TKN	* * *	* * *	NS	NS
CEC	* * *	* * *	NS	NS
Exchan. Ca	NS	NS	* * *	*
Exchan. Mg	NS	NS	* * *	NS
Exchan. Na	NS	NS	* *	NS
Exchan. K	NS	*	* *	* * *
Soluble salts	NS	* *	* * *	* * *
Soluble Ca	NS	NS	*	NS
Soluble Mg	*	NS	* * *	* * *
Soluble Na	NS	*	* * *	* * *
Soluble K	NS	*	NS	*
Soluble SO4	*	NS	NS	NS
Soluble Cl	NS	NS	* * *	* * *
Conductivity	NS	*	* * *	* * *
Extrac. Cd	NS	NS	* *	* *
Extrac. Pb	NS	NS	* *	* *
Extrac. Zn	* * *	* * *	* * *	* * *
Extrac. Cu	* * *	NS	*	NS
Total . Cd	NS	NS	NS	NS
Total . Pb	* * *	* * *	NS	NS
Total . Zn	* * *	* * *	NS	* * *
Total . Cu	* * *	* * *	*	NS
pH	NS	NS	NS	* *

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

TABLE- 5.9

POT EXPERIMENTAL DATA

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2
Layer 2 (5-16 cm)

Cow manure at 20, 40 & 80 Mg ha^{-1}

Soil Property	significance of organic amendment		significance of water type use	
	soil 1	soil 2	soil 1	soil 2
WHC	NOT DONE		NOT DONE	
Aggr stability	NOT DONE		NOT DONE	
TOC	NS	*	*	* *
PO4	NS	NS	NS	* *
TKN	* * *	* * *	NS	NS
CEC	*	* * *	NS	NS
Exchan. Ca	NS	NS	* *	NS
Exchan. Mg	NS	NS	NS	NS
Exchan. Na	NS	NS	NS	NS
Exchan. K	NS	*	* * *	NS
Soluble salts	NS	NS	NS	NS
Soluble Ca	NS	NS	* *	NS
Soluble Mg	NS	NS	NS	NS
Soluble Na	NS	NS	* *	NS
Soluble K	NS	NS	*	* *
Soluble SO4	NS	NS	NS	* *
Soluble Cl	NS	NS	* *	NS
Conductivity	NS	NS	NS	NS
Extrac. Cd	NS	NS	* *	* *
Extrac. Pb	NS	NS	NS	*
Extrac. Zn	NS	NS	NS	NS
Extrac. Cu	NS	NS	* * *	*
Total . Cd	NS	NS	NS	NS
Total . Pb	NS	NS	NS	NS
Total . Zn	NS	* *	NS	* * *
Total . Cu	NS	NS	NS	NS
pH	NS	NS	NS	NS

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

5.1.4 Leaching water differences following treatment with three manures, at 40 Mg ha -1.

Leaching waters from the pots were collected for the duration of the experiment. Analysis of the mean chemical composition of the leaching water revealed few statistically significant differences. Table 5.11 shows results of ANOVA comparisons of the leachate from different organic amendments. Mean chemical composition in the leachate are given in the appendix, (Table-7 & 8).

5.1.4.1 N, P, K and pH

TKN and K levels in the leachates showed significant increases after treatment. Average values of NO3-N, and K are shown in Table-5.10 for two soil types and two water types. In the case of the Hamala soil, there was no statistically significant difference in P levels after the treatment, but Budaiya soil leachate showed a very small difference in P levels after treatment.

The chicken manure treatments resulted in more leaching of nitrogen (TKN) (1.1-13.8 mg l^{-1}) from two soils studied. High salinity water had a tendency to leach more N and K. The average TKN concentration in the Hamala soil leachate increased about 13 fold in the chicken manure treatment compared to the control. In the Budaiya soil the changes were not so pronounced. Nitrates in the leachates from sludge treatments were similar and showed an average 5 fold increase in all soils. Nitrate content of the leachates were significantly higher after chicken manure and sludge treatments. Here also high salinity water had the greatest influence. pH value of the leachates were neutral to slightly alkaline and there was no significant difference after the treatment.

Table-5.10

Leachate results after pot experiment

		NO3-N (mg L^{-1})		K (mg L^{-1})		Cd (ug L^{-1})	
		WT1	WT2	WT1	WT2	WT1	WT2
Control	ST1	7.20	66.75	137.50	456.50	1.01	1.00
	ST2	11.25	25.40	182.50	278.10	0.94	0.95
Cow	ST1	4.10	41.25	137.50	264.20	0.75	1.10
	ST2	3.67	63.10	232.50	287.30	0.66	2.10
Chick	ST1	60.70	159.65	255.0	427.25	0.64	1.00
	ST2	107.50	230.75	550.00	480.50	0.83	1.35
Sludge	ST1	27.80	204.25	130.00	202.15	0.97	1.75
	ST2	112.85	218.10	272.50	304.55	1.52	1.50

ST1 = Hamala soil, ST2 = Budaiya soil
WT1 = Low salinity water, WT2 = High salinity water.

5.1.4.2 Trace metals

Only cadmium concentrations in the leachate from soil treated with sewage sludge were significantly affected by the treatments (table. 5.11), although the increases were small (Table-5.10). No other significant differences in metal concentrations were found. Water type also had an effect on the metal leaching. In Budaiya soil (soil type-2) high salinity water (WT2) leached more Cd , Pb and Cu than low salinity water (WT1). Leaching loss of metals were variable and Cu and Zn showed the tendency to leach more than other metals. The leaching losses were maximum in the chicken manure and sludge treated soils (Tables-7 & 8 in the appendix)

TABLE- 5.11

POT EXPERIMENTAL DATA

LEACHATE ANALYSIS IN POT EXPERIMENTS

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2

Cow manure, chicken manure & sewage sludge at 40 Mg ha^{-1}

Soil Property	significance of organic amendment		significance of water type use	
	soil 1	soil 2	soil 1	soil 2
TKN	* * *	NS	NS	* * *
PO4	NS	*	*	*
K	*	* *	* *	NS
NO3 (1:5)	* *	* *	* *	* *
Total . Cd	* *	* *	* *	* *
Total . Pb	NS	NS	NS	* *
Total . Zn	NS	NS	NS	NS
Total . Cu	NS	NS	NS	* *
pH	NS	NS	NS	NS

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

5.1.5. Leaching water differences following different rates of addition of cow manure.

Table.5.12 shows the results of ANOVA comparisons of the leachates. Mean chemical composition of the leachates are given in appendix, in Tables-7 & 8.

5.1.5.1 N, P, K and pH

In the case of both soils, there was no statistically significant difference in Nitrate-N, P and K levels after treatment. There were significant differences in only a few of the properties measured among the organic treatments. In the case of Hamala soil, leaching water nitrogen (TKN) showed significant difference after the treatment. TKN value ranged from 1.1 for the control to 3.75 mg l^{-1} for 80 Mg ha^{-1} treatment. pH value did not show any significant difference after the cow manure treatment.

5.1.5.2 Trace metals

There was no statistically significant differences in most of the metals in the leachate after cow manure treatment. However, in Hamala soil Cu and in Budaiya soil Zn showed a significant difference after the cow manure treatment (Table-5.12). Watertype also had very little affect on the metal leachability. In Budaiya soil (soil type-2) high salinity water (WT2) leached more Pb and Cu than water of low salinity (WT2).

TABLE. 5.12

POT EXPERIMENTAL DATA

LEACHATE ANALYSIS IN POT EXPERIMENTS

ANOVA RESULTS

Soil 1 & 2
Water type 1 & 2

Cow manure, at 20, 40 & 80 Mg ha^{-1}

Soil Property	significance of organic amendment		significance of water type use	
	soil 1	soil 2	soil 1	soil 2
TKN	*	NS	*	*
PO4	NS	NS	NS	* *
K	NS	NS	* *	NS
NO3 (1:5)	NS	NS	* *	NS
Total . Cd	NS	NS	* *	* *
Total . Pb	NS	NS	NS	* *
Total . Zn	NS	* *	NS	NS
Total . Cu	* *	NS	NS	* *
pH	NS	NS	NS	NS

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

Trace element balance in pot experiments.

Trace metal analysis results are shown in Tables-5 & 6 in the appendix. The trace element balance are clearly shown for each metal in Tables-9 to 16 in Appendix. Calculations were done as follows. In the case of copper :

Total metal (Cu) added in soil (0-5 cm) through manure + water = 300 ug.

Total metal (Cu) got after the experiment (0-5 cm layer) = 8.0 ug/g

Total metal (Cu) before the experiment (0-5 cm layer) = 7.5 ug/g

Total gain was 0.5 ug/g

Total weight of soil was 1500 g

Total weight of soil in 0-5 cm layer = 500 g.

Metal got after the experiment at (0-5 cm) = 0.5 x 500 g = 250 ug.

$$\% \text{ gain} = \frac{250}{300} \times 100 = 83.33.$$

Of the added metals Cd showed a gain in the soil surface, only in the case of sewage sludge treatment. All the other metals added were not found in the surface soil as shown below (both soils together considered) after the experiment. The retained metals ranged as follows :

Cu - 58.0 - 116 % WT1 use
- 67.0 - 104 % WT2 use

Pb - 51.2 - 102.4 % WT1 use
- 52.7 - 115.4 % WT2 use

Zn - 85.4 - 106.0 % WT1 use
- 92.0 - 100.6 % WT2 use

Cd - 0 - 115 % WT1 use
- 0 - 101 % WT2 use.

The amount of metal added in pots should be equal to soil gain + leaching loss. But in certain cases the values have been much lower or higher than 100 %. These values depended on the concentration of the metal got in the atomic absorption measurements. A small difference of 0.1 can lead to a difference of 5 ug g^{-1} in the final value.

Most of the metals found in the 0-5 cm were proportional to the metals added via manure. The highest metals were added via sewage sludge.

5.2 Field Experiments :

Soils from three depths at 17 farms, grouped according to their amendment use as cow manure, chicken manure, sewage sludge or control were compared by one way ANOVA. The results of the ANOVA are shown in Table-5.13. Some relationships are also shown in graphical form. All original data are listed in Appendix, Tables-17-25.

5.2.1 Soil differences among farms using different organic amendments.

Results of the physical and chemical properties of the soils at three depths from 17 farms are shown in Tables.17-25 in appendix.

Texture of most soils were sandy and with few loamy sands and sandy loams. Sand content varied from 58.2 to 94.84% . All the farms were cultivated and the site characteristics of the farms were described in Chapter-4. There were no stones in the uppermost 50 cm of soil, showing that these farms were considerably modified earlier for agricultural purposes. pH of the soils (1:5 solution) were neutral and most of the soils were moderately saline, showing that farms were properly drained.

Properties of the soils from the experimental plots were highly variable and a few of the ANOVA comparisons were significant. Organic amendment effects were most often significant in the uppermost soil layer.

Organic Carbon contents differed significantly among treatments at the 0-5 cm and 25-50 cm depths but not at 5-25 cm. N and P showed no significant difference at any depth. CEC was significantly different in all three layers. Exchangeable cations were very variable. In the 0-5 cm layer, Ca, Mg and K, and in the 5-25 cm layer only Ca, showed statistically significant differences among treatments. Differences in concentrations of soluble salts were statistically significant in the 0-5 cm and 25-50 cm layers, but not in the 5-25 cm layer. Extractable Pb, Zn and Cu were all significantly different in the 0-5 cm layer and Cd, Pb and Cu in the 5-25 cm and 25-50 cm layers. In the case of total metals, Cd and Zn showed significant differences in the surface layer. Only Cd showed a significant difference in the bottom layers. The surface layer generally contained the largest metal concentrations. Some of the major differences are described below.

TABLE- 5.13

FIELD EXPERIMENTAL DATA

ONE WAY ANOVA RESULTS

Chicken manure
Cow manure
Sewage sludge
Control

Soil Property	significance of organic amendment use 0-5 cm layer	 5-25 cm layer	 25-50 cm layer
WHC	NS	-	-
Aggr stability	* * *	-	-
TOC	*	NS	*
PO4	NS	NS	NS
TKN	NS	NS	NS
CEC	* *	*	*
Exchan. Ca	* *	*	NS
Exchan. Mg	* *	NS	NS
Exchan. Na	NS	NS	NS
Exchan. K	* *	NS	NS
Soluble salts	* *	NS	*
Soluble Ca	* *	NS	*
Soluble Mg	* *	NS	NS
Soluble Na	NS	NS	*
Soluble K	NS	NS	NS
Soluble SO4	* *	NS	*
Soluble Cl	NS	*	*
Conductivity	* *	NS	NS
Extrac. Cd	NS	* * *	* * *
Extrac. Pb	*	* *	* *
Extrac. Zn	*	NS	NS
Extrac. Cu	* *	* * *	* * *
Total . Cd	* * *	*	* *
Total . Pb	NS	NS	NS
Total . Zn	* *	NS	NS
Total . Cu	NS	NS	NS
pH	* *	*	NS
ABD	* *		

p = 0.05 - 0.01 *
p = 0.01 - 0.001 * *
p = < 0.001 * * *
NS = not significant

5.2.1.1 Organic Carbon, Nitrogen & Phosphorus:

Generally in Bahrain, organic amendments are added regularly (monthly basis) and total addition for a crop comes to approximately 40 Mg ha^{-1}. Inorganic fertilizers are also added depending on the nature of the crop at a maximum rate of 160 kg ha^{-1} (Van-ollenbach, 1977). This has been a regular practice and so additions of organic matter are usually constant.

Organic Carbon contents were small in all the plots examined and averaged 1.13 % for chicken manure treatment area, 2.01% for cow manure and 1.28% for sewage sludge treatment area with a range of 0.86-3.56%. Organic carbon contents in different layers are shown in (Figure.5.23). Mean C content was greatest in the 0-5 cm layer following amendment with cow manure. Sewage sludge and chicken manure plots had smaller carbon contents, but still greater than the control sites. TKN averaged 1275.83 mg kg^{-1} for chicken, 862.60 mg kg^{-1} for cow and 2230.67 mg kg^{-1} for sludge treated area with a range of 616-5250 mg kg^{-1} in the amended plots. Within treatment variability was large and there was no significant difference among the treatments. Mean Nitrogen concentrations of all treated soils were, however much greater than that of the control soil, and the largest plot mean of 2230.67 mg kg^{-1} was found under the sewage sludge treatment (Figure.5.24).

Phosphorus values did not show any significant difference at any depth and values ranged from 25.8-278.5 mg kg^{-1}., in the surface layer with an average value of 67.93 mg kg^{-1} for chicken manure 80.78 mg kg^{-1} for cow manure and 117.80 mg kg^{-1}. sludge treated area. The largest P content again resulted from sewage sludge use (Figure-5.25).

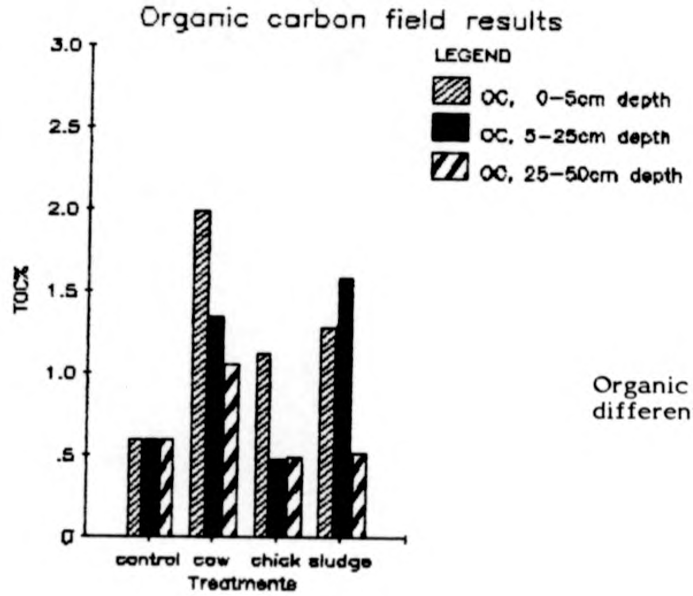


FIGURE - 5.23

Organic Carbon in field experiments different layers.

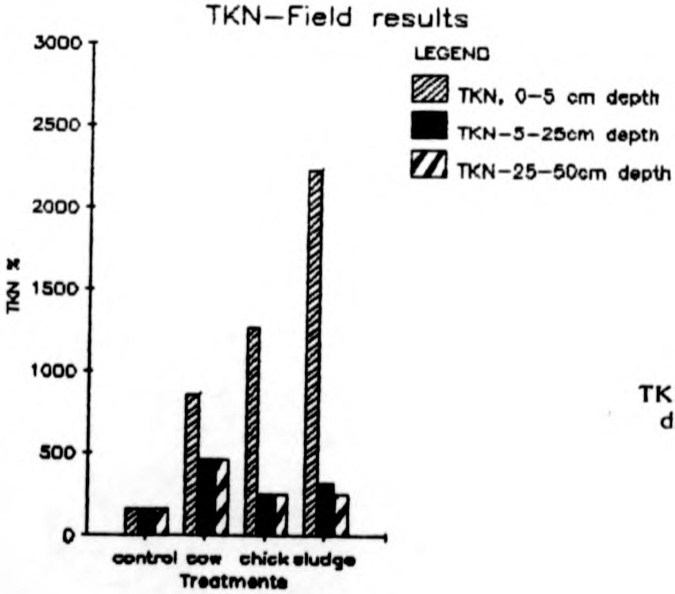


FIGURE - 5.24

TKN in field experiments different layers.

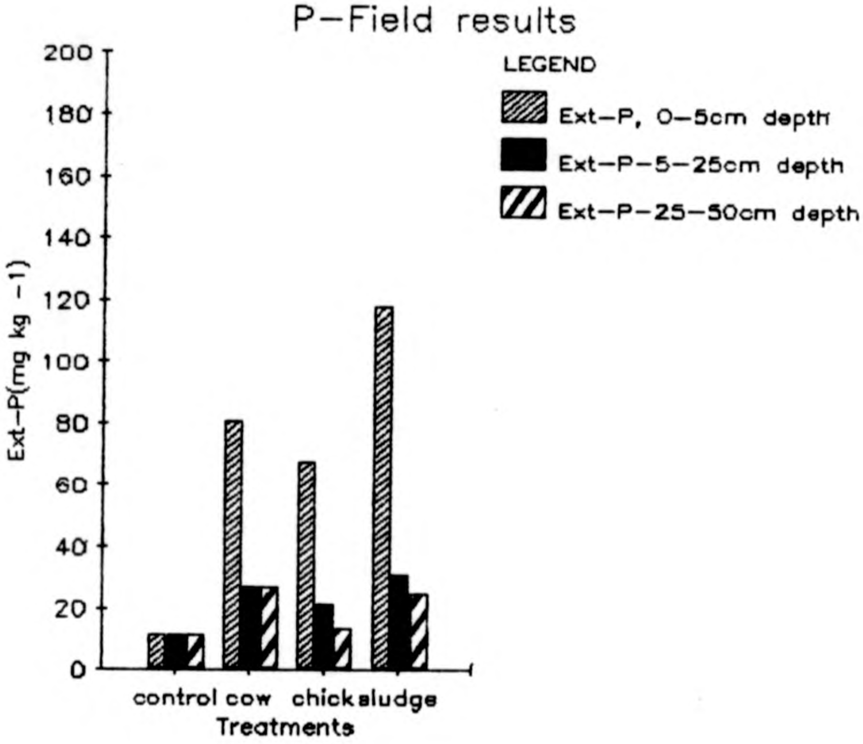


FIGURE - 5.25

Extractable - P in field experiments at different layers.

5.2.1.2 Aggregate Stability & Water Holding Capacity:

Aggregate stability was very small in the control soils with no water stable aggregates found. Stability was increased slightly to approximately 2 % water stable aggregates in the 0-5 cm soil by the organic amendments. Chicken manure treatment area showed the highest value (10.6%) for WHC. Differences in Water Holding Capacity (WHC) among treatments were not significant. Values for all soils were between 9.8-10.6 %.

5.2.1.3 Salinity & Soluble Salts:

Soluble salts were variable and showed few significant differences in values which ranged from 0.02-0.69 % with mean of 0.23 %. Among the soluble salts in the 1:5 (soil: water) solution, calcium was the predominant cation and sulphate the predominant anion. Conductivity (a measure of salinity) of the 1:5 solution ranged from 0.05 to 1.06 S m^{-1} (Table-18).

5.2.1.4 Extractable & Total metals :

Extractable and total metal concentrations at each layers of soil in different farms are shown in Figures-5.26 to 5.33. Results of Analysis of Variance are given in Table-5.13. Total and extractable cadmium concentrations differed slightly among the treatments in the 0-5 cm layer. Mean extractable cadmium in the plots treated with farm manures were similar to that in the control soil, with values ranging from 0.02-0.20 mg kg^{-1}.

One plot (Al-Akr-3) treated with cow manure had a slightly larger extractable cadmium (0.20 mg kg^{-1}). The sewage sludge treated plots had a higher mean extractable cadmium of 0.29 mg kg^{-1} with a range of 0.08-0.80 mg kg^{-1} (Table-25). The significant difference among total cadmium concentrations in the 0-5 cm layer was also the result of a large mean value in the sewage sludge treated plots (1.26 mg kg^{-1}). Concentrations in the control plots ranged from 0.19 - 0.44 mg kg^{-1}. Similar patterns of differences were found in the lower soil layers.

Extractable copper was significantly different among the treatments in all three soil layers (Table-5.14), but total copper differences were not significant. The difference in extractable copper was again mainly due to the large concentrations in the sludge treated plots. In the 0-5 cm layer these ranged from 1.20-5.80 mg kg^{-1} (mean 3.37 mg kg^{-1}). Cow and chicken manure treated plot means were 0.89, and 0.33 mg kg^{-1} respectively, compared to the control soil mean of 0.18 mg kg^{-1}. Al-Akr-3 again was different from the other cow manure plots with an extractable copper of 2.78 mg kg^{-1}. Mean total copper in the 0-5 cm layer under sewage sludge was 55 mg kg^{-1}. Values for all other sites never exceeded 8 mg kg^{-1}, with the exception again of the Al-Akr-3 plot.

Extractable lead was significantly different among the treatments in all three layers. Differences between sludge treated plots and other soils were not as large as for cadmium and copper. Largest lead concentration was found under cow manure treatment at Al-Akr-3 (8.68 mg kg^{-1}). Total lead followed the same pattern, though not significantly different. Al-Akr-3 again had the largest mean lead of 51.29 mg kg^{-1}.

Extractable and total zinc, both showed significant difference only in the 0-5 cm layer. Mean concentrations were greatest under sludge treatment area (26 and 78 mg kg^{-1} respectively), with maximum extractable and total zinc of 51 and 139 mg kg^{-1}, respectively, found at the Hamala site after 3 years of sludge application. Zinc concentration were also much larger in cow and chicken manure treated plots than in control soil. Extractable zinc in the manured plots ranged from 2-23 mg kg^{-1}, compared to 0.34 mg kg in the control (Table-25).

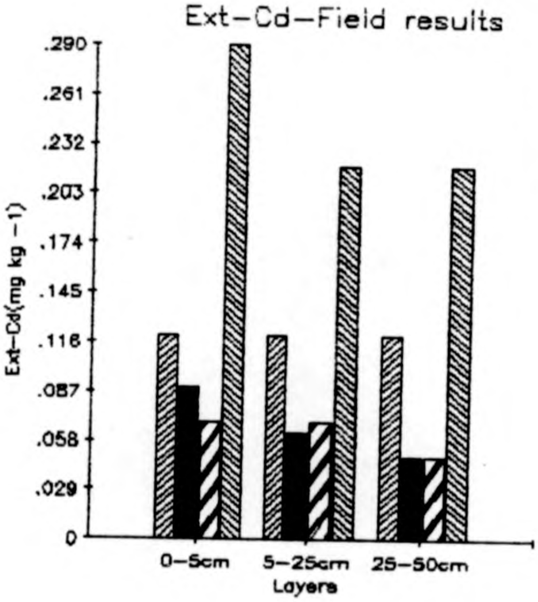


FIGURE - 5.26

Extractable - Cd in field experiments at different layers.

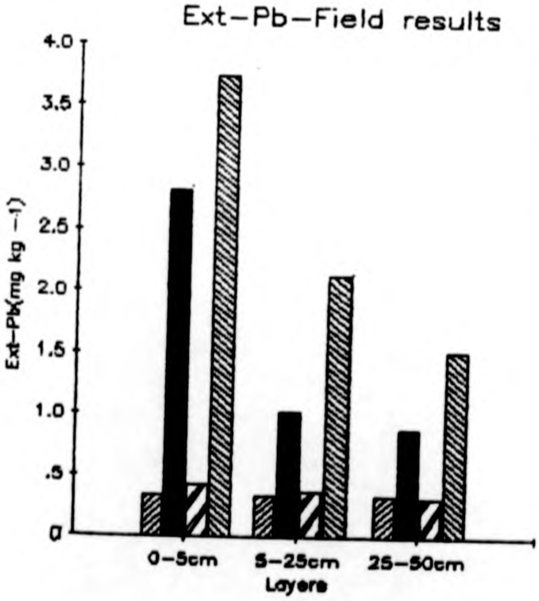


FIGURE - 5.27

Extractable - Pb in field experiments at different layers.

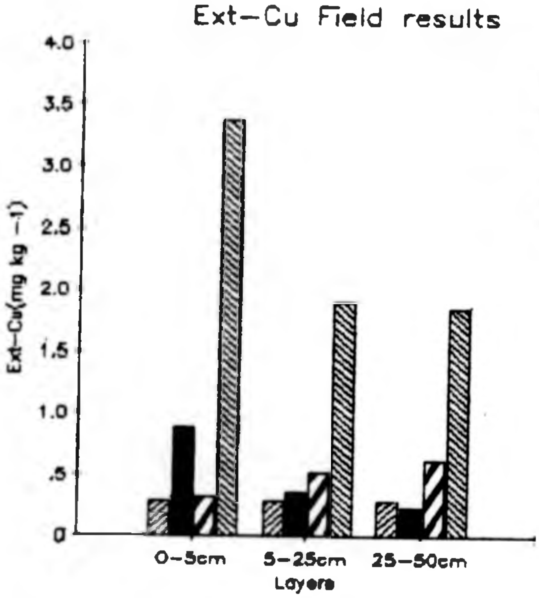


FIGURE - 5.28

Extractable - Cu in field experiments at different layers.

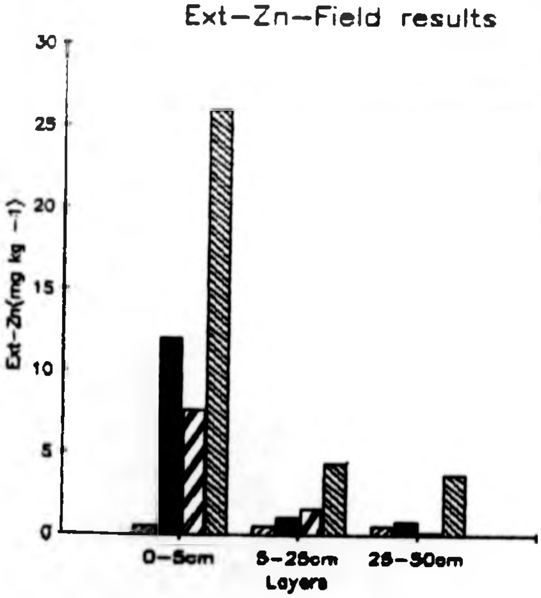


FIGURE - 5.29

Extractable - Zn in field experiments at different layers.

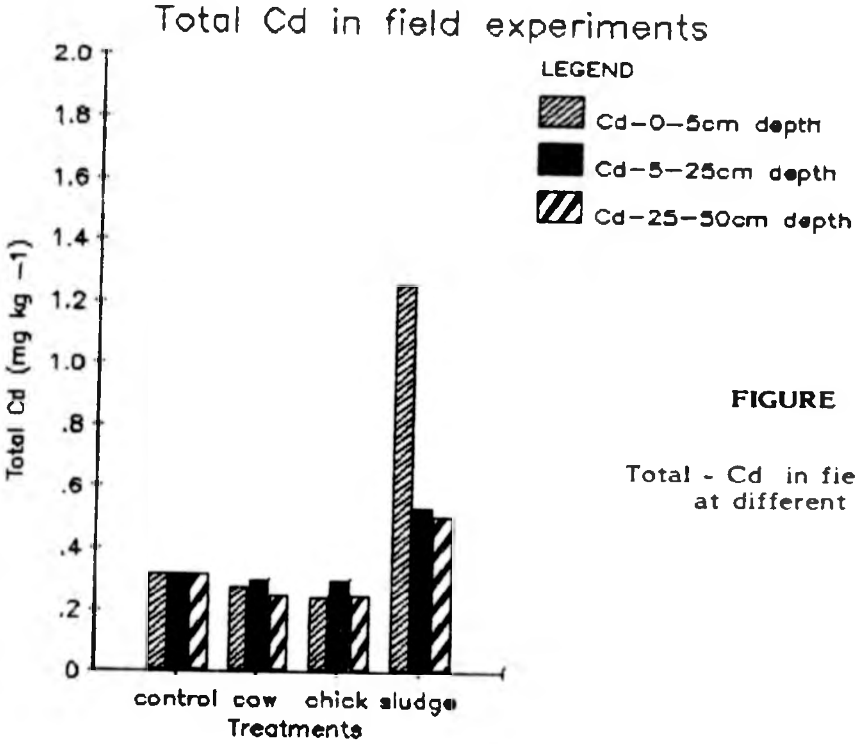


FIGURE - 5.30

Total - Cd in field experiments at different layers.

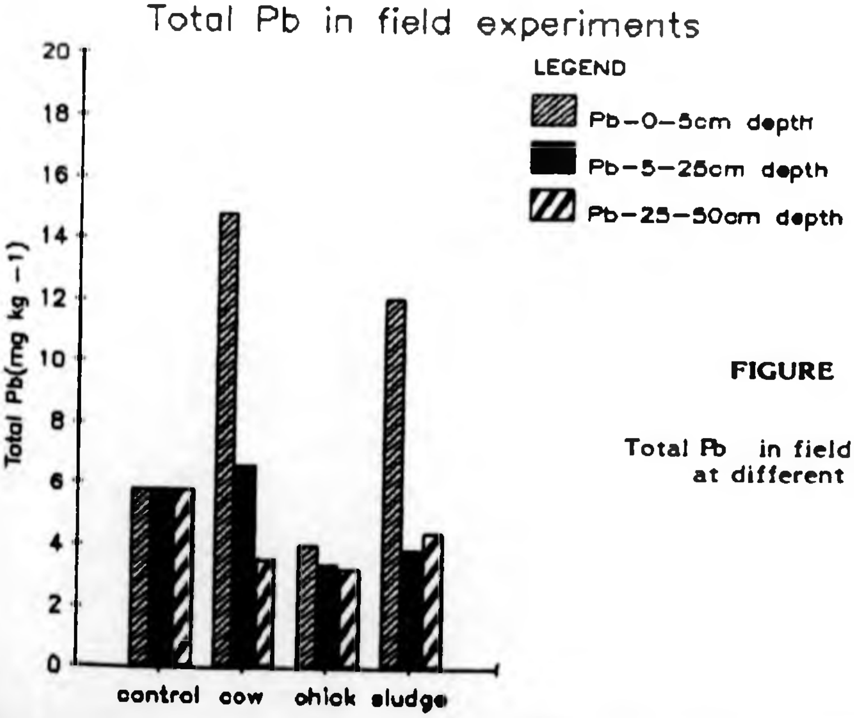


FIGURE - 5.31

Total Pb in field experiments at different layers.

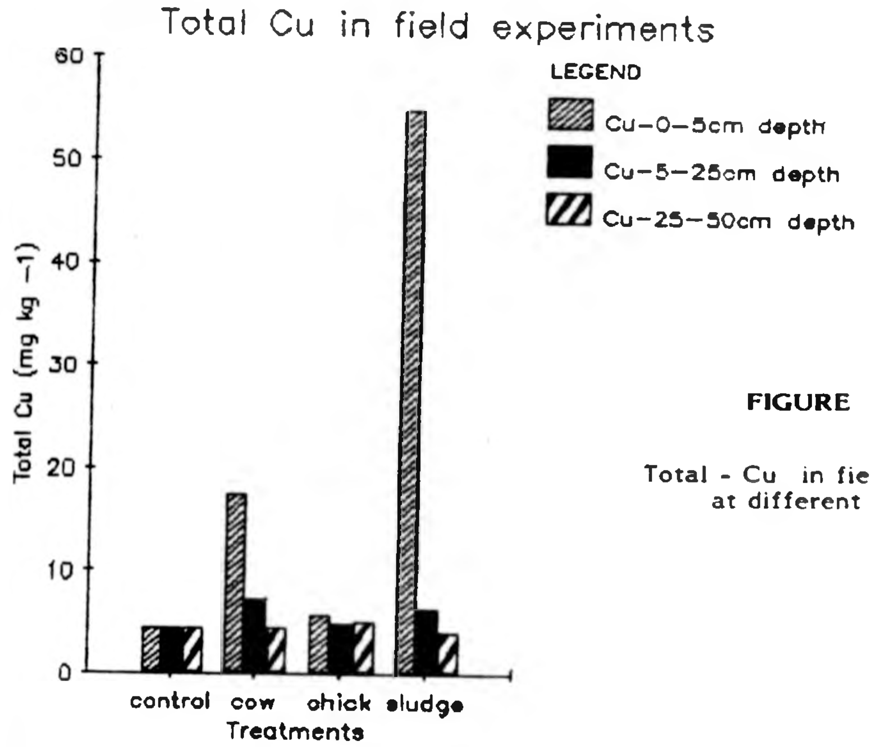


FIGURE - 5.32

Total - Cu in field experiments at different layers.

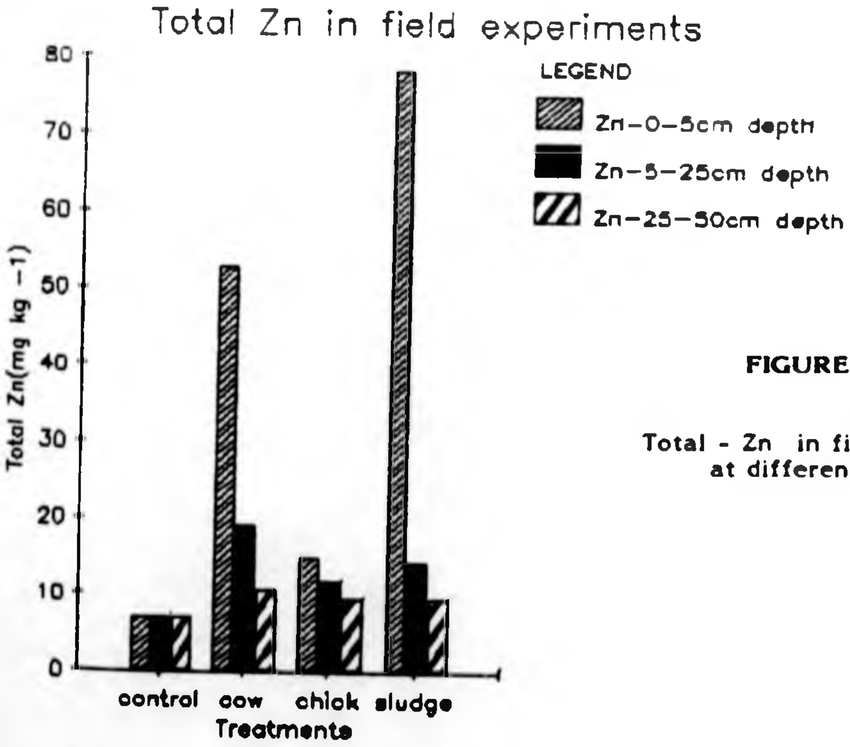


FIGURE - 5.33

Total - Zn in field experiments at different layers.

5.2.2 Effects of different organic amendments on the ground water.

The results of the ground water analyses are shown in tables-26 & 27 in Appendix. Eventhough 57 ground water samples were analysed in this study, only samples from the same treatment area are compared. Table-5.14 gives N,P,K and trace metal concentrations in ground water grouped according to the amendment treatment used. Comparisons are also given for the leachate from pot experiments treated with 40 Mg ha^{-1} cow manure, chicken manure and sewage sludge. Rank order of ions were similar in ground water and in pot leachates.

In the case of ground water, six samples were obtained from chicken manure treatment area, four from cow, 1 from sludge, and 4 from control (non-amended areas). The number of samples were insufficient for statistical analysis of the effects of the organic amendments.

5.2.2.1 N, P, K and pH

Results show that concentration of these elements in ground waters were relatively low in the sludge treated area. 1.4 mg L^{-1} NO3-N was the second smallest value observed in the area. P concentration was 0.01 mg L^{-1}. The K concentration of 38 mg L^{-1} at the sludge area was near the middle of the range for the waters sampled (16-100 mg L^{-1}). Largest concentration of N, P, K were found in the Al-Akr area (sample-55), where a NO3-N concentration of 22.5 mg L^{-1}. was observed. Otherwise concentrations of N, P, K in the control area were similar to those in treated areas. pH value was neutral and varied from 6.8-7.5.

Table- 5.14

Effects of Treatments on ground water

Properties of Ground water from different amendment treated plots

Properties	Control area	Cow manure area	Chicken manure area	sludge area	pot test leachate (40 Mg ha^{-1})			
					control	cow	chicken	sludge
	n=4	n=4	n=6	n=1	n=8_			
Conductivity at 25 C(S m^{-1})	0.53	0.90	0.63	0.70	2.72	1.58	1.51	1.90
NO3-N(mg L^{-1})	2.55	8.18	2.42	1.40	27.65	28.43	139.65	140.75
PO4-P(mg L^{-1})	0.01	0.09	0.01	0.01	0.19	0.13	0.69	0.69
K (mg L^{-1})	39.00	71.15	39.43	38.00	263.65	230.38	428.18	227.30
Cd (ug L^{-1})	0.55	0.42	0.38	0.65	0.98	1.15	0.96	1.44
Pb (ug L^{-1})	3.26	3.10	3.57	3.65	12.61	13.66	14.26	14.44
Zn (ug L^{-1})	10.53	8.27	10.75	12.50	6.87	15.50	26.13	21.75
Cu (ug L^{-1})	3.94	4.09	3.96	3.86	26.10	30.18	32.35	37.96

5.2.2.2 Trace metals.

The maximum cadmium concentration of 0.85 ug L^{-1} in ground water was found in the control area. A maximum zinc value of 14 ug L^{-1} was found in the chicken manure area, but this was only slightly greater than the concentration of 12.15 ug L^{-1} found in the control area. Lead ranged from 1.90-3.85 ug L^{-1} with again the maximum concentration in the control area. Copper concentrations in the control area were all greater than that in the sludge treated area. There was thus no evidence of systematic differences in ground water trace metal concentrations among the treated areas.

Table.5.14 compares ground water mean trace metal concentrations from sludge amended and control areas with leachates from pot experiments. For all metals, pot leachate concentration were larger than those in the ground water, particularly in the case of copper where the pot leachate was 9 times more than the concentration in ground water.

5.2.3 Effects of different treatments on drainage water

The quality of agricultural drainage water throughout Bahrain has been investigated with respect to N, P, K and trace metals. The results are shown in Tables- 30 & 31 in Appendix. Although 35 drainage waters were analysed in this study, only six drainage water samples collected from a chicken manure treatment area, 2 from a cow manure treated area, 2 from a sludge area and 1 from a control area are compared here. Table-5.15, gives N, P, K and trace metal concentrations in drainage water, grouped according to the amendment treatment used. Comparisons are made as in section 5.2.2.

5.2.3.1 N, P and K.

The results show that N, P, K concentrations in the drainage water were variable. The smallest NO3-N was observed (0.5 mg L^{-1}) at the cow manure treatment area and the highest (87.9 mg L^{-1}) at the chicken manure treatment area which was about 36 times greater than the average ground water value. Control area had 11 mg L^{-1} NO3-N. The P concentration was constant (0.01 mg L^{-1}) in all the samples except one at the sewage sludge treatment area (0.39 mg L^{-1}). K concentrations in the drainage waters varied from 46.9-110.0 mg L^{-1}, the lowest and the highest being at the chicken manure treatment area. Otherwise the N, P, K at the control area was generally similar to those in the treatment areas, and there was no regular pattern of difference among the different treatments.

Table- 5.15

Effects of Treatments on Drainage water

Properties of Drainage water from different amendment treated plots

Properties	Control area	Cow manure area	Chicken manure area	sludge area	pot test leachate (40 Mg ha^{-1}) control	cow	chicken	sludge
	n=1	n=2	n=6	n=2	n=8			
Conductivity at 25 C(S m^{-1})	0.76	1.09	1.00	0.86	2.72	1.58	1.51	1.90
NO3-N(mg L^{-1})	11.00	0.70	21.88	12.25	27.65	28.43	139.65	140.75
PO4-P(mg L^{-1})	0.01	0.01	0.01	0 .20	0.19	0.13	0.69	0.69
K (mg L^{-1})	60.20	72.25	75.72	56.95	263.65	230.38	428.18	227.30
Cd (ug L^{-1})	1.50	2.10	2.45	1.95	0.98	1.15	0.96	1.44
Pb (ug L^{-1})	9.40	15.65	18.58	13.00	12.61	13.66	14.26	14.44
Zn (ug L^{-1})	2.20	3.65	2.53	3.75	6.87	15.50	26.13	21.75
Cu (ug L^{-1})	23.50	9.35	13.12	9.65	26.10	30.18	32.35	37.96

5.2.3.2 Trace Metals

Drainage water trace metals were variable. Cadmium was highest in the chicken manure treatment area (2.8 ug L^{-1}) followed by cow manure treatment area (2.1 ug L^{-1}). The sewage sludge treatment did not increase the cadmium content (1.95 ug L^{-1}) of the drainage water. Lead, zinc and copper showed a very similar pattern, zinc showing the highest concentration after sludge treatment. Lead value was generally found higher in the treatment areas than the control ones.

Table.5.15 compares drainage water mean trace metal concentrations from sludge amended and control areas with leachates from pot experiments. There was a clear difference in metal levels in sewage sludge treated area for Cd, Pb and Zn. Copper showed a 2 fold increase in concentration in the control area.

5.2.4 Effects of organic amendment application on surface runoff.

In order to gain more information on the effects of treatments on water, all farms sampled were visited after first rain and water samples collected from amendment treated fields. The quality of agricultural runoff water throughout Bahrain has been investigated with respect to pH, salinity, conductivity, bicarbonate, chloride, sulphate, sodium, potassium, magnesium, calcium, nitrate-N, nitrite-N, ammonia-N and phosphate-P. Results of the runoff water analysis are shown in Tables-28 & 29 under Appendix.

Eventhough more than 29 water samples were analysed, only six samples from chicken manure treated area, one sample each from cow manure, sludge and from background area are shown in Table-5.16 for comparison. This Table gives N, P, K and trace metal concentrations in runoff grouped according to the amendment treatment used.

5.2.4.1 N, P & K.

Nutrient content (NPK) of runoff generally did not show high values as shown in Tables.28 & 29. NO3-N varied from 0.2-96.3 mg L^{-1}., the highest being at the chicken manure treatment area. PO4-P was constant throughout, the highest showing 0.1 mg L^{-1} at the sludge treated area. The K concentration varied from 17-550 mg L^{-1} but the sludge treated area had the lowest concentration and the control area showed the highest concentrations.

Table- 5.16

Effects of Treatments on runoff

Results of runoff from different amendment treated farms.

Properties	Control area	Cow manure area	Chicken manure area	sludge area	pot test leachate (40 Mg ha^{-1}) control	cow	chicken	sludge
	n=1	n=1	n=6	n=1	n=8			
Conductivity at 25 C(S m^{-1})	4.79	1.88	2.74	0.20	2.72	1.58	1.51	1.90
NO3-N(mg L^{-1})	0.20	3.70	25.53	0.20	27.65	28.43	139.65	140.75
PO4-P(mg L^{-1})	0.01	0.01	0.03	0.10	0.19	0.13	0.69	0.69
K (mg L^{-1})	550.00	112.00	220.70	17.00	263.65	230.38	428.18	227.30
Cd (ug L^{-1})	0.80	1.50	3.17	1.60	0.98	1.15	0.96	1.44
Pb (ug L^{-1})	15.00	28.20	51.95	22.00	12.61	13.66	14.26	14.44
Zn (ug L^{-1})	32.20	25.00	33.09	28.60	6.87	15.50	26.13	21.75
Cu (ug L^{-1})	16.00	16.20	18.54	12.00	26.10	30.18	32.35	37.96

5.2.4.2 Trace Metals;

The maximum cadmium concentration of 10.12 ug L^{-1} was found in the chicken manure treatment area and the lowest in the control area (0.8 ug L^{-1}). Lead varied from 16.1-100.2 ug L^{-1}.. Lead concentration in the run-off water from chicken manure treatment area was the highest metal concentration reported (100.20 ugL^{-1}). Zinc and copper in the runoff varied from 16.65-55.20 ug L^{-1} and 12.00-25.10 ug L^{-1} respectively. Highest zinc concentration was noted in the runoff water from chicken manure area.

Table-5.16 compares ground water mean trace metal concentrations from sludge amended and control areas with leachate from pot experiments. There was no major difference in metal levels in runoff water from sewage sludge treated area.

5.2.5 Effects of sewage sludge use on trace metals concentration in crops..

Results of the analysis of crop plants together with their allowed metal limits are shown in Table-5.17. Plant species analysed were Rye grass (Lolium multiflorum), Rhodes grass (Chloris gayana), Alfalfa (Medicago Sativa.L) and Sudan grass (Sorghum Sudanensis).

All the soils used to grow grass using sludge had a pH above 7.0 (Table-18). Average concentration of Cd, Cu, Zn and Pb in plants from sludge treated plots were

0.26, 6.21, 35.98 and 1.73 mg kg^{-1} respectively whereas from control area concentrations of Cd, Cu, Zn and Pb were 0.09, 9.87, 44.83 and 1.31 mg kg^{-1}. respectively.

Differences between plants from control area and from sludge treated plots were larger for Cu, Zn and Pb. Samples from Hamala and Al-Areen exhibited appreciable Cd, buildup in plants. But for other metals there was no evidence for increased trace metal uptake from sludge treated soils.

Plant materials grown on the sludge application sites generally exhibited metal contents within the normal ranges defined by Blackeslee (1976) for agricultural crops, except for Cd. At Hamala all the plant tissues had cadmium levels more than allowed in plants meant for feeding the animals.

Rye-grass grown on soil using sewage sludge for the past five years at Hamala showed levels of Cd, Cu, Zn and Pb of 0.54, 13.95, 60.64 and 3.45 mg kg^{-1} respectively and was the highest concentration found.

As the result shows, Cd and Pb has shown an increasing tendency in crops. Zn, Pb and Cu contents were high at Hamala grass than at Al-Areen.

Table-5.17

Trace metals in Plants

Plant sample & years of sludge use	Cd mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}	Pb mg kg^{-1}
Rye grass at Hamala (5 years use) (Lolium multiflorum)	0.54	13.95	60.64	3.45
Rhodes grass at Hamala (3 years use) (Chloris gayana)	0.28	8.20	82.70	4.80
Rhodes grass at Hamala (1 year use)	0.32	4.92	12.80	3.69
Alfalfa at Al-Areen (5 years use) (Medicago Sativa.L.)	0.55	5.19	21.80	0.35
Sudan grass at Al-Areen(5 years use) (Sorghum Sudanensis)	0.11	7.02	45.70	0.43
Rhodes grass at Al-Areen(5 years use)	0.07	4.30	45.40	0.37
Rhodes grass at Al-Areen(2 years use)	0.14	3.30	12.80	0.44
Rhodes grass at Al-Areen(1 year use)	0.06	2.80	5.97	0.29
Mean	0.26	6.21	35.98	1.73
S.D	0.19	3.61	27.13	1.91
Control area:				
Alfalfa at Al-Marooze farm(5 years)	0.07	9.20	38.10	1.67
Alfalfa	0.11	10.10	42.50	0.94
Sudan grass	0.10	10.30	53.90	1.32
Mean	0.09	9.87	44.83	1.31
S.D	0.02	0.59	8.15	0.37
* Common average composition for animal consumption.(mg kg^{-1})	0.056- 0.20	3.00- 40.00	15.00- 150.00	0.50- 5.00
* Suggested tolerance level (mg kg^{-1})	3	150	300	10

Source: Sommers & Nelson (1980). Agronomy Dept. Purdue
*** University. West Lafayette. IN 47907. Publi. AV-240.**

Main Findings :

Organic amendment use increased CEC, aggregate stability and organic carbon content of the soil in the 0-5 cm layer. This was clear from pot and field experiments. Heavy metal concentration increased in soils after the addition of amendments. But none of the metals present in the soil exceeded the maximum recommended levels as per guidelines. The major factor influencing metal concentration in soils was the use of sewage sludge. Nutrients (N, P and K) and metals were not being leached to the ground water, but runoff water from farms contained high concentration of nitrates. Phosphorus concentration was variable and highest concentrations were noted in the case of chicken manure treatment. Only cadmium content of plant materials grown on the sludge treated sites exhibited higher levels than allowed in plants intented for feeding the animals. Water of low salinity and high salinity had only a minor effect on the soil properties.

CHAPTER-6

DISCUSSION

6.0 Discussion :

6.1 Characteristics of the unamended soils and their suitability for agriculture:

The soil at Hamala was a very shallow sandy loam, with hard limestone occurring at a depth of 20-30 cm below the surface. Organic matter content, nitrogen and phosphorus were all small, (C = 0.62%, N = 910 mg Kg^{-1}, and P = 11.74 mg Kg^{-1}.) at the surface. pH and calcium carbonate content were both slightly high and the soil was highly saline, (ECe 4.52 S m^{-1}) with sodium and chloride dominant in the soil solution. Total and acetic acid-extractable trace metal concentrations were small.

The potential use of such a soil in its natural state is thus very limited. Hard limestone at shallow depths is an effective barrier to root penetration, water movement and leaching of soluble salts. The large stone content and sandy texture results in reduced water holding capacity, and the stone content also restricts the use of agricultural machinery. Chemically, nutrients are potentially limiting factors. Although calcium and magnesium concentrations and the ratio of these are adequate for plant growth, phosphorus and micronutrient availability are restricted by the neutral pH and high calcium content, and nitrogen is also in short supply. Large concentrations of soluble salts in the soil solution are a further problem for sensitive crops, and the gypsum content has considerable engineering significance, with a danger of subsidence as the mineral dissolves in irrigation water.

The soil is thus not suitable for agriculture without considerable modification. Removal of stones from the topsoil, additions of sweet sand, leaching of soluble salts with suitable irrigation water and large additions of organic manure are all essential if crops are to be grown successfully.

The soil at Budaiya was sandy and strongly saline at the surface, with a moderately saline subsurface. The predominant salt was sodium chloride. The soils were poorly drained. CEC values were very small, showing a tendency to retain negligible amounts of nutrients in the soil. Soils under investigation contained very large soluble salt concentrations (2.89% for Hamala, 3.63% for Budaiya) which can harm plant growth.

Both the soils contained insufficient primary nutrients, such as NPK, but were rich in secondary nutrients such as Ca, Mg, and S. The essential trace metals Cu and Zn, were present in the soil. Other trace metals such as lead and cadmium have no special function in plants and they are therefore treated as unwanted or toxic.

The physical properties of the soil at Budaiya are generally good for agriculture, due to the large rooting depth, and small stone content. As in all other agricultural practice in Bahrain salt leaching, addition of organic manure and provision of a good drainage system is necessary for good crop yields.

The main constraint on cropping is the limited availability and low quality of irrigation water (Ahmed, 1980). Existing ground water supplies may however be used for irrigation in sandy soils, for locally suited crops. The local Alfalfa for example, is able to tolerate a high level of salinity (up to 8000 mg L^{-1}) in irrigation water. All the important crops in Bahrain Alfalfa, Tomato, Brinjal, Onion, Okra, Cucumber and Dates have been successfully grown for years using local irrigation water without significant yield reduction. The SAR values of irrigation waters lie between 5.6 - 10.6, illustrating that these waters were in the medium to high sodium range. The severity of salinity problems are reduced in Bahrain because, waters used for irrigation are relatively high in their dissolved calcium bicarbonate and calcium sulphate concentrations and the soils are mostly coarse textured.

Frequent small applications of irrigation water and selection of vegetable varieties that are tolerant to high salinities can reduce the effects of salinity in the two areas examined. When evaporation is high, application of saline waters to vegetative surfaces can cause leaf burn. Night application of irrigation water is therefore preferred in Bahrain. Since for most crops the most sensitive stage of growth is during germination and at seedling emergence , high salinity of either soil or water, may delay or inhibit germination or early growth. This can be overcome by utilizing low salinity water for about 2 weeks during the early growth stage (Amer, 1983).

pH was neutral in both soils and alkalinity problems were not anticipated. Extractable phosphorus concentrations were very small in both the soils. Phosphorus is most available in the pH range of about 6-7. Above pH 7.0, phosphorus starts to form insoluble compounds with Ca (Leonard, 1976). As the pH was above 7.0 and soils were rich in calcium carbonate and sulphate, most of the phosphorus will not be available to plants. Soil pH also has a large effect on the availability of micronutrients. With the exception of Mo, all the micronutrients such as Fe, Mn, Cu, Zn and B become increasingly insoluble and unavailable to plants as alkalinity increases. The normal average ranges of trace metals in the soil are Cd = 0.1 - 1.0 mg kg^{-1}, Cu = 5-20 mg kg^{-1}, Pb = 0.1 - 20 mg kg^{-1} and Zn = 10-50 mg kg^{-1}. (Webber, et al, 1984). Maximum allowable concentrations are for Cd 3 mg kg^{-1}, Cu 100 mg kg^{-1}, Pb 100 mg kg^{-1}, and Zn 300 mg kg^{-1} (CEC, 1986). By these criteria the unamended soils under study had adequate amounts of essential trace elements (Cu & Zn) and showed no signs of toxic levels of heavy metals (Cd & Pb).

6.2 Effects of the organic amendments on the soils and Leaching waters : Pot experiments:.

6.2.1 Cow manure, chicken manure and sewage sludge at 40 Mg ha-1.

The pot experiments were designed to test the effects of the three organic amendments on soil properties under controlled laboratory conditions, specifically to examine the relationships between the beneficial increase in organic matter and nutrients and the potentially harmful increases in trace metals. Cow manure had the largest C:N ratio (33:1), and smallest concentrations of N, P and trace metals. Chicken manure was richer in N, P, Cu and Zn, but still had low concentrations of Cd and Pb. Sewage sludge had the greatest concentrations of major nutrients (except K) but also of potentially toxic elements. The irrigation waters used were similar in all respects except salinity. These waters were not expected to affect the nutrient or trace element content of the soil, but were used to quantify the impact of agricultural practices on soil salinity and its interaction with nutrients and trace metals.

6.2.1.1 Organic Carbon (OC), Nitrogen (TKN), Phosphorus & Potassium

Cow manure and chicken manure treatments resulted in similar carbon contents in the 0-5cm soil at the end of the pot experiment, despite the fact that the C contents of the cow manure added was only some 50% of that in the chicken manure. The oxidation calculations (Table-6.1) showed that more C from chicken manure was oxidised during the six month monitoring period. Analysis of the chicken manure revealed a much smaller C:N ratio compared to 33:1 in the cow manure and substantially greater concentrations of K and P.

Sewage sludge however had a low C:N ratio (8:1) but oxidation percentages were similar to that of cow manure and more C remained in the soil at the end of the experiment (Figure-5.1). The only major macro nutrient deficiency in sewage sludge was the very low K concentration (0.5%). Low sludge oxidation may also have been related to the substantially greater metal concentration in this material. High salinity water appeared to have an inhibitory effect on the oxidation of C from cow manure and sludge treatments. Percentage oxidation of added C was reduced to nil in the Hamala soil for these materials.

Table-6.1

OC Oxidation pattern at 0-5cm layer after the pot experiment

		Cow manure	Chicken manure	Sludge
		<---------	40 Mg ha^{-1}	------------>
Hamala : soil (WT1)	C- added (g)	5.70	12.07	10.38
	C-remaining (g)	2.55	2.55	5.05
	% oxidised	55.30	78.90	51.30
(WT2)	C-added (g)	5.70	12.07	10.38
	C-remaining (g)	7.10	5.48	11.17
	% oxidised	0.00	54.60	0.00
Budaiya Soil (WT1)	C-added (g)	5.70	12.07	10.38
	C-remaining (g)	2.53	5.63	8.03
	% oxidised	55.60	53.40	22.60
(WT2)	C-added (g)	5.70	12.07	10.38
	C-remaining (g)	4.50	3.30	7.03
	% oxidised	21.10	72.70	32.30

Aerobic sludge compost plus the organic fraction of urban refuse has been reported to bring about an increase in organic carbon in the soil (Guidi 1980). Danneberg et al (1981) in experiments on fine sand reported that addition of cattle manure had increased the percentage of Organic Matter 1.58 times after 10 years and 5.15 times after 15 years, compared to the amount of organic matter in the control soil profile. Testes (1990) and Rappaport (1988) reported that salts which are present in sewage sludge can be inhibiting to C decomposition when added to soil (25% less than in cow manure).

Stevenson (1982) found that carbon increases were less in areas using cow manure. Climatic influences were particularly apparent from the studies of Haghiri et al (1982) in Ohio. Carbon had increased at the Ohio site ranging from 0.05 to 2.4% at the end of one year for C application rates ranging from 15.5 to 99.9 Mg C ha^{-1} and an increase of 0.7 to 1.85 % was obtained after various other treatments. Seaker et al (1988) had found an organic carbon content increase to three fold on the sludge amended sites when applied at rates of 120 to 134 Mg ha^{-1} for one year. In the present study C additions were 8 to 17 Mg C ha^{-1}. Carbon decomposition studies done by Gupta et al (1970) had indicated that decomposition was not linear with time. The increase in C in their study was 67% in the first year which was reduced to 50% in the second year. This non-linearity in decomposition further complicates the problem of expressing the data on net C increases in soil as a function of C application rates (Khaleel et al. 1981).

As a rule, C/N ratio of undisturbed topsoil in equilibrium with its environment is about 10 or 12 to 1, (Golueke et al 1981). But in our soil experiment C/N ratio of soils were much higher except in the case of the chicken manure and sludge treatments showing a C/N ratio of 9.5/1, 10.7/1 respectively. This could be partly because of the higher content of NH4+-nitrogen and the generally lower amounts of carbon.

The organic amendments used also resulted in substantial increases in N and P in the treated soils (Figures- 5.2 & 5.3). Greatest increase in N were found in the sludge treated soils. Greatest increase in P were found in chicken manure treated soils, reflecting the rank order of the organic amendments for these elements. N retained in the soil after the experimental period was between 70 and 90 % of N added, (Table-6.2) whereas the added P was retained in the soil. No significant difference in the N or P concentrations between water types were found.

There was no significant difference in N and P in the 5-16 cm soil, showing that organic amendment effects are confined to surface layers only. As the nutrient contents (NPK) of the soils are related to the organic matter content of soils, most of the increased concentrations of these major nutrients N, P and K can be attributed to the increased organic matter of the soils. Nitrogen and Phosphorus balance after the pot experiments are given below in Table-6.2

Table-6.2

N and P balance after the Pot Experiment

		cow manure	gain %	chicken manure	gain %	sludge	gain%
Hamala soil	N added (g)	0.17		0.98		1.33	
	N remaining WT1(g)	0.13	76.5	0.78	79.6	1.10	82.7
	N remaining WT2(g)	0.16	94.1	0.78	79.6	0.98	73.7
	P added as tot-P g	0.13		0.49		0.43	
	P available WT1(g)	0.03	23.1	0.15	30.6	0.07	16.3
	P available WT2(g)	0.04	30.8	0.18	36.7	0.07	16.3
Budaiya soil	N added (g)	0.17		0.98		1.33	
	N remaining WT1(g)	0.08	47.0	0.68	69.4	0.93	69.9
	N remaining WT2(g)	0.11	64.7	0.62	63.3	0.87	65.4
	P added as tot P g	0.13		0.49		0.43	
	P available WT1(g)	0.03	23.1	0.13	26.5	0.06	13.9
	P available WT2(g)	0.06	46.2	0.18	36.7	0.05	11.6

Most of the N added remained in the 0-5 cm layer. More gain was noticed in the case of high saline water use (WT2), reflecting less decomposition. There was no difference in properties between two soil types (Hamala and Budaiya soils). It was seen that P release was much slower (11.6 - 46.2%) than in case of N. Phosphorus added was as total PO4-P and phosphorus extractable is considered as phosphorus available for plant uptake. In this case the added P will still be in the non-available portion constituting the total P content of the soil. Sludge treated soil showed less available phosphorus, than other treatments.

The main mineral elements that are needed for growth and development of plants, and are required in large amounts are N, P, K, Ca, Mg and S. N is an element that ensures quantity of production, P is necessary for quality. K is a catalytic agent in the various chemical processes with the plant. Mg and Ca are required for healthy seed. In the soil nutrient solution usually Ca 300 mg L^{-1}., N 200 mg L^{-1}., K 200 mg L^{-1}, P 65 mg L^{-1}, Mg 50 mgL^{-1}., Cu 0.5 mg L^{-1}. and Zn 0.5 mg L^{-1}. are required for proper plant growth (Russell, 1973).

The optimum K level in the soil appears to be 20-60 mg kg^{-1}. (Chapman, 1966) but 14.5 mg kg^{-1}. in equilibrium solution was sufficient for optimum yields. For crops like tomatoes, 8.7 mg kg^{-1} in sorption equilibrium solution would maximize growth. Concentration of water soluble K will be as low as 8 mg kg^{-1} in deficient soil. FAO (1972) has noted that K ion concentration in the soil solution is usually in the range of 10 -4 to 10 -5 molar (0.391 mg L^{-1}, FAO, 1972) and in well supplied soils 39.1 mg L^{-1} (10 -3 molar).

In this study exchangeable K was not significantly different after the treatments. The concentrations were all high to classify the soils as well supplied.

Losses of N (TKN) from soils can be attributed to leaching and to denitrification processes. In the present study, increased N was found only in the surface 5 cm indicating that it occurs mainly as NH4+ or as organic nitrogen forms. The small leaching of TKN (1.10 - 14.50 mg L^{-1}) confirms that some nitrification is occurring. Low TKN and high NO3-N content in leachates (1.50 -250.80 mg L^{-1}) showed that organic nitrogen was mineralized releasing NH4-N. It subsequently was converted to NO3-N and lost through leaching. Similar case was reported by Aschmann et al (1990).

Variations in levels of NO3-N in leachates in two pot experiments may be due to different rates of transformation of NH4-N to NO3-N. In the first case using WT1, the process might have been hindered by water saturation due to blockage of pot exit tube or due to the difference in packing of the soil.

Microorganisms will utilize any NH4+ or NO3 present in the soil to further decomposition (Tisdale et al, 1985). Otherwise nitrogen concentration will increase due to N immobilization (conversion of inorganic to organic form). Generally when organic substances with C/N ratios wider than 30 : 1 are added to soil, there is immobilization of soil N during the initial decomposition process. The pattern of C decomposition here supports this in the case of cow manure (C:N = 33:1). Those deficiencies may be corrected by the addition of nitrogenated mineral fertilizers (Golueke et al 1981, FAO, 1974, Frink , 1971)

Addition of amendments with a C/N ratio above 30 produces biological blockage of available nitrogen due to the accelerated growth of microflora that use N for their own development (Fitzpatrick, 1983). On the other hand, organic amendments with C/N ratio lower than 20 cause a smaller increase in microflora than those with C/N ratios above 30, implying that soil N is not biologically immobilized (Fitzpatrick 1983). Kuo, (1981) observed that nitrification of a sandy soil decreases gradually with increasing doses of organic matter, and among cow manure, chicken manure, sewage sludge and garbage compost, the latter is the fertilizer that least stimulates nitrification.

The total nitrogen content of the organic amendment being added to soil is a factor to be considered when predicting effects on N release. Concentrations between 1.5 and 1.7 % N are usually sufficient to minimise immobilization of soil N (Tisdale, et al, 1985).

An earlier study conducted in Bahrain (Amer, et al 1981) had indicated that there was significant steady increase in yield with the increase in the rate of organic fertilizer addition regardless of the organic fertilizer type. In his experiments, cow manure and poultry manure at the rate of 2 kg/m2 (20 Mg ha^{-1}) and a total addition of N-P2O5-K2O of 150- 300-150 Kg ha^{-1}, respectively were used. As the soils were adequate in available K, the response to added K was negligible. The experiment showed that the limiting factor in the fertility of the soil was N, and an increase in yield was possible if P and K was also added along with N regardless of their chemical sufficiency levels in soil.

Accordingly our present addition of 40 Mg ha^{-1} was sufficient to meet approximately the above criteria. But in the pot experiments, no plants were grown. So to compensate the uptake of nutrients by plants adequate supply of N-P-K either in large quantity of amendments or as inorganic fertilizers are needed for practical purposes.

Allison (1957) in studies involving cropping to non-legumes in the U.S, concluded that 15% or more of the total nitrogen applied was unexplainably lost, and Viets (1962) reported some notably larger unexplained losses. Allison (1957) indicated that no more than 50-60% of applied fertilizer N is utilized by crops even with immobilization taken into account. Residual nitrogen is least significant in very sandy soils of low WHC but does occur to some degree even with humid conditions (Pearson et al, 1967).

Effective use of fertilizer nitrogen must take into account interactions between the nitrogen and water management practices employed. According to Bremner (1965a), more than 95% of the total nitrogen in most surface soils is in the organic form. The organic soil nitrogen is mineralized by microbial process to plant-available inorganic form (NH4+ and NO3). A soil having 2% organic matter would contain about 44000 Kg of organic matter/ha (based on 2.2 x 10^6 Kg of soil/ha to a 15 cm depth), which would be equivalent to 2200 Kg N/ha (based on organic matter containing 5% N). Allowing for a mineralization rate of 2%, the soil would supply the crop with about 44 Kg N/ha which is sufficient for plant growth.

The mineralization of organic phosphorus has been studied and a C/N/P ratio of 100 : 10 : 1 for soil organic matter has been suggested. It is clear that no one set of figures will describe the ratio for all soils. It has been suggested that if the C/inorganic P is 200 : 1 or less, mineralization of P will occur, if the ratio is 300 : 1 immobilization will occur. Usually N/P ratio is closely tied in with mineralization and immobilization of P and suggests that the decreased supply of one results in the increased mineralization of the other. Thus if N, were limiting, inorganic P will accumulate in the soil and the formation of soil organic matter would be inhibited. In pot experiments C:N:P ratio of 100:10:1 was generally found in soils.

Regarding the effects of amendments on the phosphorus content of soil, field experiments have shown that these compounds contribute towards an increase in available P in soil (Bengtson & Cornette, 1973) and this same has been verified by experiments in plots and pots (Hortenstine & Rothwell, 1972; Gupta et al, 1975). Phosphorus leaching was studied by Cooke (1962) and Williams (1975), Olsen and Watanabe, (1966), Oniani et al (1973) in sandy soils and was shown to leach very rapidly to sub soil. In the present pot experiments P leaching to lower layers was not found. Even though soils used were sandy, the high calcium concentration in soil may have fixed the phosphorus in the form of insoluble compounds.

Since P is chemically immobile, it can accumulate at the surface soil. Excess P in soil is said to cause Zn and Cu deficiencies in soil. The environmental chemistry and availability of soil P, therefore are invariably influenced by the chemical forms of P in the solid phase (EPA, 1983). This explains that negligible P loss noted in leachates from the pot experiments.

The amount of total- P in soil is usually between 0.01 and 0.2%. Usually less than 0.1% of the total P in soil is soluble in water. Concentration of P in the soil solution in most soils is between 0.03-3.0 mg L^{-1}. Australian researchers indicate that concentration of 0.2 to 0.3 mg L^{-1} in soil solution are adequate for a variety of crops (Tisdale et al, 1985). Addition of cow, chicken and sludge at the lowest rate was sufficient to have adequate soluble P content in soils investigated.

6.2.1.2 Aggregate Stability & Water Holding Capacity:

Increased organic matter contents were also responsible for the increases in those soil properties which reflect the structural development of the soil. Water holding capacity and aggregate stability increased after adding organic amendments. The increases were not so marked, however as the sodium rich irrigation water tended to disperse the soil structure as it contained very little clay. Despite the small structural improvement the soils remain of low water holding capacity, and thus crop growth needs continued inputs of irrigation water.

Aggregate stability as determined by wet-sieving of dried aggregates measures both the rapid breakdown of aggregates due to wetting anbd owing to the mechanical sieving action. Arable aggregates, partly because of their low organic matter content are weakly bound together and drying causes incipient fracture faults to develop. Upon contact with water the aggregate quickly rewet owing to rapid rehydration of particle surfaces.

The resultant rapid release of energy causes considerable aggregate breakdown. Unequal pressures caused by differential swelling during rewetting and presence of entrapped air in pores also promote aggregate breakdown (Rimmer et al, 1976).

Incorporation of organic amendments plays an important role in increasing water holding capacity, an effect which may be attributed to the colloidal nature of composts (Hattori, H. and Mukai, S, 1986.; Bengtson & Cornette 1973.; Hortenstine & Rothwell.; 1972). It has been established that the application of organic amendments improves the physical properties of the soil, especially in the case of heavy soils as it appears to promote a better soil structure and reduces the process of erosion (Tietjen, 1975, Golueke et al 1981, Bear, 1964).

6.2.1.3 CEC & Exchangeable cations.

The organic matter addition increased CEC. Hortenstine & Rothwell (1972) performed a pot experiment using sandy soil with an exchange capacity of 3.67 meq/100g and found that the addition of high quantities of compost (128 or 512 metric tonnes per hectare) increased CEC to 4.81 or 7.14 meq/100g, while small doses (8 or 32 T/ha) had no significant effects.

Similar results were obtained by Bengtson & Cornette (1973), in field experiments. In the present pot experiments, CEC nearly doubled after 40 Mg ha-1 chicken manure and 4 fold after sewage sludge treatments. Small doses of cow manure had only a small effect. The increases in CEC with increase in C in the soil was consistent with other studies (Levi-Minzi et al, 1985 and Epstein, 1976).

Soil- water content for extracting soluble salts are important for judging the exchangeable ions in soil. A problem with diluting the sample with water is that, while the concentration of some ions increases on dilution, the concentration of others may decrease (EPA, 1986). As water is added to the calcareous soil, precipitated CaCO3 or CaSO4, may gradually dissolve, releasing Ca, and Mg ions into solution. This was the reason for the increased exchangeable calcium, when low salinity water was used. Concurrently, the additional concentrations of Ca and Mg in some cases displaces Na on the exchange complex, increasing the Na level in the soil solution. This was the reason of increased exchangeable sodium concentrations in the upper layer of the soil. This supports the view of Tisdale et al, (1985) that CEC, and hence the % base saturation, can be rather arbitrary figures unless the methods by which they are measured exclude concentration of soluble cations. In this study corrections for soluble salts were not applied to the exchangeable cations.

6.2.1.4 Salinity & Soluble Salts.

Changes in soluble salts and exchangeable cations were related to the type of irrigation water used, and no significant differences were found among the organic amendment treatments. As the soils are calcareous they are 100 percent base saturated and their pH values are mainly controlled by the hydrolysis of calcium carbonate and consequently the greater dissociation of the calcium hydroxide and the production of OH- ions as compared to the production of H+ ions from the weak carbonic acid. This creates an alkaline effect and the pH usually ranges from 7.0 to 8.0. Salinity is generally high in the samples as can be judged from 1:5 solution conductivities. Saline soils have sufficient soluble salts to impair plant growth, mainly by increasing the osmotic pressure of soil solution and restricting water uptake. The nature and concentration of soluble salts in saline soils influence the entrance of nutrient ions into root hairs of the plants. A comparison of Cl^-/SO_4 ratios in surface and subsurface layers will indicate the degree of leaching. In some pots, the ratios are higher due to the ineffective degree of leaching. This is expected as the packing of pots and drainage tube fixing can effect the leaching. It is expected that the proportion of Mg to Ca will not reduce the crop yield since the ratio values of Mg/Ca do not exceed 1.0 (Amer, 1981). However generally salinity increases resulting from organic amendments were not a significant problem in this experiment.

Incorporation of manure and sludge into soil increases the salt content as well as soil electrical conductivity, because of high salinity of these amendments (Hortenstine & Rothwell, 1972; Martin 1970). Guidi (1980), showed that when sewage sludges were applied on a sandy loam soil, the electrical conductivity increased in all plots, but in every case winter rainfall lowered the content of soluble salts to a level close to that of the control. In the case of sewage sludge application promote salinization states equal to or higher than 0.4 Sm^{-1} (Epstein et al 1976) representing a serious risk to the growth of several types of crops (Allison, 1973). In the present experiment, increase in salinity due to the use of sewage sludge was not found. This could be due to the generally higher amounts of irrigation water applied to the soil, which allowed salt leaching from the upper layers of the soil.

6.2.1.5 Extractable & Total trace metals.

Increases in trace metal concentrations in the soil were closely related to the organic amendments used. As expected sewage sludge increased soil trace metal concentrations by the greatest amount.

Among the trace metals (Cd, Pb, Cu and Zn) none of the metals were present at toxic level in soils and the increase in the surface layer was equal to the addition in amendments. This also was evident in the low concentration of metals in leachates from the pot experiment. Many other studies have shown that maximum contamination takes place in the top layers of soils (El-Bassam et al, 1979; Chaney, 1973) and that leaching of trace metals is insignificant under high pH conditions. The potential hazards associated with heavy metal contamination of soils thus increase with time in the absence of leaching losses.

Heavy metals are of particular concern because they may be detrimental to crop growth or mobilized through the food chain. Limits usually specify maximum concentrations of metals which may be added on an annual basis over a period of 30 years. In U.K, the limit of addition over 30 years are in (Kg ha^{-1}) Pb 1000, Cd 5.0 (Harrison, 1985). In soil, Ni, Cu and Zn are potentially the most harmful metals to plant life and it has been suggested that Ni is roughly 8 times more toxic and Copper roughly twice as toxic as Zinc. Additions of Zn, Cu and Ni can be assessed in terms of the Zn equivalent (Harrison, 1985). The zinc equivalent concept assumes that the phytotoxic effects of Zn, Cu, and Ni are additive in the ratio 1:2:8. The recommended limit of addition of Zn equivalent is 560 kg ha^{-1}. Limit of addition when Bahrain sludge is used = 220 Mg ha^{-1} (560 x 1000 / 2543.3), as the calculated Zn equivalent in Bahrain sludge is 2543.3 mg Kg^{-1}. Accordingly a total addition of about 220 Mg ha^{-1} can be made over 30 years. In this connection, an application life of around 6 years is feasible with the present quality of sludge, if additions of 40 T ha^{-1} is made every year to the same plot. This application life could be increased if additions of sludge are reduced. The condition in Bahrain are more favourable than the conditions under which the maximum cumulative limits were established in U.K or U.S.A. The soil pH level required to effectively reduce metal uptake by plants is around 6.5 and pH of most soils in Bahrain exceeds 7.0, which reduces the potential risks of plant contamination by trace metals.

Furthermore, the calcareous content of the soil will provide a buffering effect against a drop in pH.

Chaney (1973) considered that sludge with more than 0.5 Cd/Zn should not be applied to agricultural land. Our ratio is much lower than that and neutral to alkaline pH value and carbonate content of Bahrain soils are the safe key to sludge application.

The availability of heavy metals from sewage sludge to plants are largely dependent on their solubility, which is determined by using one or more of many extractants. The acetic acid extractant used in the study extracted 8-10% Cd, 6- 15% Cu, 9.7 - 57% Zn and 5-18% Pb. These extraction efficiencies were comparable to the results reported by Baghdady and Sippola (1984 a,b).

6.2.1.6 Leachate from pot test.

pH of the leachate varied from 7.5 to 8.2, showing a neutral to slightly alkaline range. Conductivity of the leachate using high TDS water was obviously higher than the low TDS water. Nutrients such as ammonia, nitrate, nitrite and phosphate showed considerable variation in this levels. Nitrate- nitrogen levels were high in the leachates using high TDS water (15.0-250.8 mg/l). This showed that NO3-N concentrations were all above environmentally acceptable level for potable groundwater. Control pots also showed levels above 10 mg L^{-1} which cannot be explained in this study.

PO4-P was very low in all leachates. Higher levels were shown in case of leachates using low TDS water. This supports the fact (Leonard, 1976) that if pH of the soil is more than 7.0 and soils contain more calcium, there is a tendency of PO4 getting precipitated in the soil and so there is a very little tendency to leach into the lower layers. In all cases nutrients are found in increasing amounts in the case of sewage sludge treated soils.

Considerable K was lost by leaching in the pot experiments. This is in agreement with previous work (Tisdale etal. 1985) which showed that large quantities of K will be lost from the sandy soil with low CEC.

Trace metals in leachates were very low (Table- 7 & 8), showing that leaching of trace metals is negligible. It could thus be said that the problem of sludge application in Bahrain is related to soil accumulation rather than the possible runoff or ground water contamination. The results show a clear tendency for zinc and copper leaching to the lower layers of the soil. Leaching losses are shown in Table -7 and 8.

Maximum leaching loss was found in the case of copper. All leaching pots had received equal additions of water. But leachate volumes in both controls and treated pots were not equalised. So volumes of leachates collected were different and so also the concentrations of leachate chemicals.

6.2.2 Cow manure at 20, 40 and 80 Mg ha^{-1}.

The pot experiment was conducted to quantify the effects of adding cow manure at three different rates on soil properties and to test whether these effects showed a linear response to applied rates. Cow manure was selected as this was the major amendment available in Bahrain.

6.2.2.1 Organic Carbon (OC), Nitrogen (TKN), Phosphorus & Potassium.

All three additions increased the total organic carbon content in the upper 5 cm of the soil, at the end of the experimental period. The oxidation pattern is shown in Table-6.3, for different treatments, for 14 g, 28 g, and 56 g of cow manure containing 20.39 % carbon, 0.62 % N, and 0.46 % P.

During the six month incubation period, the amounts of C oxidised were variable and ranged from 0-75.4%. Oxidation pattern was thus non-uniform for reasons which are not clearly understood. In some cases C increase in the soil was greater than C added, which could be due to analytical error caused by incomplete complexation of chlorides in the determination of C. High salinity water appeared to have an inhibitory effect on the oxidation of C from cow manure treatments.

In all other cases physical and chemical changes in the soil following treatment showed no difference between the two water types.

C/N ratio of the soils were much higher than the usual value of 10 or 12 to 1 in case of cow manure treatment, which was due to the decreased value of TKN. As TKN measured included NH4-N and Organic nitrogen, its low value suggests the mineralization of added N to nitrate forms in the soil.

Table-6.3

OC Oxidation pattern at 0-5cm layer after the pot experiment

		Cow manure		
		(20 Mg ha^{-1}	40 Mg ha^{-1}	80 Mg ha^{-1})
Hamala : soil (WT1)	C- added (g)	2.85	5.70	11.40
	C-remaining (g)	1.80	2.55	2.80
	% oxidised	36.80	55.30	75.40
(WT2)	C-added (g)	2.85	5.70	11.40
	C-remaining (g)	4.85	7.10	9.05
	% oxidised	0.00	0.00	20.60
Budaiya Soil (WT1)	C-added (g)	2.85	5.70	11.40
	C-remaining (g)	2.03	2.53	7.03
	% oxidised	28.80	55.60	38.30
(WT2)	C-added (g)	2.85	5.70	11.40
	C-remaining (g)	3.60	4.50	9.93
	% oxidised	0.00	21.10	12.90

Most of the increased concentrations of major nutrients N, P and K can be attributed to the increased organic matter of the soils. N and P balance after the pot experiment are given below in Table-6.4

Most of the N added remained in the 0-5 cm layer. More gain was observed in the case of high salinity water use (WT2). There was no difference in response between two soil types (Hamala & Budaiya soils). Only a portion of the added P was available in the soil for plant uptake. Fixation of P by calcium could be a reason for the non-availability of the added P at the surface.

Similar to earlier studies, exchangeable K and K in 1:5 solution were not significantly different after the treatments. The values were all high (> $5x10^{5}$ M) to classify the soils as well supplied (Russell, 1973).

Table-6.4

N and P balace after the Pot Experiment (0-5cm layer)

		cow manure 20 Mg ha^{-1}	gain %	cow manure 40 Mg ha^{-1}	gain %	cow manure 80 Mg ha^{-1}	gain%
Hamala soil	N added (g)	0.09		0.17		0.34	
	N remaining WT1(g)	0.08	88.9	0.13	76.5	0.31	91.2
	N remaining WT2(g)	0.07	77.8	0.16	94.1	0.32	94.1
	P added as tot P g	0.06		0.13		0.26	
	P available WT1(g)	0.02	33.3	0.03	23.1	0.07	26.9
	P available WT2(g)	0.04	66.7	0.04	30.8	0.20	76.9
Budaiya soil	N added (g)	0.09		0.17		0.34	
	N remaining WT1(g)	0.03	33.3	0.08	47.0	0.26	76.5
	N remaining WT2(g)	0.02	22.2	0.11	64.7	0.29	85.3
	P added as tot P g	0.06		0.13		0.26	
	P available WT1(g)	0.01	16.7	0.03	23.1	0.11	42.3
	P available WT2(g)	0.02	33.3	0.06	46.2	0.19	73.1

6.2.2.2 Aggregate Stability & Water Holding Capacity:

Organic matter addition increased the aggregate stability by a very small amount in the Hamala soil, but in the Budaiya soil there was no significant increase. Water holding capacity did not improve significantly after adding cow manure at different rates. Cow manure alone was thus insufficient to promote aggregate formation, and addition of other colloidal substances like compost is required to increase Water holding capacity as mentioned earlier.

6.2.2.3 CEC & Exchangeable cations.

CEC showed a very slight increase in the surface layer of soils after cow manure treatment. Exchangeable cations were variable and similar to the one mentioned under 6.2.1.

6.2.2.4 Salinity & Soluble salts

Changes in soluble salts and exchangeable cations were related to the type of irrigation water used and no significant differences were found after the three different rates of application of cow manure. Water of high salinity reduced the exchangeable Ca to a little extent.

6.2.2.5 Extractable & Total metals

Cow manure had the smallest heavy metal content, and at the largest application rate of 80 Mg ha^{-1}, did not cause trace metal concentration to increase to potentially toxic concentrations. Because of this relatively low metal content cow manure has been considered suitable for use at large application rates for preparation of land for agriculture. However, the results reported here indicate that beneficial effects on soil C and soil structure are not proportional to rates of addition. Consideration thus must be given to more frequent applications at low rates rather than to individual larger applications.

6.2.2.6 Leachate from pot experiment

There was no statistically significant difference in properties of leachates after various treatments with cow manure. Water type had very little effect on the metal leachability and leaching losses of metals were also very insignificant. Low concentrations of nutrients and trace metals reflect lack of mobility of these in sandy soils. Cow manure had very little nutrients and as such lack of availability was proportional to the levels in the original manure.

6.3 Effects of organic amendments on field soils.

6.3.1 Effect of sewage sludge and animal manures on the physical and chemical properties of the soil.

17 farms were investigated to find how their physical properties and nutrients they contained were affected by manuring. Their physical and chemical properties in the 0-5, 5-25 and 25-50 cm depth are shown in Tables -17 to 22 and the results were discussed in detail in Chapter-5. Most of the crops grown in this area (except alfalfa) are shallow rooted crops and it is preferable to reduce the rates of application of the soil amendments by mixing them only within the root zone depth to obtain maximum beneficial effect.

In the 0-5 cm layer, the soil texture of the farms were mainly coarse sand making about more than 80 % of the soil particles, while the fine particles (silt+clay) make up only <20 %. The soils of the sites are sandy or loamy sand through the entire vegetable root zone depth, but occasionally sandy loam or loamy sand at surface underlain by a sandy loam layer. Coarse texture commonly favours rapid water movement, low water holding capacity and low fertility potential (Amer, 1983). It is expected that the clay minerals present would be sepiolite-palygorskite-attapulgite since these minerals are frequently found in argillaceous sediments associated with salinity in arid zones (Amer, 1983).

Texture is an important property of a soil (Shirazi et al, 1988). Sandy soils dry more quickly, drain faster and need more frequent watering to keep plants alive than fine textured clay soils. They not only hold less water than silt or clay, but also have low CEC and less surface area to hold plant nutrients. Numerous data demonstrate that the major portion of soil organic matter is found in silt and clay size fractions (Anderson et al, 1981).

To improve the texture of very sandy soils in Bahrain, loam (sandy loam) is usually added and mixed with the surface 10-15 cm, at the rate of about 800 m3/ha (FAO, 1977b).

Soil moisture retention data under different treatments at 10 kPa (field capacity) and 1500 kPa (wilting point) and the available moisture as expressed in per cent by weight for some soils were as follows (Nagmoush, 1981).

	10 kPa	1500 kPa	available moisture
control	3.46	1.48	1.98
20t/ha chick manure	4.59	2.02	2.57

Such small moisture increase would be of limited significance in Bahrain due to the large evaporation rates.

The major cations were Na+, Ca++ and Mg++, while the dominant anions Cl and SO_4. The WHC of soils were very low and infiltration rate was very rapid, about 12 cm /hr.

The effect of different treatments on the properties such as pH, CEC, exchangeable cations, soluble salts, aggregate stability, organic carbon, total nitrogen, extractable phosphorus, extractable trace metals and total metals are discussed below for the 0-5cm layer. Measurements of aggregate stability were made on > 2mm aggregate of the soil, and other properties on < 2mm soil.

6.3.1.1 Effect on pH:

pH difference among the different organic amendment treated soils were small. Soils studied were neutral and samples from all the farms showed an average pH value of 7.49 in the 1:5 (soil:water) solution. All the soils investigated were calcareous and 100 % base saturated; pH values were mainly controlled by the hydrolysis of calcium carbonate. Consequently the dissociation of $Ca(OH)_2$ and the production of OH ions will be greater than the production of H+ ions from the weak carbonic acid. This creates an alkaline effect and the pH of the soil is neutral to alkaline.

Soil reaction is an important factor in soil productivity and plant growth. Soil pH is highly technique dependent, and many soil or experimental factors may influence measured values (Moore, 1969, Russell, 1973). Bacteriological activity in the soil, and the availability of nutrients in soils and fertilizers for temperate crops, are greatest when the soil pH is between 6 and 7 (FAO, 1972). This neutral pH also limits the potential solubility of toxic metals such as Cd, Zn,Cu and Pb , whose solubility is at a maximum at low pH.

6.3.1.2. Effect on CEC :

CEC was substantially increased by the amendment treatments in the surface 0-5 cm layer in all the farms investigated which averaged 4.59 meq/100g. The control soil showed very low CEC.

The CEC showed a moderate correlation with the amount of organic matter present in the soil (CEC meq/100g = 2.3 + 1.6 C% with R^2 =0.3).

The ability of a soil to hold cations in exchangeable form is a property of its fine mineral particles and of its humus component (Hesse, 1971). The soils used for this study ranged from sandy to sandy loam texture. In mineral soils the clay fraction is most responsible for the cation exchange properties (Epstein et al 1976, Baxter et al 1983). Clay content in the 0-5 cm layer varied from 0.5% to 10.0% in the soils investigated. Maximum CEC was noted in farm No. 17, where sewage sludge was used as an amendment for the past 3 years (Table-19). In Bahrain soils, low organic matter, low humus and clay content may be the reason for the very low CEC.

Usually at low pH values, CEC is low but increases as the pH value rises (Fitzpatrick, 1983). Soils with a low CEC have little nutrient holding ability and are also likely to have poor natural fertility due to their low content of humus and clay (Leonard, 1976). Additions of organic amendments had only a minor effect on improving the CEC of the soil. To improve CEC of the soil, large quantities of organic manure additions are required.

6.3.1.3 Effect on Organic Carbon:.

In routine analyses for categorising soils, only the total amounts of Carbon are determined and results reported as percentage by weight. The carbon percentages usually are multiplied by the conversion factor of 1.72 to give an indication of the total amounts of organic matter present (FitzPatrick, 1983).

Organic carbon in surface 0-5 cm soils showed variation in different farms. Farms 7, 9, 11 and 17 showed a value of 2.03, 2.48, 3.56 and 2.03 %, respectively. All other soils showed low values, implying very low organic matter and thus very low microbiological activity. Organic carbon value at the surface layer in farms are all different. It could be due to the fact that in the presence of the loam (sand) addition in some plots, organic matter might have decomposed at different rates. Higher value in some plots were due to the mixing of organic amendment directly with the sandy soil. Seaker et al (1988), found that C/N ratio of about 25 was that of nutritionally balanced soil and that of most native soils was 10 to 12. Organic matter helps stabilize soil structure and partially decomposed organic residues can prevent soil particles from coalescing and so maintain an open structure (Johnston, 1986). The amount of organic matter in the soil depends upon the input of organic matter and its rate of oxidation both of which are affected by farming system i.e. soil use and management, and by soil texture and climatic conditions. Results obtained showed clearly the importance of using organic matter as a means of improving sandy soil. Additions of organic amendments has increased about 2.5 times the OC of the surface layer.

However in most cases organic carbon content did not show a set pattern of increasing tendency with time. In the field experiments the cow manure treated plots showed the highest C concentration. This was also in line with the pot experimental findings, where it was reported that most of the added C in cow manure remained in the soil surface layer unoxidised. This can be attributed to the low oxidising nature and large C/N ratio of cow manure. It could also be due to the common practice in Bahrain to add some fresh loam to the top layer of soil every year then disk it before cultivating.

6.3.1.4 Effect of amendment use on Aggregate Stability:

In all farms examined, soil aggregate stability was very poor. Aggregate stability varied from 1.5-2.6 % only. Earlier in pot experiments aggregate stability of soils was found to be varying from 1-8% and water of low salinity was found to improve the aggregate stability to a great extent. The small aggregate stability in field experiments may be caused by irrigation waters of different salinities and due to the small percentage of organic matter in the soil. As the aggregate stability is low, the soil structure is unlikely to be able to withstand deformation under stress in the field. There is a possibility of breakdown of surface structures in the field and all soils should be cultivated with care. The electrolyte content of water influences the degree of dispersion. The more salt content, the less aggregate stability. Upon contact with water the aggregates quickly rewet owing to rapid rehydration of particle surfaces. The resultant rapid release of energy causes considerable aggregate breakdown (Guidi et al, 1980).

One very important property of soil structure is the stability of the compound particles or aggregates towards dispersion under conditions of stress such as cultivation or raindrop impact (Grieve, 1979). Soil aggregate stability was measured in the laboratory as the resistance of a sample of aggregates towards a standardised breakdown force. Since soils are most liable to degradation in the wet state, the test also involves wetting the sample aggregates. Aggregate stability is thus a measure of resistance to both wetting and mechanical dispersion.

6.3.1.5 Effect of amendments on exchangeable cations:

Exchangeable cations were very variable in all the farms examined. In all the surface 0-5 cm soils examined, Ca was found to be the predominant cation. As the Bahrain soils are highly saline and calcareous, exchangeable cation level did not depend on the treatment, but on the amount of salt content of the soil.

Exchangeable cations determined included exchangeable and soluble cations due to the leaching of calcium from the soil.

This was in line with the finding of Misopolinos et al (1984) who reported that saturating solution used to determine exchangeable cation in calcareous soils always dissolve a quantity of Ca and Mg salts that interfere in the determination.

6.3.1.6. Effect of amendments on the soluble salts in the soil

Soluble salts occur in significant proportions in almost all the farms due to the salt accumulation. Salts accumulate because the annual precipitation is insufficient to leach the soils or because the water table is at a shallow depth and moisture is drawn to the surface by capillarity bringing with it dissolved salts which are left behind as the moisture evaporates (Fitzpatrick, 1983).

The determination of EC and cations and anions in the soils did not show any effect of the various treatments on the soluble salts content of the soil. In only some samples EC of the surface layer increased slightly which received organic matter. The dominant anion was chloride followed by SO4. The dominant cation was Na followed by Ca. At low salt content Ca becomes the dominant cation followed by Na and the dominant anion is SO4, followed by Cl.

The predominant anions are sulphate and chloride while the cations include sodium, calcium, magnesium and small amounts of potassium. These ions occur in widely varying proportions and depending upon the particular ratio they impart a number of properties to the soil, some of which are detrimental to plant growth.

Most of the soils examined are highly saline. It is a common agricultural practice in Bahrain to add loam (loamy sand) for amelioration of sandy soil which usually results in a slight increase in salinity of the surface soil. It was noticed that electrical conductivity of the lower layer 25-50 cm was always high and had almost similar value in all treatments. The EC increase in this layer is probably due to the capillary rise from the water table which rises during summer to about 90 cm from the soil surface due to formation of perched water table on top of the slowly permeable" sabkha" layer due to daily irrigation (Nagmoush, 1981).

Saline soils have sufficient soluble salts to impair plant growth, mainly by increasing the osmotic pressure of soil solution and restricting water uptake. The nature and concentration of soluble salts in saline soils also influence the entrance of nutrient ions into root hairs of the plants. A comparison of Cl/SO_4 ratios in surface and subsurface layers will indicate the degree of leaching. In farms 4,6,8,9 and 10, Cl/SO_4 ratios indicate the dominance of chlorides over sulphates.

The pH values ranged from 6.2 to 8.2 with average value 7.5 in the surface layer, but did exhibit no trend with depth. In an evaporitic system $CaCO_3$ is one of the first minerals expected to precipitate as solute concentration of the soil solution increases. In certain farms, sodium levels in the 0-5 cm layers were high. The increase in sodium concentration is due to higher solubility of sodium salts such as NaCl and Na2SO4 and the mobility of Na+, Cl- and SO_4^{--} with the capillary movement of ground water. The potassium concentration of soils is greatly influenced by vegetation and biological activities (Leonard, 1976). Potassium is removed by plants from different depths and concentrates at the surface, where plants die and recycle the potassium. The role of potassium in plants are not clear. Its function include favouring cell organization and permeability, controlling plant water relations and activating protein synthesis (Azpiazu et al, 1986). The greatest potassium concentration was found at the surface soil. Increased levels of potassium seen in some lower horizons were probably from the ground water or due to leaching from the surface layer than from biological activity.

Most of the calcium in the soils is probably in the form of gypsum and is less likely to be redistributed by dissolution or reprecipitation, compared to halite. Solubility of gypsum decreases as sulphate concentration increases, due to common ion effect. Magnesium distribution in the soil layers were similar to calcium except that the overall magnesium concentration was much less than calcium.

6.3.1.7.1 Effect of amendments on Total Nitrogen in soils.

In most soils the bulk of nitrogen is in organic forms and usually near the surface. The principal source of plant-available nitrogen in unfertilized soils is the organic nitrogen which is microbiologically converted via ammonium and nitrite to nitrate, and the rate of production of nitrate is controlled by the rate of the first process, the breakdown of organic nitrogen to ammonium. Nitrate-nitrogen is much more easily leached from the soil than ammonium nitrogen (NH_4), since the latter is attracted to the negatively charged clay and humus particles. In Bahrain, temperatures are always high enough to favour a rapid conversion of ammonium to leachable nitrate. Total nitrogen shows an average values of 1491.29 mg/kg in this investigation. Compared to background levels 171.7 mg/kg, addition of organic amendments has increased total nitrogen levels to approximately 10 fold. Sewage sludge treatment has the highest effect on the total nitrogen content of soils.

Organic waste application rates are generally based on crop yield goals and estimate of N availability from the waste during growing season. As the greatest % of the N in poultry manure is in the organic fraction, information on the rate and extent of N mineralization is necessary to predict N availability. Additionally from 20 to 40 % of the total N in poultry manure has been reported to be in the inorganic form (Sims, 1986).

6.3.1.7.2 Nitrogen release from sewage sludge

It is nitrogen that limits plant growth and crop production. However, the amount of nitrogen in sludge and its availability varies considerably as a result of the different forms of treatment to which sewage and sewage sludge may be subjected. Even though N content was 4.8 % the proportion of soluble nitrogen may be from < 5% to > 70% of the total nitrogen present and the rate of mineralization of the organically bound nitrogen depends on the degree of suitability of the organic matter and the C:N ratio of the sludge (Catroux et al, 1982). At Al-Areen highest TKN in the upper layer was found in 6 month old plot (3399.00 mg kg^{-1}) and lowest in 5 year old one (672.00 mg kg^{-1}). In Hamala highest TKN was found in 3 year old plot (5250.00 mg kg^{-1}) and lowest in 5 year old plot (2268.00 mg kg^{-1}). This variation in levels were possible as at Hamala additions were made every 2 years and at Al-Areen only single addition was made. Highest level was possible in recently applied plot as sludge did not decompose, and available nitrogen was much less in the first year .

All solid sludges have lower nitrogen values than liquid sludges as a result of soluble nitrogen being lost during dewatering (Hall, 1983). As the organic matter has a high available carbon content, decomposition and hence nitrogen release to the crop is more rapid than for anaerobically digested sludges. With air dried sludge, Coker et al (1982) found 13 % availability in the first year after application to clay, followed by 5.4, 2.2 and 0.85 in the subsequent years.

6.3.1.8 Effect of amendments on extractable phosphorus content

In the field study, chemically determined available phosphorus values are high in the surface 0-5cm layer, ranging from 25.8-278.5 mg kg^{-1} with an average of 89.31 mg kg^{-1}., in all plots examined, (10-15 mg kg^{-1} normal).

Compared to background levels (11.97 mg/kg) there was approximately an 8 fold increase in PO4-P levels after treatment. Sewage sludge addition has increased the extractable PO4-P content to a considerable extent in the 0-5 cm layer than any other treatment. Taking into consideration the sludge treated farms 12,13,14,15,16 and 17, it was seen that PO4-P was more available in the recently treated farms than older ones.

In pot experiments, highest P concentration were noted in the case of chicken manure treatment (335 mg kg^{-1}) at 40 Mg ha^{-1}. Cow manure treatment at 80 Mg ha^{-1} also yielded similar results. Highest P concentration after chicken manure treatment could be due to the highest concentration of P in the manure (1.78%). Even though the P available depended on the concentration of P in amendments, P coming from the inorganic fertilizers are also to be considered in this field results. Availability to plants found in sludge amended soils may be due to humic acids and other organic compounds contained in the sludge which may prevent the P fixation in the soil (Sinha, 1971).

The assimilative (conversion) capacity for P is based on crop uptake and the soil capacity to retain or fix P. The plant-soil assimilative capacity for P is 248 kg ha^{-1} per year for a sandy loam soil (FAO, 1972) which amounts to approximately 344 mg kg^{-1} as per the pot test soil figures. P values found in pot tests were quite normal and within the soil fixation capacity.

In pot experiments carried out over two years using different types of water leaching, similar to field conditions, no great increase in phosphorus concentrations in the leachate was observed.

Although surface soil 0-5 cm was rather showing an increased level of PO_4, no increase was noticeable in the deeper layers. Highest PO_4-P was seen in the case of sewage sludge application site at Hamala 278.5 mg/kg. In other organic manure treated sites, PO_4-P levels were quite normal. In all cases investigated, P saturated zones were not found and there is thus no possibility that P may reach the ground water. Analysis of ground water near the farms confirmed this observation.

P is most available within a pH range of about 6-7, although appreciable amounts will still be tied up with organic matter. As the pH drops below 6.0, increasing amounts of P become fixed by iron and aluminium, whereas above pH 7.0, phosphorus fixation by calcium and magnesium increases (Leonard, 1976).

Only about 5-25% of the added P will be available during the crop growth. The rest becomes fixed, in the form of fairly insoluble compounds with Ca. Except in very sandy soils, losses of P by leaching are negligible. Generally a concentration of <0.1 mg P L^{-1}. in the soil solution generally results in minimal leaching losses of P (EPA, 1983).

Sludge is undoubtedly an effective source of P for plants and comparable to those of commonly used soluble mineral fertilizers (Furrer et al, 1983). To efficiently utilize the sludge-phosphate and avoid environmental hazards, it is important that the sludges are spread on land at rates which meet crop requirements avoiding overfertilization, accumulation and loss by leaching and run-off in the soils. Excess P in the soil impairs plant growth via indirect action. Zinc deficiency was traced to P inhibition at the root surface when soluble phosphate were present. However, as amendment application add both P and Zn to soil, the potential P-Zn interaction will be minimised.

6.3.1.9 Effect of amendment use on extractable & total trace metals:

Several studies have been published showing data on the metal concentrations found in sewage sludges (Doty et al, 1977; Page, 1974; Sommers et al, 1976; Silvera and Sommers, 1977; Sommers, 1980; William, 1983; Webber et al, 1984; Purves, 1966; Chaney, 1980).

The sludge applied to the plots at Hamala & Al-Areen was not heavily contaminated with trace metals (Cd, Zn, Cu & Pb). Concentrations were at the lower ends of the ranges of metal concentrations in 42 sludges from England and Wales surveyed by Berrow and Webber (1972), and were also lower than other values reported in U.K and U.S.A (EPA, 1983.; Lester, 1984.;, Webber 1984). But the results were comparable to the levels in sludges from Sweden (Sjoqvist, 1984). Consequently, trace metal concentrations in the treated soils were also low (Table- 22). The composition of sludges generated by the treatment plant in Bahrain are not varying much as there are no industries connected to it and variation in the input of metals are not anticipated.

Distribution of metals with depth in the uppermost 50 cm of the soil showed that (Figure-5.26 to 5.28), all the metals generally remained in the surface 5 cm layer. Among the extractable metals Cu showed significant difference in all the different layers. Zn was the most extractable metal found in the sludge treated soils.

In the field samples extractable and total zinc in the surface layer were 25.93 and 78.46 mg kg^{-1}. respectively in the sludge treated plots. In the pot experiments with 40 Mg ha^{-1}. treatment average extractable and total Zn concentrations were 37.7 and 54.9 mg kg^{-1}. respectively. This showed that sewage metal concentrations in sludge treated field plots were similar to 40 Mg ha^{-1} sludge addition in pot experiments.

Pot experiments had shown that leaching of trace metals was very small but Zn and Cu showed a tendency to leach into the lower layers of the soil. This was in agreement with the findings in the field experiments.

The levels of trace metals in Bahrain sludges are lower than suggested limits for application on agricultural land (CEC, 1986.; Webber et al, 1984). Rappaport, (1988) reported that green house research with sewage sludges on corn production on a Warsaw sandy loam had shown that corn yields had increased at sludge rates of 125 and 251 Mg ha^{-1} and decreased at the 502 Mg ha^{-1} sludge rates. The yield decrease was attributed to toxic concentrations of heavy metals and to high soluble salt levels. However the characteristics of the local soil and prevailing environmental conditions should be taken into consideration (Samhan and Ghobrial, 1987). But there is an adequate evidence that applications of sewage sludges to agricultural land can lead to substantial enhancement of the available metals in the soil (Sommers, 1980; William, 1983; Webber et al, 1984; Davis, 1983; Purves, 1966; Page, 1974).

Heavy metal loading rates on sludge application projects are limited to prevent significant increases of heavy metals in the food chain, phytotoxicity and water pollution (Sommers, 1980; Davis, 1984; Purves, 1966).

Soil CEC plays a major role in enabling the soil to retain the heavy metals contained in the sludge (EPA, 1983). Soils having a CEC in the range of 5 to 15 meq/100 g are acceptable for sludge utilization provided sludge application rates do not result in heavy metals being applied to land in excess of the amounts listed in Table- 6.5. (EPA, 1983). We also have the possibility here of insolubility of metals due to the usual level of high soil pH.

Table-6.5

Maximum acceptable heavy metal loading rates over the life of a project site.

Metal	(kg/ha) CEC 0-5 meq/100g	kg/ha CEC 5-15 meq/100g
Pb	560.0	1120.0
Zn	280.0	560.0
Cu	140.0	280.0
Cd	5.0	10.0

Source: US Environmental Protection agency, 1983

Sludge application is not usually recommended for soils of CEC < 5.00 meq/100 g, if required sludge user may apply only half of the heavy metal loading rates.

Table- 6.6

Metal Loading rate & life of a project

Metal	Conc. in sludge mg/kg	Annual metal loading kg/ha/year	Maximum metal loading kg/ha	site life years
Cd	4.83	0.19	5.00	26
Pb	171.33	6.85	560.00	82
Zn	733.30	29.30	280.00	10
Cu	505.00	20.20	140.00	7

Application rate 40 T/ha (Mg ha^{-1}) .

This example indicates that the zinc and copper loadings are the most restrictive to the site life time. Therefore the sites should not be used for more than 7 years, however updated sludge analysis and different application rates may change these site lifetimes. Where the soil contains harmful concentration of heavy metals this may be reduced by deep ploughing, or mixing top soil with sub soil. This could however have an adverse effect on ground water, which would need monitoring.

The pattern of extractable and total trace metal concentrations in individual soil profiles are shown in Figure- 5.26 to 5.29. There were great variations in the extractability of metals in 2.5 % acetic acid. In the sludge treated plots, extractable metals Cd, Pb, Zn and Cu were 22.2, 31.0, 33.0 and 6.1 % of the total metals found in the surface 0-5 cm layer. There were variations in metal levels in each plot probably due to the non-uniform spatial distribution of sludge within the plot.

Among extractable metals zinc showed the maximum value, indicating its availability for plant uptake. The chemical form of heavy metals in soil are affected by pH, CEC and other factors (Xoettl, . , 1985). Increase in pH values results in higher adsorption of Cd, Zn and Cu by soils and reduces plant uptake of Cd, Zn and Pb. It has been reported that the soluble form of heavy metals and their uptake rate by plants are closely related (Xoettl, , 1985).

Since the sludge applied to the soils in this study was not heavily contaminated with trace metals, the treated soils were also low and the rank order of extractable trace metals in the treated soils were variable. But the rank order of total metals has generally been found to be the same as that in the sludge , Cd < Pb < Cu < Zn.

In general, trace metal concentrations in the sludge applied soils were all low in comparison to published normal ranges (EPA, 1983) for trace metals in soils (Cd = 0.01-0.7 ug g^{-1}, Pb = 2-200 ug g^{-1}, Zn = 10-300 ug g^{-1}, Cu 2-100 ug g^{-1})

As the background concentrations of metals in the soils were low, the increases in soil metals depended on rate of sludge addition only.

Fluctuation in the concentration of heavy metals in sludge treated soils with progress of time were observed (Table-25). Such behaviour suggests that more complex processes are operating in the soil (Mashhady, 1984)

Distribution of metals with depth in the uppermost 0-5 cm of the soil showed that most of the highest metals were in the 0-5 cm layer and in the bottom layers results were variable. In the case of lead, the results were not much different in different layers. The reason could be due to the less availability of lead to plants as it can be in firmly bound non-exchangeable forms.

In the sludge treated area, zinc and copper showed a downward movement in the soil. Similar movement of applied copper in cultivated organic soils has been reported by Dinel (1988), but the copper migration was shown to be associated with the downward movement of partly degraded organic materials (Dumontet, 1990). Similarly Kuntze (1988) reported some accumulations of heavy metals, mainly Zn, Cu and Pb on peatland pastures following sewage sludge applications. Some metal migration into the profile took place, the highest enrichment ratios were found into 10 to 20 cm layer, but very little metal contamination was shown beyond the 40 cm depth. In the few instances, mentioned above the downward movement of heavy metals took place under drained conditions, in cultivated organic soils where the water table was quite low. Under sandy soil conditions, however, the deposition, distribution, and accumulation of heavy metals would be quite different mainly because of differences in the vegetative cover, water table behaviour, drainage, aeration and redox conditions. Generally very little downward migration is seen below the 25 cm depth (Dumontet ., 1990). Some workers have pointed out that Zn would leach through peat more easily than Copper and Lead.

In connection with the specific behaviour of Cu in soils, Mathur et al (1984) have noted that, at pH above 5, heavy Cu applications (1500 ug/g of soil) to organic soils did not cause downward movement of the metal because Cu starts to dechelate only at pH below 4.7 and desorb at pH 3.0 or lower (Dumontet 1990). The much higher enrichment of Pb, and Cd in the surface layer indicate a lower degree of mobility.

The distribution of Cd between soil and soil solution is supposedly a key question in evaluating the fate of Cd in terrestrial environments. Many soil solution parameters have been reported to significantly affect Cd distribution,e.g, solution pH, Ca concentration, the presence of other competing heavy metals and the presence of complexing ligands in solution (Christensen, 1989). Many authors have found that high organic matter or additions of organic matter decreases solution concentrations of Cd and plant uptake. A higher clay content is assumed to result in stronger adsorption and less plant uptake (Eriksson, 1988, Gerritse et al, 1982)

6.4 Effects of organic amendments on ground, drainage and runoff waters.

6.4.1 Effects of organic amendments on ground water:

Salinity of the ground waters were high (>3.00 ppt). The water, therefore according to World Health Organization guidelines on drinking water (WHO, 1984), is not suitable for drinking purposes, but could be used for irrigating plants with good salt tolerance, such as date palm trees and alfalfa crops. Nevertheless, in some area in Bahrain such water is used for human consumption.

Ground water salinity showed a spatial trend. Ground water from the north western zone of Bahrain generally had the smallest salinity. Maximum salinities were found in the south eastern zone on the coastline. Al-Akr and Sitra (see Figure- 4.1) on the south east coast have salinity values ranging from 4.49 to 9.30 ppt and averaged 6.0 ppt. There are several factors which may have contributed to this high salinity in ground waters. Over exploitation and excessive pumping of ground water have caused a disturbance of the state of equilibrium of the reservoirs, resulting in a lowering of the water table and decreased pressure in the aquifers. In coastal areas, this behaviour eventually has led to the intrusion of sea water into ground water. This situation is exacerbated by the very low natural recharge rate of the aquifers and high rate of evaporation (mean evaporation 2364 mm per annum) in Bahrain (Madany et al , 1987).

Concentrations of chloride, sodium, magnesium and sulphate in ground water followed similar patterns to that of salinity. Elevated levels of bicarbonate and calcium in ground water which ranged from 98-370 mg/l and 108-636 mg/l respectively, can be probably attributed to the presence of limestone formations in all ground water aquifers in Bahrain.

Comparison of the concentrations of chloride, sodium and sulphate in ground water with the WHO guidelines (WHO, 1984) illustrate that most of of the wells exceeded the guidelines, (Cl=250, Na= 200, SO4= 400 mg L^{-1}.)

Nutrient content of ground water was variable but generally conformed with the WHO guidelines. Only few wells exceeded the WHO guidelines for Nitrate-N (10 mg L^{-1}.)

There has been a localized problem in only one area, namely Al-Akr in the south eastern coast, as shown in Figure- 4.1. The level of nitrate-N in Al-Akr ranged from 3.1 - 23.3 mg/l (Table-26) and this may be due to the use of cow manure and to the concentration of livestock farms in this area. The shallow ground water in the area has also contributed to the ease of its contamination with nitrate-N.

In U.S.A, Bitzer et al (1988) reported that applying poultry manure to croplands at rates > 13.5 Mg ha consistently resulted in NO3-N levels in ground water in excess of the 10 mg/l limit established by USEPA.

Compared to other areas, the values of ammonia and phosphate which ranged from 14.9-1658 and 8.1- 374 ug/l, respectively are considered also high.

Regarding trace metals in ground water , it has been reported that the metallic concentrations were within the guideline (Raveendran et al. 1989). (US EPA Standard for Cd =0.01, Pb=0.05, Cu =1.0 and Zn = 5.0 mg L^{-1}). USEPA guidelines for trace elemets in irrigation waters are Cd = 0.01, Pb=5.0, Cu = 0.2 and Zn =2.0 mg L^{-1}.

There was therefore little evidence of leaching of either nutrients or trace metals to ground water. This is consistant with the leaching results from pot experiments for trace metals. It is apparent that additions of organic amendments remain in the upper soil and are generally not leached into lower layers.

6.4.2 Effects of amendment use on drainage water:

The quality of drainage water reflected the quality of groundwater due to the exclusive use of ground water for irrigation purposes.

The level of salinity of the drainage water is high. There were two factors which had contributed to the elevated salinity values of drainage water. Firstly, the quality of ground water which was exclusively used for irrigation purposes reflects the quality of drainage water. Soil properties along with harsh climate conditions prevailing in Bahrain is the second factor responsible for the elevated salinity values of drainage water.

Salinity values showed a specific trend being the lowest in the north western zone of Bahrain and increasing from north east reaching maximum values at the south eastern zone on the coastline. Similar trends of salinity values were also observed with drainage water being the highest in the north east, namely 34 and 35 (Figure- 4.1). In addition, the area of channels 34 and 35 is very low lying with respect to sea water, leading to the flow of sea water to the low land and mixing with drainage water during high tides. The soil here is light in texture (loamy sand to sandy loam) and contains significant amount of sodium chloride due to its proximity to the sea.

The values for the natural salinity of the soil show that very high salinity values are common. The values measured in electrical conductivity ($S\ m^{-1}$) range from 0.7 to 5.98 and average 3.55 (Groundwater Development Consultants, 1978). The main agricultural area in Bahrain which occupies the northern and north western coast is characterized by the presence of calcareous sandy soils, often rich in gypsum, of high permeability (average infiltration rate of soils of Bahrain is 23.8 cm/hr; Italconsult, 1971) and very low water holding capacity. The soil depth is quite shallow ranging from few centimeters to 2 or 3 meters, and the water table is at depth varying between 0.3 and 3 m depending on topography and the presence of the impermeable layer. The shallow water table and its rise by capillary action in conjunction with high rates of evaporation has resulted in the elevation of soil salinity, and subsequent increase in drainage water salinity.

The high values of bicarbonate, sulphate and calcium can be probably attributed to soil composition which consist mainly of limestone and gypsum (Bridges and Burnham, 1980), and the use of sulphate compounds as fertilizers.

Table - 6.7 shows the load of nutrients in tonnes/year.

Table- 6.7
Nutrient loads to the marine environment (tonnes/year)

Nutrient	Load
Nitrite-N	5.4
Nitrate-N	203.0
Ammonia-N	19.9
Phosphate-P	0.6
Cd, Pb, Cu & Zn	very small

Average flow = 2.0 x 10^7. m3/year (643 liter/ sec)

These nutrients can have a significant impact on marine life since it is directly discharged into shallow intertidal zones with depths varying between 0.0 and 0.3 meters. However, comparing the average drainage water quality with various standards available for effluents discharged into sea, it can be concluded that the water as such cannot cause eutrophication problems in the near vicinity of discharge and the problems of pollution from agricultural use of organic amendments are small.

Nutrient content of drainage water varied somewhat, and generally did not show high values. Nitrate-N levels in percolates generally exceeded the EPA potable standards except in the drainage from cow manure treatment area (0.7 mg L^{-1}). The highest value for NO3-N was found in drainage from the chicken manure treatment area.

Analyses of soil percolate water from pot experiments after various amendment applications and leaching for 6 months, showed very high values for nitrate-N ranging from 27.65 - 140.75 mg L^{-1} in the final leachate. In pot experiments there were no plants grown in soil and since there was no nitrogen consumption by plants, all the nitrates leached out from the soil.

Even though there was a clear increase in Cd, Pb, and Zn in drainage waters from sewage sludge treatment area, none exceeded the drinking water standards (USEPA, 1983). These concentration increases were minimal and pose no threat to human or animal health. Results also indicated that percolate water quality, even though not meeting EPA drinking water standard for nitrate-N, has not shown any tendency to leach in to ground water.

6.4.3. Effect of amendment use on run-off water.

Concentration of nutrients in the runoff water showed very high values. Nitrate-N averaged 14.5 mg/l, far above the 10 mg/l allowed in drinking water. Runoff water from 8 plots exceeded the 10 mg/l NO_3-N limit. Trace metals Cd, Pb, Zn and Cu averaged 2.14, 60.97, 33.01 and 18.59 ug/l respectively but were all meeting the standard criteria (EPA, 1983). Large concentration of lead in the runoff could be due to lead deposition from air.

Leaching of fertilizer nutrients N,P and K, applied to agricultural land has been shown to be highly influenced by soil texture, N- source, rate and timing, irrigation and rainfall. Nitrate-nitrogen and ammonia nitrogen representing the inorganic pool were high in the samples investigated. Phosphorus was very low in all samples and this was due to the high calcium carbonate content of the soils in Bahrain and precipitation of PO4 as calcium phosphate in soil layer. Even though the nitrogen has many agronomic benefits, the environmental impact may overshadow the positive factors in ground water sensitive areas (Brown et al. 1982). Run off waters ends up in the drainage system. This could be the reason of high nutrients in drainage water.

Analysis of drainage water from these areas also shows high levels of nutrients in it. But ground water analysis from these area did not show any excessive nitrate levels. The reason could be due to the impermeable soil strata of Bahrain.

6.5 Effects of sewage sludge on trace metal concentrations in crops :.

Plant materials grown on the sludge application sites generally exhibited metal contents within the normal ranges defined by Blakeslee (1976), for agricultural crops, except for cadmium (allowed Cd = 0.05-0.2, Zn 15-150, Pb = 0.5-5.0 and Cu 3-40 ug/g dry weight) (Webber, et al 1983).

Zn, Pb and Cu contents are higher in Hamala grasses than at Al-Areen. Sludge treatment greatly increased the zinc content of the plant material.

There were differences in metal levels in vegetation from control and treated sites. All the metals in vegetation were below the suggested tolerance levels reported by Melsted (1973) and the Council for Agricultural Sciences and Technology (1976) (Cu = 150 mg kg^{-1}., Zn = 300 mg kg^{-1}., Pb = 10 mg kg^{-1} and Cd = 3 mg kg^{-1}.). These levels represent the level at which a yield reduction might occur and do not represent levels at which severe toxicity occurs. There were however no phytotoxicity symptoms observed for any vegetation on the sludge treated areas. Kim et al (1988) had reported a value of 4.69 ug g^{-1} for cadmium and 53.29 ug g^{-1} for zinc in some plants grown on sludge treated soils.

Much of the concern about metal accumulation in sludge-treated soils relates to their possible uptake by crops and consequent effects on the crops themselves and on the food chain. Cd & Pb are principally zootoxic and for these metals interest is directed at contamination of the food chain (Davies, 1988). Cu & Zn are principally phytotoxic so the concern here is mainly at effects on crop yield and soil fertility. The most mobile metals in sludge treated soil are Cd & Zn, Cu is intermediate and the others like Pb are immobile. Even for the more mobile elements crop uptake removes less than 0.05% of the metal added to the soil in sludge (Davies, 1988). Sludge application increases both the soil and plant Cd. Increased Cd levels in plant materials are of concern because Cd has no known biologic function and is toxic to both plants and animals (Webber et al 1983). It accumulates in the liver and kidneys of animals and causes kidney damage. Increased levels of Zn in plant materials resulting from sludge application are desirable because there is increasing concern about deficiencies for both plants and animals (Allaway, 1968). The danger of toxicity from excess dietary zinc is minimal and plant toxicity occurs at concentration exceeding approximately 500 ug/g [illegible] Zn plays an important role in the protein synthesis, and growth symptoms of zinc toxicity in plants are similar to those of zinc deficiency.

Concentrations of Zn exceeding 1 mg L in nutrient solution have shown to cause adverse effects in some experiments (Anna-Maj et al, 1989). A study on non-tolerant Festuca rubra reported 0.1 mg L^{-1} to be sufficient to cause cytological changes as well as reduced root elongation (Powel, et al, 1986, a, b). Cu concentrations of 0.05 to 0.1 mg L^{-1} are reported to be toxic to non-tolerant plants. Adverse effects of Cd in nutrient solution have been observed from 0.03 to 0.06 mg L^{-1} in Alnus rubra seedlings and from 0.1 mg L^{-1} in Quercus palustris. With Pb, decreased root elongation in Picea abies seedlings was measured from 0.1 mg L^{-1} and decreased root production in Zea mays from 0.21 mg L^{-1}. The ionic composition of the solution , e.g. the phosphate concentration is probably quite important to the critical Pb limit (Tyler et al. 1989).

Among the zootoxic elements, Cd is undoubtedly the one most available for crop uptake. Comparative data from different crops (Davies, 1988), suggest that Cd is assimilated from soil by leafy vegetables, like lettuce, spinach, cabbages with lower concentration in storage roots, cereal grains and legumes. Studies showed that Cd content of the crop was related to the Cd concentration in the soil, and not on the original Cd content of the sludge (Davis, 1984). So it follows that limits for Cd should be directed principally at the Cd concentration in the soil rather than the Cd content of the sludge. Interpretation of the significance of Cd concentration in grass grown on sludge treated soil (0.54 ug/g) is difficult as the amount of sludge metals added is not properly quantified by the farm management. At Hamala, sludge was added every third year and at Al-Areen, sludge was added only once in the soil. Even though the plant cadmium is higher than allowed by Blackeslee, the limits of metals allowed are quite high in other countries. Plant available Cd and Pb were not high in the soil as judged by the extractable metal contents. A considerable amount of Cd and Pb might have been immobilized in the soil due to adsorption (Levi Minzi et al, 1976) and precipitation with CaCO3 (Street et al, 1977, Juwarkhar & Shende, 1986). Dietary scenario studies in the U.S.A (Ryan, 1982) has shown that a Cd loading rate limit of 5 kg/ha is appropriate for soils receiving sludge. Webber and Monks (1983) concluded that 5 kg/ha added to agricultural soil represents little if any hazard to the human food chain. A loading rate of 5 kg Cd/ha is equivalent to a soil concentration of 3.5 mg/kg, assuming that the sludge is cultivated into the soil to a depth of 20 cm and that the background concentration of Cd in the soil is 1.0 mg/kg. Sharma et al(1979) has concluded that Cd concentrations in animal feed of up to 10 mg/kg would cause no appreciable increase in the Cd content of meat, or eggs. In most plant species toxic effects have been obtained when leaf tissue contain between 3 and 10 ug g^{-1} Cd dry wt, in a nutrient solution corresponding 100 ug Cd L^{-1}. Many plant species have a critical limit in the leaf tissue at 10 ug Cd g^{-1} dry wt. Compared to Cd, the phytotoxicity of Pb to plants is relatively low, due to a very limited availability and uptake from soil and soil solution. Nutrient solutions containing 100-200 ug L^{-1}. is shown to affect root growth and elongation.

Erikson, 1990 in pot experiments on sandy soil in Sweden found that increasing the soil pH does not always reduce plant uptake of Cd in rye grass and that the relative adsorption of Cd by the soil and uptake of Cd by plants were approximately the same. For soils of the same Cd content, cadmium was more soluble and more plant available in sandy soil than in clay soil.

Increased Zn concentrations in soils from the field and pot experiments were reflected in the high Zn concentrations found in plants from the sludge treated site. This was similar to the case found by Alberici et al in (1989) in U.S.A.

The temporal change of soil adsorption of Cd has mostly been studied in connection with sludge application. Hinesly et al (1979) compared Cd contents in corn leaves at the last years of application and 4 years later. The contents of the latter occasion were considerably lower. Some authors have reported a decrease in plant uptake between the first and second year after sludge application but there was no decreasing trend in the seven consecutive years (Erikson, 1988). These results were in agreement with the laboratory experiment by Christensen (1989).

From solution culture experiments with vascular plants some general information on the relative toxicity of heavy metal ions may be obtained. On average, at equimolar concentrations, the relative toxicity decreases in the order Cd > Cu > Pb > Zn, a sequence generally valid (Tyler et al, 1989).

At higher soil levels copper would be extremely toxic, phosphorus deficiency in the plant may enhance the toxicity of copper (Wallace, 1984). Copper in excess reduces the iron contents of various plant organs, particularly uptake of K, whereas Ca uptake appears to be less susceptible. The critical concentration limit for copper in leaf tissue is 15-20 ug g^{-1} dry wt (Anna-Maj et al, 1989).

CHAPTER-7

CONCLUSIONS

7.0 Conclusions:

Soils of two different textures (sandy loam & sand) were examined to find how their physical and chemical properties and nutrients were affected by manuring. Cow manure, chicken manure and sewage sludge were applied at different rates in pot experiments. Fields treated with these amendments were also sampled. Chemical analyses of soils, leachates, ground and runoff waters were used to quantify the effects of organic amendment use on heavy metal accumulation in soils and plants.

The results clearly show well how the nature and amount of added organic matter interact to determine physical and chemical properties. The conclusions are divided into three parts. The first part gives the conclusions derived from pot experiments, second from field experiments and third a general conclusion arrived from both of these.

7.1 : Pot experiments:

1). Sandy loam and sand used for pot experiments showed that saline water upto 5000 mg L^{-1} total dissolved solids (salinity 5.00 %) is suitable for agriculture in Bahrain. Low salinity water and high salinity water did not affect the physical and chemical properties of the soils to a great extent. Even though crop growth after amendment use was not studied, generally high saline water was found useful for salt tolerant crops in Bahrain.

2). Additions of organic amendments considerably increased organic carbon, CEC, aggregate stability, water holding capacity, and trace metals in the surface 5 cm layer of both the soils. Very few effects were found below this depth.

3). CEC nearly doubled after 40 Mg ha^{-1} chicken manure treatment and 4 fold after the same amount of sewage sludge treatment.

4). Most of the increased concentration of the major nutrients N,P, and K can be attributed to the increased concentration of organic matter in the soil and increases were generally related to the amount of nutrient in the amendment.

5). Chicken manure treatment gave the highest increase in extractable-P concentration in the 0-5 cm soil layer.

6). Sludge treatment gave the highest organic carbon in the top 5 cm layer of the soil.

7). There was no major difference in properties between two soil types after the treatments. Both soils responded to the amendments in a similar manner.

8). 40 Mg ha^{-1} addition of organic amendments were sufficient to meet all the nutrient needs and soil physical and chemical characteristics.

9). In the sewage sludge treated soils organic matter had large effects on soil aggregate stability, than in cow manure and chicken manure treatment.

10). Increases in extractable and total metal concentrations in the soils were closely related to their concentration in organic amendments. As expected sewage sludge increased soil trace metal concentrations to the maximum extent. The acetic acid extractant used in the study, extracted 8-10% Cd, 6-15% Cu, 9.7-57% Zn and 5-18% Pb.

11). pH of the leachates from pot experiments were neutral to slightly alkaline. Nitrate levels were high in the leachates and were in most cases above the acceptable levels for potable ground water.

12). Phosphate-P was very low in leachates and showed no tendency to leach to the lower layers. Considerable amounts of K was found in the leachate.

13). Trace metals in the leachates were small, showing that problem of sludge application in Bahrain is only related to soil accumulation rather than to possible runoff or ground water contamination.

14). Cow manure treatment at different rates increased CEC, O.C, WHC to a very small extent. Cow manure alone was thus insufficient to promote aggregate formation. High salinity water appeared to have an inhibitory effect on the oxidation of C from cow manure treatments, thus showing that cow manure treatment can retain organic carbon in the soil for a longer period.

7.2. Field experiments :

17 farms were investigated, 5 farms mainly using cow manure, 6 chicken manure and 6 sewage sludge. Soil texture of most of the farms were mainly coarse sand making more than 80 % of the soil particles.

The distribution and fate of fertilizer nutrients NPK applied to agricultural farms has not been studied completely. The findings are limited to a small set of conditions on 17 large agricultural farms in Bahrain.

The following conclusions are based on the main findings of the physical and chemical analysis of soils from the above farms.

1). Additions of organic amendments increased organic carbon, CEC, aggregate stability, extractable-P and trace metals in the surface 5 cm layer of the soil. WHC was very poor in all the farms investigated.

2). CEC increased in all farms compared to control. It increased 3-4 fold after cow and chicken manure treatments, and increased to an average 6 fold in sewage sludge treated plots.

3). Compared to background levels addition of organic amendments has increased total nitrogen and available phosphorus levels to approximately 8-10 fold. Sewage sludge treatment has the highest effect on the nitrogen and phosphorus content of the soils. In all the cases investigated, P saturated zones were not found and there is thus only a remote possibility that P may reach ground water in these calcareous soils.

4). Nitrate-N representing the inorganic nitrogen pool was high in the surface 0-5 cm of the soil samples investigated, still it did not reach the ground water.

5). Leaching of fertilizer nutrients NPK applied to agricultural land has been shown to be highly influenced by soil texture, nitrogen source, rate and timing and irrigation. Generally NPK showed the same trend in the 0-5 cm layer. Nitrogen, phosphorus and potassium did not show any tendency to leach into the ground water, except at Al-Akr. Levels of nitrate-nitrogen in ground waters at Al-Akr are high. The wells investigated are all hand dug, and lots of organic and inorganic fertilizers used in the farms has leached into these wells.

6). Drainage water and runoff water contained high concentrations of nutrients but did not show a tendency to leach in to ground water.

7). Sludge in Bahrain was not heavily contaminated with trace metals. Since CEC was poor in Bahraini soils (<5 meq 100 g^{-1}), Zn and Cu additions are most restrictive to the site life time. So sites should not be used for more than 6 years if additions are made at 40 Mg ha-1 every year.

9). Although the use of sewage sludge increased the concentration of trace metals in surface soil, there was no significant difference in plant trace metal concentrations except for Cd and Pb. These concentrations were still below phytotoxic levels. There is no clear pattern in trace metal movement from soil to vegetation that can be attributed to sludge treatment alone.

10). Plant species from sludge treated plots did not concentrate Cd above soil Cd concentrations, but a tendency to accumulate more Zn than soil Zn concentration was shown. Cd concentration in plants from sludge treated plots, however were greater than concentrations for fertilizer treated control plots.

11). Cd concentration in soils increased significantly as years of addition increased. Even though additions were made only once, Cd was organically bound, hence weathering and decomposition was required to make Cd in the available form in the soil. Because a major portion of the organic matter present in sewage sludge resists decomposition, the observed lag in soil Cd concentrations is understandable.

12). Lead concentrations in plants were higher at sites receiving sludge more than once. Increases in Pb concentration after sludge treatment have been documented for soils . Specific difference in Pb uptake could account for the difference between plant species. Lead concentration in vegetation were less than that in soils for all treatments.

13). Zn concentrations were high in plants from sludge treated and fertilizer treated plots. No treatment differences were observed for Zn in grass sampled from these plots. This confirms that Zn does have a lower soil-bonding energy coefficient than Cd, Cu and Pb (Kiekens and Cottenie , 1983).

14). Copper concentration were not different in plants from sludge treated plots and control plots. This was contrary to other reports (Levine et al, 1989).

15). Underground brackish water is considered at present as the only source of irrigation water and is mainly of poor quality with TDS ranging from 2000-5000 ppm. Soil salinity hazard is great as a result of using this water for irrigation.

7.3. General conclusions:

The data reported in this study greatly support earlier findings of many investigations (Baker, et al, 1975); Chesnin et al, 1975; Jones, et al, 1973; Eriksson 1988, Sadiq, M, 1985). However, due to different behaviour and responses of the various soil-plant systems receiving highly varied amendment quantities and compositions it is difficult to generalize quality control criteria particularly when developed under different soil, plant, and climatic conditions. The analysis and observations in this study require further, extended soil-plant studies both under field and greenhouse conditions to evaluate the problem and develop quality parameters.

The following conclusions can be drawn from the results of these investigations.

1). Soils are poor in CEC and are moderate to highly saline.

2). Potassium was sufficient in soils, but due to high leaching, extra K in inorganic fertilizers need to be added to the soil to solve K deficiency. To minimise leaching K should be applied in 2-3 applications.

3). Applications of organic amendments at a rate of 40 Mg kg^{-1} are sufficient to convert the two soils studied suitable for agriculture in terms of N, P and organic matter.

4). Sandy loam soil is quite unstable in water, is easily compressed and is liable to erode with heavy wind and rain. Most of the soils were saline. Aggregate stability was poor due to low organic matter in the soils.

5). To improve water availability in sandy soils, continued inputs of irrigation water were required.

6). The cow manure treated plot showed the highest C concentration. This was also in line with the pot experimental findings, where it was reported that most of the added C in cow manure, remained in the soil surface layer unoxidised.

7). TKN had improved much in all the farms. Sewage sludge treatment had the highest effect on the total nitrogen content of the soils, and this also gave the highest extractable-P in the surface layer. This was contrary to the pot experimental findings wherein chicken manure treatment had given the highest extractable-P.

8). The long term trends varied between farms presumably depending upon the relationship between original organic matter level and the equilibrium levels for the soil, climate and various rotations. The difference in soil organic matter content between farms were quite small in all farms. The increases due to 5 years use compared with 3 years use were small but were appreciable at farms using sewage sludge more than once. The effect of cow manure and chicken manure treatment on soil organic matter was very small.

9). Heavy metals in soils never exceeded the maximum recommended levels as per EEC guidelines.

10). Crops grown on sludge-amended soils generally showed higher Cd and Pb content than the control ones. At Hamala agricultural farm Cd levels exceeded the normal range found in plants (0.05-0.2 ug g^{-1}), but it did not exceed the suggested tolerance (3.0 ppm).

11). Crops grown on sludge-amended soils did not show alterations directly connected to the treatment and no symptoms of toxicity due to the great metal enrichment of soil were observed.

12). Considering the high dose of sludge employed, data point out that chemical forms of sludge-borne metals were not immediately available for crops as the pH of the soil was neutral to alkaline.

13). The low mobility of the sludge metals in soil indicate that ground water contamination from land application of sludge is unlikely.

14). Judging by Zinc equivalent of Bahrain sludge, a total of 200 Mg ha^{-1} of sludge can be added over 30 years as per U.K guidelines. According to U.S guidelines, zinc and copper loading are the most restrictive to the site lifetime. Therefore, the sites should not be used for more than 6 years, however updated sludge analysis and different application rates may change these site lifetimes.

16). Zn and Cu levels did increase in the sludge treated plants to values nearly as high as those reported by Berrow and Burridge (1980)

17). The study has clearly identified that the two soils studied for pot experiments, will definitely benefit by the incorporation of sludge as demonstrated by improved physical and chemical soil characteristics provided that additions of metals are limited to the quantities indicated above.

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APPENDIX

Table-1

Results of Pot Experiments

			Water Holding Capacity (%)		.O.C. (%)		Aggregate Stability (%)		T.K.N. (mg/Kg)		Extractable PO_4-P (mg/Kg)		Exchangable Cations (me/Kg)								meq/10 C. E. C.	
													Type - I Water				Type - II Water					
			WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	Ca	Mg	Na	K	Ca	Mg	Na	K	WT_1	W
1.	HAMALA Control	0-5cm	10.4	10.2	0.76	0.85	1.0	1.0	200	280	0.99	7.90	2187.6	7.99	47.8	3.0	1373.6	23.8	141.0	7.9	1.2	1.
2.	HAMALA Control	5-16cm			0.71	0.88			192	190	2.94	7.92	2331.3	16.00	22.6	1.5	2147.6	8.1	23.0	4.2	1.2	1.
3.	HAMALA Control	0-5cm	10.5	10.5	0.92	0.73	1.1	1.0	200	110	11.74	6.50	2355.3	8.05	17.4	1.5	1349.3	87.1	203.0	10.7	1.4	1.
4.	HAMALA Control	5-16cm			1.10	0.89			182	180	11.00	7.32	2299.3	7.99	17.4	1.5	1333.3	39.9	31.0	5.3	1.2	1.
5.	HAMALA 20T/ha Cow manure	0-5cm	11.0	11.9	1.30	1.70	3.0	1.2	340	336	58.70	84.00	1908.0	7.99	34.7	3.0	1013.9	91.9	19.0	7.3	1.8	1.
6.	HAMALA 20T/ha Cow manure	5-16cm			0.76	0.98			200	220	13.21	24.06	2395.2	7.99	17.4	2.0	1680.6	20.1	20.0	3.6	1.2	1.
7.	HAMALA 20T/ha Cow manure	0-5cm	11.1	10.2	1.10	1.82	3.1	1.2	380	348	45.50	85.00	2363.2	23.99	34.7	3.5	998.0	135.9	106.0	6.2	1.7	1.
8.	HAMALA 20T/ha Cow manure	5-16cm			0.70	0.97			190	200	17.62	22.60	2075.8	32.00	26.0	2.5	1892.2	32.1	20.0	3.8	1.2	1.
9.	HAMALA 40T/ha Cow manure	0-5cm	10.9	10.2	1.40	2.34	4.4	1.5	452	582	64.59	89.00	2195.6	16.00	43.4	4.0	902.2	63.9	59.0	4.7	1.9	1.
10.	HAMALA 40T/ha Cow manure	5-16cm			0.75	0.93			310	300	19.10	24.36	2275.4	63.90	17.4	2.5	1764.4	32.1	20.0	4.0	1.3	1.
11.	HAMALA 40T/ha Cow manure	0-5cm	11.6	10.2	1.30	2.08	7.7	2.0	450	442	68.99	85.00	2179.6	23.90	43.9	5.6	1365.3	96.0	128.0	9.5	1.9	1.
12.	HAMALA 40T/ha Cow manure	5-16cm			0.80	0.88			290	400	13.20	76.32	2195.6	11.10	24.3	3.6	2067.8	60.0	24.0	4.6	1.2	1.
13.	HAMALA 80T/ha Cow manure	0-5cm	11.8	10.9	1.40	3.12	6.1	2.0	800	860	149.70	352.00	1996.0	23.90	30.4	5.1	1485.0	139.9	138.0	7.0	2.0	2.
14.	HAMALA 80T/ha Cow manure	5-16cm			0.80	0.89			350	308	27.90	24.96	1976.0	12.30	19.1	3.6	1660.6	39.9	20.0	4.6	1.3	1.
15.	HAMALA 80T/ha Cow manure	0-5cm	11.6	11.7	1.40	2.08	6.2	2.0	850	810	126.30	456.00	1956.0	56.00	34.7	5.1	1317.0	87.9	114.0	11.0	2.2	2.
16.	HAMALA 80T/ha Cow manure	5-16cm			0.71	0.92			340	328	16.14	32.58	2019.9	16.00	26.0	4.1	1277.4	87.9	24.0	4.8	1.2	1.
17.	HAMALA 40T/ha Chick manure	0-5cm	12.1	12.5	1.30	1.95	5.6	2.0	1694	1694	329.30	399.00	2283.4	47.90	56.5	11.8	1357.0	119.9	143.0	1.5	2.6	2.
18.	HAMALA 40T/ha Chick manure	5-16cm			0.76	0.89			400	428	22.01	30.54	2205.5	23.00	26.0	10.2	1764.5	48.0	16.0	5.2	1.2	1.
19.	HAMALA 40T/ha Chick manure	0-5cm	12.6	12.2	1.40	1.82	5.8	2.0	1820	1820	273.00	333.00	2035.9	87.90	52.2	9.7	1413.0	135.9	144	17.0	2.5	2.
20.	HAMALA 40T/ha Chick manure	5-16cm			0.72	0.95			380	400	24.96	20.54	2095.8	47.70	34.7	5.1	1852.2	44.1	20.0	6.8	1.2	1.
21.	HAMALA 40T/ha Sewage sludge	0-5cm	11.6	12.8	1.50	2.99	7.4	3.0	2200	2192	164.20	136.00	2115.8	39.90	26.0	3.0	1445.0	72.0	105.0	6.5	4.6	4.
22.	HAMALA 40T/ha Sewage sludge	5-16cm			0.80	0.97			400	420	24.60	13.80	2187.6	0.0	22.6	4.1	1920.2	75.9	30.0	3.6	1.3	1.
23.	HAMALA 40T/ha Sewage sludge	0-5cm	12.1	12.9	2.20	3.06	9.2	2.5	2600	2118	108.60	122.00	2203.5	56.00	55.6	4.1	1796.4	39.9	164.0	9.7	5.2	4.
24.	HAMALA 40T/ha Sewage sludge	5-16cm			0.90	0.92			300	308	23.48	14.66	2155.67	17.7	27.8	5.1	2015.9	27.9	35.0	4.7	1.3	1.

T/ha — Mg ha-1

Table-2 Results of Pot Experiments

			Water Holding Capacity (%)		.O.C. (%)		Aggregate Stability (%)		T.K.N. (mg/Kg)		Extractable PO_4-P (mg/Kg)		Exchangable Cations (me/Kg)								C. E. C. meq/100g	
													Type - I Water				Type - II Water					
			WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	WT_1	WT_2	Ca	Mg	Na	K	Ca	Mg	Na	K	WT_1	WT_2
25.	BUDAIYA Control	0-5cm	11.0	11.0	0.92	0.48	1.5	1.0	280	294	31.10	49.60	1197.6	47.9	21.7	2.5	1381.2	39.9	101.0	4.8	1.4	1.4
26.	BUDAIYA Control	5-16cm			0.80	0.94			220	210	30.20	53.20	1097.8	16.3	17.4	2.0	1149.6	6.0	17.0	2.2	1.2	1.2
27.	BUDAIYA Control	0-5cm	12.0	11.6	0.87	0.59	1.5	1.0	290	308	30.10	15.10	1285.4	159.9	17.8	1.7	966.1	0.0	145.0	6.4	1.4	1.4
28.	BUDAIYA Control	5-16cm			0.80	0.90			210	266	30.20	32.60	1207.6	16.1	26.0	3.3	902.2	15.9	17.0	2.7	1.2	1.2
29.	BUDAIYA 20T/ha Cow manure	0-5cm	12.0	11.6	1.30	1.25	3.0	1.5	380	338	55.80	55.60	1261.5	39.9	39.1	4.1	878.0	24.0	99.0	5.5	1.8	1.7
30.	BUDAIYA 20T/ha Cow manure	5-16cm			0.80	0.90		-	200	210	35.20	59.00	886.2	7.9	22.6	3.0	1205.6	15.9	15.0	2.5	1.2	1.2
31.	BUDAIYA 20T/ha Cow manure	0-5cm	12.2	11.6	1.30	1.27	3.0	1.2	310	324	63.20	87.00	1325.3	47.9	17.4	1.7	1181.6	39.9	123.0	6.8	1.9	1.8
32.	BUDAIYA 20T/ha Cow manure	5-16cm			0.80	0.99			220	230	28.60	49.40	1207.6	9.5	18.2	3.0	978.0	20.1	24.0	3.2	1.2	1.2
33.	BUDAIYA 40T/ha Cow manure	0-5cm	12.2	10.9	1.40	1.42	5.9	1.6	420	500	89.60	168.00	1253.5	47.9	21.7	2.5	966.1	63.95	134.0	7.2	1.9	1.8
34.	BUDAIYA 40T/ha Cow manure	5-16cm			0.76	0.76			300	308	30.80	62.80	1265.5	9.8	15.6	3.6	1069.8	32.10	17.0	2.8	1.2	1.3
35.	BUDAIYA 40T/ha Cow manure	0-5cm	12.6	10.6	1.40	1.46	11.1	1.2	480	562	86.60	136.0	1253.4	16.0	17.4	1.7	1021.9	43.90	89.0	6.0	1.8	1.9
36.	BUDAIYA 40T/ha Cow manure	5-16cm			0.74	0.84			298	310	30.10	55.0	1377.2	0.0	24.3	3.6	1097.8	3.90	21.0	3.2	1.3	1.3
37.	BUDAIYA 80T/ha Cow manure	0-5cm	11.2	11.2	2.03	2.96	5.9	2.0	800	866	352.00	466.0	1269.5	32.0	30.4	4.1	918.0	63.90	134.0	8.7	2.2	2.0
38.	BUDAIYA 80T/ha Cow manure	5-16cm			0.83	0.85			298	300	32.30	64.60	1307.4	13.5	26.0	3.9	1149.7	8.10	7.0	2.7	1.3	1.3
39.	BUDAIYA 80T/ha Cow manure	0-5cm	10.8	11.5	2.57	2.09	10.6	2.0	810	888	168.00	346.00	1029.9	16.0	34.8	5.1	974.0	56.10	75.0	6.6	2.4	2.6
40.	BUDAIYA 80T/ha Cow manure	5-16cm			0.82	0.83			310	320	31.10	35.20	1207.6	12.5	27.8	4.1	1093.8	8.10	19.0	4.1	1.3	1.3
41.	BUDAIYA 40T/ha Chick manure	0-5cm	12.5	12.6	1.54	1.17	11.1	2.5	1690	1592	402.00	424.00	1245.5	47.9	52.1	7.9	942.0	72.00	94.0	7.4	2.8	2.4
42.	BUDAIYA 40T/ha Chick manure	5-16cm			0.72	0.87			412	380	64.60	57.20	1485.0	15.9	48.7	6.1	790.6	27.9	17.0	3.9	1.4	1.4
43.	BUDAIYA 40T/ha Chick manure	0-5cm	12.2	12.8	2.50	1.23	11.6	2.5	1580	1505	163.00	359.60	1061.8	63.9	39.1	5.1	942.0	0.0	96.0	9.6	1.2	1.4
44.	BUDAIYA 40T/ha Chick manure	5-16cm			0.80	0.96			360	385	38.90	41.40	1237.5	23.9	52.1	8.1	538.9	36.0	17.0	4.5	3.2	2.8
45.	BUDAIYA 40T/ha Sewage sludge	0-5cm	12.0	12.8	2.50	1.60	20.0	2.8	2100	2324	174.00	146.00	1229.5	25.3	41.7	7.6	1117.8	32.1	75.0	6.3	5.6	5.8
46.	BUDAIYA 40T/ha Sewage sludge	5-16cm			0.95	0.83			380	400	54.30	41.60	1277.4	24.6	31.3	9.3	966.1	79.8	17.0	3.2	1.5	1.2
47.	BUDAIYA 40T/ha Sewage sludge	0-5cm	12.8	12.4	2.50	2.29	13.3	2.6	2200	1756	116.00	136.00	1229.5	25.3	36.5	5.1	798.4	15.95	77.0	4.8	5.5	5.2
48.	BUDAIYA 40T/ha Sewage sludge	5-16cm			0.95	0.89			325	490	38.70	25.60	1373.2	7.9	26.0	3.6	990.0	8.10	13.0	2.2	1.3	1.2

TABLE - 3

RESULTS OF POT EXPERIMENTS

		pH (1:5)		Conductivity dsm^{-1} 25°C	Soluble Salts (%)	Soluble Salts in 1:5 Solution (MeKg^{-1}) WT$_1$						Conductivity 25°C dsm^{-1}	Soluble Salts (%)	Soluble Salts in 1:5 Solution (MeKg^{-1}) WT$_2$					
		WT$_1$	WT$_2$	WT$_1$	WT$_1$	Ca	Mg	Na	K	SO$_4$	Cl	WT$_2$	WT$_2$	Ca	Mg	Na	K	SO$_4$	Cl
1. HAMALA Control	0-5cm	7.1	7.7	4.15	0.28	162	14	37	3	165	28	6.70	0.47	190	30	156	3	158	200
2. HAMALA Control	5-16cm	7.3	7.2	3.20	0.26	160	10	29	2	162	30	3.38	0.28	140	30	45	2	160	50
3. HAMALA Control	0-5cm	7.5	8.0	3.30	0.26	170	10	43	3	165	30	6.75	0.48	180	70	130	6	171	200
4. HAMALA Control	5-16cm	7.6	7.5	2.93	0.25	164	10	21	2	165	30	3.38	0.29	160	10	47	2	163	49
5. HAMALA 20T/ha Cow manure	0-5cm	7.7	7.5	4.10	0.28	160	16	37	3	166	30	6.00	0.41	170	40	167	4	150	200
6. HAMALA 20T/ha Cow manure	5-16cm	7.7	7.5	3.10	0.26	158	13	20	3	156	30	3.15	0.24	150	10	64	1	169	49
7. HAMALA 20T/ha Cow manure	0-5cm	7.8	7.5	3.31	0.27	174	6	40	3	166	30	6.62	0.46	170	30	165	4	137	200
8. HAMALA 20T/ha Cow manure	5-16cm	7.8	7.8	3.10	0.26	170	8	26	2	155	30	3.56	0.26	150	15	26	2	160	25
9. HAMALA 40T/ha Cow manure	0-5cm	7.9	7.4	3.68	0.29	160	18	31	4	166	30	5.50	0.39	160	45	103	3	128	150
10. HAMALA 40T/ha Cow manure	5-16cm	7.8	7.5	3.12	0.26	168	19	19	2	158	30	3.32	0.28	150	5	57	2	156	49
11. HAMALA 40T/ha Cow manure	0-5cm	7.8	7.4	3.80	0.27	166	22	20	4	156	28	6.72	0.47	200	45	113	4	120	169
12. HAMALA 40T/ha Cow manure	5-16cm	7.8	7.6	2.98	0.25	165	21	22	3	157	30	3.35	0.28	160	20	42	2	152	50
13. HAMALA 80T/ha Cow manure	0-5cm	7.9	7.5	4.00	0.31	168	32	43	5	163	28	6.80	0.45	190	60	82	6	180	100
14. HAMALA 80T/ha Cow manure	5-16cm	7.6	7.5	3.80	0.28	172	14	33	3	165	30	5.00	0.30	140	20	66	2	178	42
15. HAMALA 80T/ha Cow manure	0-5cm	7.8	7.5	4.00	0.31	174	30	62	5	166	30	8.20	0.59	190	60	185	4	188	150
16. HAMALA 80T/ha Cow manure	5-16cm	7.9	7.4	2.98	0.25	161	14	19	3	157	28	3.56	0.26	160	10	23	2	163	25
17. HAMALA 40T/ha Chick manure	0-5cm	7.9	7.4	4.88	0.41	181	37	66	12	178	30	8.28	0.59	190	60	188	7	180	171
18. HAMALA 40T/ha Chick manure	5-16cm	7.9	7.5	3.25	0.27	166	14	20	5	167	30	3.32	0.28	150	20	41	2	175	28
19. HAMALA 40T/ha Chick manure	0-5cm	7.8	7.5	4.98	0.42	180	30	73	10	180	31	9.80	0.67	200	40	248	9	163	200
20. HAMALA 40T/ha Chick manure	5-16cm	7.8	7.4	3.80	0.28	168	14	18	4	176	30	3.41	0.28	150	5	51	3	158	38
21. HAMALA 40T/ha Sewage sludge	0-5cm	8.0	7.4	4.20	0.33	176	26	32	3	164	30	8.50	0.56	180	70	182	4	167	200
22. HAMALA 40T/ha Sewage sludge	5-16cm	7.9	7.5	3.20	0.27	162	12	21	2	165	28	3.36	0.28	145	20	45	2	163	35
23. HAMALA 40T/ha Sewage sludge	0-5cm	8.0	7.6	4.55	0.36	179	33	64	3	165	30	9.72	0.64	200	50	232	3	167	209
24. HAMALA 40T/ha Sewage sludge	5-16cm	7.8	7.8	3.50	0.27	176	8	25	3	157	30	5.30	0.33	155	25	68	2	160	50

TABLE - 4

RESULTS OF POT EXPERIMENTS

		pH (1:5)		Conductivity 25°C dsm^{-1}	Soluble Salts (%)	Soluble Salts in 1:5 Solution (MeKg^{-1}) WT$_1$						Conductivity 25°C dsm^{-1}	Soluble Salts (%)	Soluble Salts in 1:5 Solution (MeKg^{-1}) WT$_2$					
		WT$_1$	WT$_2$	WT$_1$	WT$_1$	Ca	Mg	Na	K	SO$_4$	Cl	WT$_2$	WT$_2$	Ca	Mg	Na	K	SO$_4$	Cl
25. BUDAIYA Control	**0-5cm**	7.8	7.7	3.25	0.25	156	14	21	3	168	17	6.02	0.43	180	30	131	2	184	150
26. BUDAIYA Control	**5-16cm**	7.7	7.7	3.30	0.25	150	5	19	2	167	17	3.32	0.27	175	10	27	2	171	40
27. BUDAIYA Control	**0-5cm**	7.8	7.7	3.38	0.27	158	14	21	2	173	30	6.71	0.48	180	20	182	1	175	197
28. BUDAIYA Control	**5-16cm**	7.4	7.5	3.32	0.26	156	8	22	3	167	29	3.30	0.27	150	10	45	1	165	38
29. BUDAIYA 20T/ha Cow manure	**0-5cm**	7.8	7.7	4.10	0.32	166	20	43	4	178	16	6.50	0.48	170	35	167	5	163	171
30. BUDAIYA 20T/ha Cow manure	**5-16cm**	7.7	7.7	3.40	0.27	163	5	26	2	178	25	3.35	0.26	150	10	37	1	163	30
31. BUDAIYA 20T/ha Cow manure	**0-5cm**	7.8	7.7	4.10	0.31	158	10	43	2	177	24	6.52	0.47	150	45	165	6	158	171
32. BUDAIYA 20T/ha Cow manure	**5-16cm**	7.9	7.8	3.42	0.27	154	4	40	2	178	29	3.50	0.30	180	20	21	1	169	25
33. BUDAIYA 40T/ha Cow manure	**0-5cm**	7.8	7.6	4.12	0.32	160	14	40	3	178	30	8.02	0.54	165	25	220	6	167	197
34. BUDAIYA 40T/ha Cow manure	**5-16cm**	7.7	7.8	3.50	0.28	158	5	42	3	183	28	3.56	0.27	155	45	11	1	163	42
35. BUDAIYA 40T/ha Cow manure	**0-5cm**	8.0	7.5	4.08	0.31	162	12	41	2	177	30	6.56	0.49	150	30	199	5	175	171
36. BUDAIYA 40T/ha Cow manure	**5-16cm**	7.8	7.7	3.52	0.28	158	6	40	2	177	30	3.25	0.25	150	10	29	1	158	25
37. BUDAIYA 80T/ha Cow manure	**0-5cm**	7.9	7.5	4.05	0.31	158	18	36	4	169	40	8.08	0.52	160	40	195	7	201	175
38. BUDAIYA 80T/ha Cow manure	**5-16cm**	7.9	7.7	3.50	0.29	160	4	40	2	177	41	3.20	0.22	145	15	8	1	122	42
39. BUDAIYA 80T/ha Cow manure	**0-5cm**	8.0	7.6	4.15	0.34	164	14	48	5	175	41	8.20	0.51	140	30	217	5	175	169
40. BUDAIYA 80T/ha Cow manure	**5-16cm**	7.9	7.6	3.50	0.28	162	12	20	3	178	41	3.30	0.22	155	5	6	2	122	38
41. BUDAIYA 40T/ha Chick manure	**0-5cm**	7.8	7.5	4.52	0.39	169	22	68	8	185	16	8.98	0.62	190	40	209	8	191	197
42. BUDAIYA 40T/ha Chick manure	**5-16cm**	7.9	7.5	3.50	0.27	156	4	22	5	177	30	3.30	0.26	155	15	26	2	151	32
43. BUDAIYA 40T/ha Chick manure	**0-5cm**	7.8	7.5	4.58	0.36	164	14	42	6	178	28	8.50	0.56	160	20	220	7	188	162
44. BUDAIYA 40T/ha Chick manure	**5-16cm**	7.8	7.5	3.62	0.28	164	4	22	4	178	40	3.50	0.22	160	20	9	2	155	25
45. BUDAIYA 40T/ha Sewage sludge	**0-5cm**	8.0	7.5	4.12	0.33	160	16	19	2	178	17	8.52	0.54	160	40	206	5	176	169
46. BUDAIYA 40T/ha Sewage sludge	**5-16cm**	7.8	7.6	3.52	0.27	156	10	22	2	177	30	3.30	0.25	160		10	2	153	14
47. BUDAIYA 40T/ha Sewage sludge	**0-5cm**	7.8	7.6	4.50	0.37	168	22	59	4	183	31	6.88	0.49	160	10	202	3	188	150
48. BUDAIYA 40T/ha Sewage sludge	**5-16cm**	8.0	7.6	3.52	0.27	166	5	24	2	177	30	3.28	0.21	150	4	11	1	133	27

TABLE - 3
RESULTS OF POT EXPERIMENTS

			2.5% Acetic Acid Extractable Metals (ugg^{-1}) WT$_1$ 1988				2.5% Acetic Acid Extractable Metals (ugg^{-1}) WT$_2$ 1989				Total Trace Metals (ugg^{-1}) WT$_1$ 1988				Total Trace Metals (ugg^{-1}) WT$_2$ 1989			
			Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb
1.	HAMALA Control	0-5cm	0.02	0.5	1.2	0.2	0.02	0.8	1.2	0.3	0.2	7.5	12.3	1.1	0.2	7.5	12.2	1.1
2.	HAMALA Control	5-16cm	0.02	0.4	0.5	0.2	0.02	0.2	0.5	0.3	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
3.	HAMALA Control	0-5cm	0.02	0.4	1.2	0.2	0.02	0.4	1.6	0.3	0.2	7.5	12.3	1.1	0.2	7.5	12.2	1.1
4.	HAMALA Control	5-16cm	0.02	0.4	0.6	0.2	0.02	0.2	0.5	0.3	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
5.	HAMALA 20T/ha Cow manure	0-5cm	0.02	0.6	1.7	0.2	0.02	0.6	3.6	0.2	0.2	8.0	14.2	1.3	0.2	8.0	14.2	1.2
6.	HAMALA 20T/ha Cow manure	5-16cm	0.02	0.4	0.5	0.2	0.02	0.2	0.6	0.2	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
7.	HAMALA 20T/ha Cow manure	0-5cm	0.02	0.7	1.8	0.2	0.02	0.6	3.8	0.3	0.2	8.2	14.2	1.2	0.2	8.0	14.2	1.2
8.	HAMALA 20T/ha Cow manure	5-16cm	0.02	0.4	0.5	0.2	0.02	0.2	0.6	0.3	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
9.	HAMALA 40T/ha Cow manure	0-5cm	0.02	0.8	2.2	0.2	0.02	1.6	3.8	0.3	0.2	8.6	16.2	1.4	0.2	8.5	16.3	1.4
10.	HAMALA 40T/ha Cow manure	5-16cm	0.02	0.5	0.6	0.2	0.02	0.2	0.6	0.2	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
11.	HAMALA 40T/ha Cow manure	0-5cm	0.02	1.3	2.8	0.2	0.02	1.6	5.0	0.3	0.2	8.6	16.1	1.4	0.2	8.6	16.3	1.5
12.	HAMALA 40T/ha Cow manure	5-16cm	0.02	0.4	0.6	0.3	0.02	0.2	0.6	0.2	0.2	7.5	12.3	1.1	0.2	7.5	12.2	1.1
13.	HAMALA 80T/ha Cow manure	0-5cm	0.02	1.2	3.1	0.2	0.02	1.6	6.4	0.3	0.2	9.7	19.4	1.5	0.2	9.5	19.6	1.7
14.	HAMALA 80T/ha Cow manure	5-16cm	0.02	0.5	0.6	0.3	0.02	0.2	0.5	0.2	0.2	7.5	12.5	1.1	0.2	7.5	12.2	1.1
15.	HAMALA 80T/ha Cow manure	0-5cm	0.02	1.3	3.8	0.2	0.02	1.6	6.6	0.2	0.2	9.6	19.5	1.7	0.2	9.6	19.8	1.7
16.	HAMALA 80T/ha Cow manure	5-16cm	0.02	0.5	0.5	0.3	0.02	0.2	0.5	0.2	0.2	7.5	12.2	1.1	0.2	7.5	12.2	1.1
17.	HAMALA 40T/ha Chick manure	0-5cm	0.02	4.3	10.2	0.2	0.02	3.6	19.6	0.3	0.2	9.2	37.0	1.4	0.2	9.1	37.2	1.4
18.	HAMALA 40T/ha Chick manure	5-16cm	0.02	0.4	0.5	0.3	0.02	0.2	0.5	0.3	0.2	7.5	12.5	1.1	0.2	7.5	12.4	1.1
19.	HAMALA 40T/ha Chick manure	0-5cm	0.02	4.0	10.0	0.2	0.02	3.6	19.0	0.3	0.2	9.2	37.1	1.4	0.2	9.1	37.6	1.4
20.	HAMALA 40T/ha Chick manure	5-16cm	0.02	0.5	0.8	0.3	0.02	0.2	0.6	0.2	0.2	7.5	12.5	1.1	0.2	7.5	12.3	1.1
21.	HAMALA 40T/ha Sewage sludge	0-5cm	0.04	5.3	34.0	0.4	0.04	5.2	44.2	0.7	0.5	35.5	56.0	10.2	0.5	36.0	53.6	10.5
22.	HAMALA 40T/ha Sewage sludge	5-16cm	0.02	0.5	3.2	0.4	0.02	0.2	1.5	0.2	0.2	7.6	12.2	1.2	0.2	7.5	12.2	1.3
23.	HAMALA 40T/ha Sewage sludge	0-5cm	0.04	5.4	30.2	0.5	0.05	5.6	44.8	0.7	0.5	35.8	53.2	10.4	0.4	35.6	53.0	10.4
24.	HAMALA 40T/ha Sewage sludge	5-16cm	0.02	0.4	2.8	0.3	0.02	0.3	1.4	0.2	0.2	7.5	12.2	1.2	0.2	7.6	12.3	1.2

TABLE - 6

RESULTS OF POT EXPERIMENTS

		2.5% Acetic Acid Extractable Metals (ugg^{-1}) WT_1 1988				2.5% Acetic Acid Extractable Metals (ugg^{-1}) WT_2 1989				Total Trace Metals (ugg^{-1}) WT_1 1988				Total Trace Metals (ugg^{-1}) WT_2 1989			
		Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd	Cu	Zn	Pb
25. BUDAIYA Control	0-5cm	0.02	1.2	1.4	0.2	0.02	1.6	3.8	0.2	0.2	7.9	15.3	1.4	0.2	7.9	15.2	1.4
26. BUDAIYA Control	5-16cm	0.02	0.5	0.5	0.3	0.02	0.3	0.7	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
27. BUDAIYA Control	0-5cm	0.02	1.2	1.3	0.2	0.02	1.8	3.4	0.2	0.2	7.9	15.3	1.4	0.2	7.9	15.2	1.4
28. BUDAIYA Control	5-16cm	0.02	0.4	0.8	0.2	0.02	0.4	0.7	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
29. BUDAIYA 20T/ha Cow manure	0-5cm	0.02	1.6	3.3	0.2	0.02	1.6	6.0	0.3	0.2	8.3	17.2	1.5	0.2	8.4	17.2	1.5
30. BUDAIYA 20T/ha Cow manure	5-16cm	0.02	0.5	0.5	0.3	0.02	0.3	0.7	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
31. BUDAIYA 20T/ha Cow manure	0-5cm	0.02	1.8	3.6	0.2	0.02	1.6	6.2	0.3	0.2	8.3	17.0	1.5	0.2	8.3	17.2	1.5
32. BUDAIYA 20T/ha Cow manure	5-16cm	0.02	0.4	0.8	0.2	0.02	0.4	0.7	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
33. BUDAIYA 40T/ha Cow manure	0-5cm	0.02	1.9	4.2	0.2	0.02	1.6	6.6	0.2	0.2	8.9	19.2	1.7	0.2	9.0	19.2	1.6
34. BUDAIYA 40T/ha Cow manure	5-16cm	0.02	0.4	0.8	0.3	0.02	0.4	0.9	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
35. BUDAIYA 40T/ha Cow manure	0-5cm	0.02	1.9	4.8	0.2	0.02	1.6	9.8	0.3	0.2	9.0	19.1	1.6	0.2	9.1	19.3	1.6
36. BUDAIYA 40T/ha Cow manure	5-16cm	0.02	0.5	0.9	0.3	0.02	0.4	0.9	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
37. BUDAIYA 80T/ha Cow manure	0-5cm	0.02	1.4	10.8	0.2	0.02	1.8	12.8	0.3	0.2	10.2	22.8	1.9	0.2	10.0	22.8	1.9
38. BUDAIYA 80T/ha Cow manure	5-16cm	0.02	0.5	0.8	0.2	0.02	0.5	0.9	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.3	1.4
39. BUDAIYA 80T/ha Cow manure	0-5cm	0.02	1.8	10.0	0.2	0.02	2.0	16.6	0.3	0.2	10.0	23.0	1.8	0.2	10.0	22.7	1.9
40. BUDAIYA 80T/ha Cow manure	5-16cm	0.02	0.6	0.5	0.2	0.02	0.4	1.0	0.2	0.2	7.9	15.4	1.4	0.2	7.9	15.5	1.4
41. BUDAIYA 40T/ha Chick manure	0-5cm	0.02	1.8	36.0	0.2	0.02	1.8	44.0	0.2	0.2	9.5	41.0	1.7	0.2	9.2	40.5	1.7
42. BUDAIYA 40T/ha Chick manure	5-16cm	0.02	0.6	0.8	0.3	0.02	0.5	1.5	0.2	0.2	7.9	15.3	1.4	0.2	7.9	15.2	1.4
43. BUDAIYA 40T/ha Chick manure	0-5cm	0.02	1.8	32.0	0.2	0.02	1.8	40.8	0.3	0.2	9.2	40.8	9.7	0.2	9.4	41.0	1.6
44. BUDAIYA 40T/ha Chick manure	5-16cm	0.02	0.7	1.8	0.3	0.02	0.5	1.3	0.2	0.2	7.9	15.2	1.4	0.2	7.9	15.2	1.4
45. BUDAIYA 40T/ha Sewage sludge	0-5cm	0.03	3.2	40.0	0.5	0.04	5.0	44.4	0.3	0.5	36.2	55.5	11.0	0.5	36.0	56.0	11.0
46. BUDAIYA 40T/ha Sewage sludge	5-16cm	0.02	2.0	1.2	0.3	0.02	0.5	2.7	0.2	0.2	7.9	15.6	1.4	0.2	8.0	15.3	1.4
47. BUDAIYA 40T/ha Sewage sludge	0-5cm	0.03	3.8	31.0	0.4	0.03	4.6	33.0	0.3	0.5	36.0	56.0	10.8	0.5	36.0	56.0	10.9
48. BUDAIYA 40T/ha Sewage sludge	5-16cm	0.02	1.2	2.6	0.3	0.02	0.5	3.0	0.2	0.2	8.0	15.3	1.4	0.2	8.1	15.4	1.4

THIS VOLUME HAS A VERY TIGHT BINDING

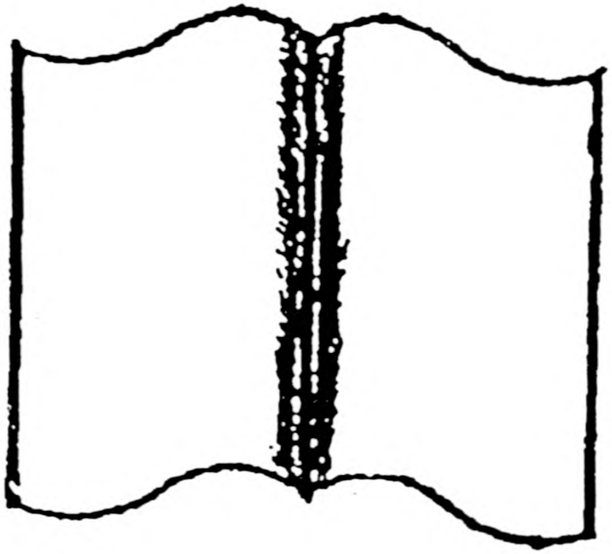

TABLE - 7

LEACHATE ANALYSIS RESULTS

ACH 88

LOW SALINITY WATER USE (WT$_1$)

Sample details	VOLUME COLLECTED	PH	COND. dS m^{-1}	NH4-N mg/L	NO3-N mg/L	NO2-N mg/L	PO4-P mg/l	TKN mg/l	K mg/l	Metals (µg/L). Cd	Cu	Zn	Pb	Leaching Loss (ug) Cd	CU	Zn	Pb
Hamala control	260	7.50	17.40	1.00	4.20	0.29	0.30	1.10	137.5	0.93	36.40	5.00	11.60	0.242	9.464	1.3	3.016
Hamala control	600	7.50	16.50	1.00	10.10	0.29	0.30	1.10	137.5	1.09	36.00	11.00	10.50	0.654	21.6	6.6	6.3
Hamala 20T/ha cow manure	1000	8.00	11.00	0.80	3.90	0.11	0.12	2.01	120	0.80	44.70	18.00	11.60	0.8	44.7	18	11.6
Hamala 20T/ha cow manure	700	7.80	13.50	1.30	6.10	0.18	0.14	2.10	150	0.87	39.60	3.00	12.70	0.609	27.72	2.1	8.89
Hamala 40T/ha cow manure	1000	8.10	10.40	0.50	6.70	0.09	0.12	2.50	120	0.64	39.70	9.00	15.70	0.64	39.7	9	15.7
Hamala 40T/ha cow manure	700	8.00	11.90	1.30	1.50	0.14	0.12	2.65	155	0.86	34.20	11.00	10.80	0.602	23.94	7.7	7.56
Hamala 80T/ha cow manure	700	8.00	11.70	0.40	1.53	0.07	0.12	3.36	190	0.58	44.90	5.00	11.70	0.406	31.43	3.5	8.19
Hamala 80T/ha cow manure	50	7.80	12.00	1.50	1.60	0.05	0.01	4.15	200	0.65	46.40	16.00	13.30	0.033	2.32	0.8	0.665
Hamala 40T/ha chicken manure	700	8.10	9.50	11.60	51.90	1.20	1.45	14.50	265	0.58	47.80	22.00	13.20	0.406	33.46	15.4	9.24
Hamala 40T/ha chicken manure	800	8.20	10.80	6.63	69.50	1.85	1.30	13.08	245	0.70	15.40	8.00	13.00	0.56	12.32	6.4	10.4
Hamala 40T/ha sewage sludge	1200	8.00	13.30	2.60	20.00	0.50	1.30	6.60	120	0.91	46.20	10.00	11.10	1.092	55.44	12	13.32
Hamala 40T/ha sewage sludge	200	8.10	15.30	3.10	35.60	0.50	1.29	6.40	140	1.03	12.10	14.00	11.00	0.206	2.42	2.8	2.2
Budaiya control	800	8.00	14.70	0.80	19.10	0.20	0.25	1.80	195	1.00	12.20	4.00	11.50	0.8	9.76	3.2	9.2
Budaiya control	800	8.10	12.90	1.10	3.40	0.10	0.34	1.90	170	0.88	17.10	4.00	12.80	0.704	13.68	3.2	10.24
Budaiya 20T/ha cow manure	300	8.00	16.80	0.06	1.20	0.15	0.13	1.80	305	1.13	19.10	16.00	9.80	0.339	5.73	4.8	2.94
Budaiya 20T/ha cow manure	900	7.90	13.20	0.79	1.98	0.17	0.12	1.65	220	0.97	18.00	16.00	12.40	0.873	16.2	14.4	11.16
Budaiya 40T/ha cow manure	900	7.80	11.90	0.74	6.20	0.07	0.12	1.10	225	0.62	16.70	13.00	11.60	0.558	15.03	11.7	10.44
Budaiya 40T/ha cow manure	950	8.20	12.50	0.95	1.15	0.10	0.12	1.00	240	0.70	14.80	34.00	11.40	0.665	14.06	32.3	10.83
Budaiya 80T/ha cow manure	950	8.10	10.80	0.49	8.90	0.12	0.12	1.26	240	0.45	19.50	32.00	13.20	0.427	18.53	30.4	12.54
Budaiya 80T/ha cow manure	900	8.10	11.40	0.79	9.10	0.18	0.12	1.50	250	0.53	43.20	37.00	14.40	0.477	38.88	33.3	12.96
Budaiya 40T/ha chicken manur	950	8.20	10.10	11.40	103.00	0.70	1.20	14.20	550	0.63	8.70	42.00	14.20	0.599	8.265	39.9	13.49
Budaiya 40T/ha chicken manur	900	8.00	13.50	4.90	112.00	1.80	1.20	10.20	550	1.02	8.90	46.00	19.10	0.918	8.01	41.4	17.19
Budaiya 40T/ha sewage sludge	1000	8.00	13.30	3.10	106.50	1.20	1.20	4.80	190	0.94	46.20	41.00	11.30	0.94	46.2	41	11.3
Budaiya 40T/ha sewage sludge	200	8.00	19.40	3.20	119.20	0.60	1.19	4.65	355	2.09	43.30	38.00	11.30	0.418	8.66	7.6	2.26

Volume collected = ml.

TABLE - 8

LEACHATE ANALYSIS RESULTS
HIGH SALINITY WATER USE (WT_2)

LEACH 89

Sample details	Volume Collected	PH	COND. mmhos/c	NH4-N mg/L	NO3-N mg/L	NO2-N mg/L	PO4-P mg/l	TKN mg/l	K mg/l	TRACE METALS (ug/L) Cd	Cu	Zn	Pb	Leaching Loss (ug) Cd	Cu	Zn	Pb
:1 Hamala control	700.00	7.20	30.10	1.19	49.60	1.10	0.09	1.20	334.50	1.00	30.50	10.00	10.00	0.70	21.35	7.00	7.00
:2 Hamala control	600.00	8.24	65.00	0.99	83.90	0.60	0.08	1.20	578.50	1.00	33.00	10.00	15.00	0.60	19.80	6.00	9.00
:3 Hamala 20T/ha cow manure	1100.00	8.06	17.60	1.29	33.20	0.50	0.12	3.64	216.30	0.90	34.00	18.00	9.60	0.99	37.40	19.80	10.56
:4 Hamala 20T/ha cow manure	200.00	8.29	19.60	2.19	38.10	3.10	0.16	2.80	252.40	1.00	35.00	20.00	11.60	0.20	7.00	4.00	2.32
:5 Hamala 40T/ha cow manure	500.00	8.03	16.90	2.69	38.70	1.20	0.30	2.80	197.10	1.00	42.00	9.00	19.60	0.50	21.00	4.50	9.80
:6 Hamala 40T/ha cow manure	1000.00	8.20	23.80	1.39	43.80	3.20	0.08	3.61	331.30	1.20	28.00	7.00	14.70	1.20	28.00	7.00	14.70
:7 Hamala 80T/ha cow manure	1000.00	8.22	16.70	0.89	25.60	0.20	0.08	3.50	278.70	1.00	42.00	8.00	14.20	1.00	42.00	8.00	14.20
:8 Hamala 80T/ha cow manure	1100.00	7.81	16.50	1.65	28.60	0.39	0.09	4.20	243.00	1.20	45.00	9.00	12.50	1.32	49.50	9.90	13.75
:9 Hamala 40T/ha chiken manure	1100.00	7.81	17.40	0.99	150.50	0.28	0.09	10.20	417.30	1.00	41.00	4.00	10.00	1.10	45.10	4.40	11.00
:10 Hamala 40T/ha chiken manure	890.00	8.36	20.30	1.69	168.80	0.33	0.09	10.60	437.20	1.00	15.00	8.00	10.00	0.89	13.35	7.12	8.90
:11 Hamala 40T/ha sewage sludge	600.00	8.08	21.20	2.49	212.50	0.35	0.08	5.10	220.10	2.00	15.87	2.00	11.50	1.20	9.52	1.20	6.90
:12 Hamala 40T/ha sewage sludge	100.00	8.00	21.20	1.89	196.00	1.50	0.30	6.20	184.20	1.50	46.00	17.00	16.40	0.15	4.60	1.70	1.64
:13 Budaiya control	900.00	8.17	23.60	1.99	15.00	0.26	0.12	1.30	184.20	1.00	18.70	5.00	16.40	0.90	16.83	4.50	14.76
:14 Budaiya control	600.00	8.09	37.00	2.09	35.80	0.30	0.09	1.20	372.00	0.90	25.00	6.00	13.10	0.54	15.00	3.60	7.86
:15 Budaiya 20T/ha cow manure	1000.00	8.31	18.30	2.25	53.50	0.30	0.18	3.50	211.60	1.00	47.00	10.00	18.30	1.00	47.00	10.00	18.30
:16 Budaiya 20T/ha cow manure	900.00	8.26	18.60	2.09	40.60	0.75	0.13	2.85	234.60	1.20	46.00	16.00	13.60	1.08	41.40	14.40	12.24
:17 Budaiya 40T/ha cow manure	1000.00	8.22	18.10	2.19	62.90	0.25	0.09	3.88	235.30	2.00	24.00	9.00	11.00	2.00	24.00	9.00	11.00
:18 Budaiya 40T/ha cow manure	900.00	8.37	20.00	2.19	63.30	0.34	0.09	2.96	339.30	2.20	42.00	32.00	14.50	1.98	37.80	28.80	13.05
:19 Budaiya 80T/ha cow manure	600.00	8.50	15.40	1.19	36.10	0.32	0.17	4.00	232.80	1.80	40.00	25.00	17.20	1.08	24.00	15.00	10.32
:20 Budaiya 80T/ha cow manure	600.00	8.13	23.60	0.89	117.50	0.31	0.08	3.80	421.40	2.00	60.00	45.00	16.00	1.20	36.00	27.00	9.60
:21 Budaiya 40T/ha chicken manure	1000.00	8.00	20.10	41.07	223.70	0.31	0.10	47.56	497.70	1.20	76.00	67.00	16.90	1.20	76.00	67.00	16.90
:22 Budaiya 40T/ha chicken manure	1100.00	7.78	18.70	1.19	227.80	5.72	0.12	5.60	463.30	1.50	46.00	12.00	17.70	1.65	50.60	13.20	19.47
:23 Budaiya 40T/ha sewage sludge	600.00	8.14	29.90	1.45	250.80	0.64	0.09	4.20	401.40	1.50	47.00	20.00	23.20	0.90	28.20	12.00	13.92
:24 Budaiya 40T/ha sewage sludge	250.00	8.07	18.70	1.19	185.40	0.27	0.10	4.80	207.70	1.50	47.00	32.00	19.70	0.38	11.75	8.00	4.93

$mmhos\ cm^{-1} = dsm^{-1}$

TABLE - 9

COPPER 88 TRACE METAL BALANCE

(WT$_1$)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	20.00	0.00	9.46	7.50	7.50	0.00	0.00
	2	20.00	0.00	21.60	7.50	7.50	0.00	0.00
	3	20.00	280.00	44.70	8.00	7.50	250.00	83.33
	4	20.00	280.00	27.72	8.20	7.50	350.00	116.67
	5	20.00	560.00	39.70	8.60	7.50	550.00	94.83
	6	20.00	560.00	23.94	8.55	7.50	525.00	90.52
	7	20.00	1120.00	31.43	9.65	7.50	1075.00	94.30
	8	20.00	1120.00	2.32	9.58	7.50	1040.00	91.23
	9	20.00	840.00	33.46	9.20	7.50	850.00	98.84
	10	20.00	840.00	12.32	9.20	7.50	850.00	98.84
	11	20.00	14140.00	55.44	35.50	7.50	14000.00	98.87
	12	20.00	14140.00	2.42	35.80	7.50	14150.00	99.93
Budaiya Soil 0 - 5 cm	13	20.00	0.00	9.76	7.90	7.90	0.00	0.00
	14	20.00	0.00	13.68	7.90	7.90	0.00	0.00
	15	20.00	280.00	5.73	8.30	7.90	200.00	66.67
	16	20.00	280.00	16.20	8.25	7.90	175.00	58.33
	17	20.00	560.00	15.03	8.95	7.90	525.00	90.52
	18	20.00	560.00	14.06	9.00	7.90	550.00	94.83
	19	20.00	1120.00	18.53	10.20	7.90	1150.00	100.88
	20	20.00	1120.00	38.88	10.00	7.90	1050.00	92.11
	21	20.00	840.00	8.27	9.50	7.90	800.00	93.02
	22	20.00	840.00	8.01	9.20	7.90	650.00	75.58
	23	20.00	14140.00	46.20	36.20	7.90	14150.00	99.93
	24	20.00	14140.00	8.66	36.00	7.90	14050.00	99.22
								ERR
Hamala Soil 5 - 16 cm	25	20.00	0.00		7.50	7.50	0.00	0.00
	26	20.00	0.00		7.50	7.50	0.00	0.00
	27	20.00	280.00		7.50	7.50	0.00	0.00
	28	20.00	280.00		7.50	7.50	0.00	0.00
	29	20.00	560.00		7.50	7.50	0.00	0.00
	30	20.00	560.00		7.50	7.50	0.00	0.00
	31	20.00	1120.00		7.50	7.50	0.00	0.00
	32	20.00	1120.00		7.50	7.50	0.00	0.00
	33	20.00	840.00		7.50	7.50	0.00	0.00
	34	20.00	840.00		7.50	7.50	0.00	0.00
	35	20.00	14140.00		7.60	7.50	100.00	0.71
	36	20.00	14140.00		7.50	7.50	0.00	0.00
Budaiya Soil 5 - 16 cm	37	20.00	0.00		7.90	7.90	0.00	0.00
	38	20.00	0.00		7.90	7.90	0.00	0.00
	39	20.00	280.00		7.90	7.90	0.00	0.00
	40	20.00	280.00		7.90	7.90	0.00	0.00
	41	20.00	560.00		7.90	7.90	0.00	0.00
	42	20.00	560.00		7.90	7.90	0.00	0.00
	43	20.00	1120.00		7.90	7.90	0.00	0.00
	44	20.00	1120.00		7.90	7.90	0.00	0.00
	45	20.00	840.00		7.90	7.90	0.00	0.00
	46	20.00	840.00		7.95	7.90	50.00	5.81
	47	20.00	14140.00		7.90	7.90	0.00	0.00
	48	20.00	14140.00		8.00	7.90	100.00	0.71
								ERR

COPPER 89 TRACE METAL BALANCE **TABLE - 10**

(WT_2)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	16.25	0.00	21.35	7.50	7.50	0.00	0.00
	2	16.25	0.00	19.80	7.50	7.50	0.00	0.00
	3	16.25	280.00	37.40	8.00	7.50	250.00	84.39
	4	16.25	280.00	7.00	8.00	7.50	250.00	84.39
	5	16.25	560.00	21.00	8.50	7.50	500.00	86.77
	6	16.25	560.00	28.00	8.60	7.50	550.00	95.44
	7	16.25	1120.00	42.00	9.50	7.50	1000.00	88.01
	8	16.25	1120.00	49.50	9.60	7.50	1050.00	92.41
	9	16.25	840.00	45.10	9.10	7.50	800.00	93.43
	10	16.25	840.00	13.35	9.10	7.50	800.00	93.43
	11	16.25	14140.00	9.52	36.00	7.50	14250.00	100.66
	12	16.25	14140.00	4.60	35.60	7.50	14050.00	99.25
Budaiya Soil 0 - 5 cm	13	16.25	0.00	16.83	7.90	7.90	0.00	0.00
	14	16.25	0.00	15.00	7.90	7.90	0.00	0.00
	15	16.25	280.00	47.00	8.40	7.90	250.00	84.39
	16	16.25	280.00	41.40	8.30	7.90	200.00	67.51
	17	16.25	560.00	24.00	9.00	7.90	550.00	95.44
	18	16.25	560.00	37.80	9.10	7.90	600.00	104.12
	19	16.25	1120.00	24.00	10.00	7.90	1050.00	92.41
	20	16.25	1120.00	36.00	10.00	7.90	1050.00	92.41
	21	16.25	840.00	76.00	9.20	7.90	650.00	75.91
	22	16.25	840.00	50.60	9.40	7.90	750.00	87.59
	23	16.25	14140.00	28.20	36.00	7.90	14050.00	99.25
	24	16.25	14140.00	11.75	36.00	7.90	14050.00	99.25
Hamala Soil 5 - 16 cm	25	16.25	0.00		7.50	7.50	0.00	0.00
	26	16.25	0.00		7.50	7.50	0.00	0.00
	27	16.25	280.00		7.50	7.50	0.00	0.00
	28	16.25	280.00		7.50	7.50	0.00	0.00
	29	16.25	560.00		7.50	7.50	0.00	0.00
	30	16.25	560.00		7.50	7.50	0.00	0.00
	31	16.25	1120.00		7.50	7.50	0.00	0.00
	32	16.25	1120.00		7.50	7.50	0.00	0.00
	33	16.25	840.00		7.50	7.50	0.00	0.00
	34	16.25	840.00		7.50	7.50	0.00	0.00
	35	16.25	14140.00		7.50	7.50	0.00	0.00
	36	16.25	14140.00		7.60	7.50	100.00	0.71
Budaiya Soil 5 - 16 cm	37	16.25	0.00		7.90	7.90	0.00	0.00
	38	16.25	0.00		7.90	7.90	0.00	0.00
	39	16.25	280.00		7.90	7.90	0.00	0.00
	40	16.25	280.00		7.90	7.90	0.00	0.00
	41	16.25	560.00		7.90	7.90	0.00	0.00
	42	16.25	560.00		7.90	7.90	0.00	0.00
	43	16.25	1120.00		7.90	7.90	0.00	0.00
	44	16.25	1120.00		7.90	7.90	0.00	0.00
	45	16.25	840.00		7.90	7.90	0.00	0.00
	46	16.25	840.00		7.90	7.90	0.00	0.00
	47	16.25	14140.00		8.00	7.90	100.00	0.71
	48	16.25	14140.00		8.10	7.90	200.00	1.41

LEAD 88 TRACE METAL BALANCE **TABLE - 11**

(WT$_1$)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	19.25	0.00	3.02	1.10	1.10	0.00	0.00
	2	19.25	0.00	6.30	1.10	1.10	0.00	0.00
	3	19.25	78.40	11.60	1.30	1.10	100.00	102.41
	4	19.25	78.40	8.89	1.20	1.10	50.00	51.20
	5	19.25	156.80	15.70	1.40	1.10	150.00	85.20
	6	19.25	156.80	7.56	1.40	1.10	150.00	85.20
	7	19.25	313.60	8.19	1.50	1.10	200.00	60.09
	8	19.25	313.60	0.67	1.70	1.10	300.00	90.13
	9	19.25	158.20	9.24	1.40	1.10	150.00	84.53
	10	19.25	158.20	10.40	1.40	1.10	150.00	84.53
	11	19.25	4797.24	13.32	10.20	1.10	4550.00	94.47
	12	19.25	4797.24	2.20	10.40	1.10	4650.00	96.54
Budaiya Soil 0 - 5 cm	13	19.25	0.00	9.20	1.40	1.40	0.00	0.00
	14	19.25	0.00	10.24	1.40	1.40	0.00	0.00
	15	19.25	78.40	2.94	1.50	1.40	50.00	51.20
	16	19.25	78.40	11.16	1.50	1.40	50.00	51.20
	17	19.25	156.80	10.44	1.70	1.40	150.00	85.20
	18	19.25	156.80	10.83	1.60	1.40	100.00	56.80
	19	19.25	313.60	12.54	1.88	1.40	240.00	72.10
	20	19.25	313.60	12.96	1.80	1.40	200.00	60.09
	21	19.25	158.20	13.49	1.70	1.40	150.00	84.53
	22	19.25	158.20	17.19	1.70	1.40	150.00	84.53
	23	19.25	4797.24	11.30	11.00	1.40	4800.00	99.66
	24	19.25	4797.24	2.26	10.80	1.40	4700.00	97.58
Hamala Soil 5 - 16 cm	25	19.25	0.00		1.10	1.10	0.00	0.00
	26	19.25	0.00		1.10	1.10	0.00	0.00
	27	19.25	78.40		1.10	1.10	0.00	0.00
	28	19.25	78.40		1.10	1.10	0.00	0.00
	29	19.25	156.80		1.10	1.10	0.00	0.00
	30	19.25	156.80		1.10	1.10	0.00	0.00
	31	19.25	313.60		1.10	1.10	0.00	0.00
	32	19.25	313.60		1.10	1.10	0.00	0.00
	33	19.25	158.20		1.10	1.10	0.00	0.00
	34	19.25	158.20		1.10	1.10	0.00	0.00
	35	19.25	4797.24		1.20	1.10	100.00	2.08
	36	19.25	4797.24		1.20	1.10	100.00	2.08
Budaiya Soil 5 - 16 cm	37	19.25	0.00		1.40	1.40	0.00	0.00
	38	19.25	0.00		1.40	1.40	0.00	0.00
	39	19.25	78.40		1.40	1.40	0.00	0.00
	40	19.25	78.40		1.40	1.40	0.00	0.00
	41	19.25	156.80		1.40	1.40	0.00	0.00
	42	19.25	156.80		1.40	1.40	0.00	0.00
	43	19.25	313.60		1.40	1.40	0.00	0.00
	44	19.25	313.60		1.40	1.40	0.00	0.00
	45	19.25	158.20		1.40	1.40	0.00	0.00
	46	19.25	158.20		1.40	1.40	0.00	0.00
	47	19.25	4797.24		1.40	1.40	0.00	0.00
	48	19.25	4797.24		1.40	1.40	0.00	0.00

LEAD 89 TRACE METAL BALANCE TABLE - 12

(WT_2) .

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	16.40	0.00	7.00	1.10	1.10	0.00	0.00
	2	16.40	0.00	9.00	1.10	1.10	0.00	0.00
	3	16.40	78.40	10.56	1.20	1.10	50.00	52.74
	4	16.40	78.40	2.32	1.20	1.10	50.00	52.74
	5	16.40	156.80	9.80	1.40	1.10	150.00	86.61
	6	16.40	156.80	14.70	1.50	1.10	200.00	115.47
	7	16.40	313.60	14.20	1.70	1.10	300.00	90.91
	8	16.40	313.60	13.75	1.70	1.10	300.00	90.91
	9	16.40	158.20	11.00	1.40	1.10	150.00	85.91
	10	16.40	158.20	8.90	1.40	1.10	150.00	85.91
	11	16.40	4797.24	6.90	10.45	1.10	4675.00	97.12
	12	16.40	4797.24	1.64	10.40	1.10	4650.00	96.60
Budaiya Soil 0 - 5 cm	13	16.40	0.00	14.76	1.40	1.40	0.00	0.00
	14	16.40	0.00	7.86	1.40	1.40	0.00	0.00
	15	16.40	78.40	18.30	1.50	1.40	50.00	52.74
	16	16.40	78.40	12.24	1.50	1.40	50.00	52.74
	17	16.40	156.80	11.00	1.60	1.40	100.00	57.74
	18	16.40	156.80	13.05	1.60	1.40	100.00	57.74
	19	16.40	313.60	10.32	1.90	1.40	250.00	75.76
	20	16.40	313.60	9.60	1.95	1.40	275.00	83.33
	21	16.40	158.20	16.90	1.70	1.40	150.00	85.91
	22	16.40	158.20	19.47	1.60	1.40	100.00	57.27
	23	16.40	4797.24	13.92	11.00	1.40	4800.00	99.72
	24	16.40	4797.24	4.93	10.85	1.40	4725.00	98.16
Hamala Soil 5 - 16 cm	25	16.40	0.00		1.10	1.10	0.00	0.00
	26	16.40	0.00		1.10	1.10	0.00	0.00
	27	16.40	78.40		1.10	1.10	0.00	0.00
	28	16.40	78.40		1.10	1.10	0.00	0.00
	29	16.40	156.80		1.10	1.10	0.00	0.00
	30	16.40	156.80		1.10	1.10	0.00	0.00
	31	16.40	313.60		1.10	1.10	0.00	0.00
	32	16.40	313.60		1.10	1.10	0.00	0.00
	33	16.40	158.20		1.10	1.10	0.00	0.00
	34	16.40	158.20		1.10	1.10	0.00	0.00
	35	16.40	4797.24		1.30	1.10	200.00	4.15
	36	16.40	4797.24		1.20	1.10	100.00	2.08
Budaiya Soil 5 - 16 cm	37	16.40	0.00		1.40	1.40	0.00	0.00
	38	16.40	0.00		1.40	1.40	0.00	0.00
	39	16.40	78.40		1.40	1.40	0.00	0.00
	40	16.40	78.40		1.40	1.40	0.00	0.00
	41	16.40	156.80		1.40	1.40	0.00	0.00
	42	16.40	156.80		1.40	1.40	0.00	0.00
	43	16.40	313.60		1.40	1.40	0.00	0.00
	44	16.40	313.60		1.40	1.40	0.00	0.00
	45	16.40	158.20		1.40	1.40	0.00	0.00
	46	16.40	158.20		1.40	1.40	0.00	0.00
	47	16.40	4797.24		1.40	1.40	0.00	0.00
	48	16.40	4797.24		1.40	1.40	0.00	0.00

ZINC 88 TRACE METAL BALANCE **TABLE - 13**

(WT_1)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	52.50	0.00	1.30	12.30	12.20	50.00	95.24
	2	52.50	0.00	6.60	12.30	12.20	50.00	95.24
	3	52.50	1001.00	18.00	14.20	12.20	1000.00	94.92
	4	52.50	1001.00	2.10	14.20	12.20	1000.00	94.92
	5	52.50	2002.00	9.00	16.20	12.20	2000.00	97.35
	6	52.50	2002.00	7.70	16.10	12.20	1950.00	94.91
	7	52.50	4004.00	3.50	19.40	12.20	3600.00	88.75
	8	52.50	4004.00	0.80	19.50	12.20	3650.00	89.98
	9	52.50	12880.00	15.40	37.00	12.20	12400.00	95.88
	10	52.50	12880.00	6.40	37.10	12.20	12450.00	96.27
	11	52.50	20532.40	12.00	56.00	12.20	21900.00	106.39
	12	52.50	20532.40	2.80	53.20	12.20	20500.00	99.59
Budaiya Soil 0 - 5 cm	13	52.50	0.00	3.20	15.30	15.20	50.00	95.24
	14	52.50	0.00	3.20	15.30	15.20	50.00	95.24
	15	52.50	1001.00	4.80	17.20	15.20	1000.00	94.92
	16	52.50	1001.00	14.40	17.00	15.20	900.00	85.43
	17	52.50	2002.00	11.70	19.20	15.20	2000.00	97.35
	18	52.50	2002.00	32.30	19.12	15.20	1960.00	95.40
	19	52.50	4004.00	30.40	22.80	15.20	3800.00	93.68
	20	52.50	4004.00	33.30	23.00	15.20	3900.00	96.14
	21	52.50	12880.00	39.90	41.00	15.20	12900.00	99.75
	22	52.50	12880.00	41.40	40.80	15.20	12800.00	98.98
	23	52.50	20532.40	41.00	55.50	15.20	20150.00	97.89
	24	52.50	20532.40	7.60	56.00	15.20	20400.00	99.10
Hamala Soil 5 - 16 cm	25	52.50	0.00		12.20	12.20	0.00	0.00
	26	52.50	0.00		12.20	12.20	0.00	0.00
	27	52.50	1001.00		12.20	12.20	0.00	0.00
	28	52.50	1001.00		12.20	12.20	0.00	0.00
	29	52.50	2002.00		12.20	12.20	0.00	0.00
	30	52.50	2002.00		12.30	12.20	100.00	4.87
	31	52.50	4004.00		12.50	12.20	300.00	7.40
	32	52.50	4004.00		12.20	12.20	0.00	0.00
	33	52.50	12880.00		12.50	12.20	300.00	2.32
	34	52.50	12880.00		12.50	12.20	300.00	2.32
	35	52.50	20532.40		12.20	12.20	0.00	0.00
	36	52.50	20532.40		12.20	12.20	0.00	0.00
Budaiya Soil 5 -16 cm	37	52.50	0.00		15.20	15.20	0.00	0.00
	38	52.50	0.00		15.20	15.20	0.00	0.00
	39	52.50	1001.00		15.20	15.20	0.00	0.00
	40	52.50	1001.00		15.20	15.20	0.00	0.00
	41	52.50	2002.00		15.20	15.20	0.00	0.00
	42	52.50	2002.00		15.20	15.20	0.00	0.00
	43	52.50	4004.00		15.40	15.20	200.00	4.93
	44	52.50	4004.00		15.30	15.20	100.00	2.47
	45	52.50	12880.00		15.20	15.20	0.00	0.00
	46	52.50	12880.00		15.20	15.20	0.00	0.00
	47	52.50	20532.40		15.60	15.20	400.00	1.94
	48	52.50	20532.40		15.30	15.20	100.00	0.49

ZINC 89 TRACE METAL BALANCE **TABLE - 14**

(WT_2)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	44.50	0.00	7.00	12.20	12.20	0.00	0.00
	2	44.50	0.00	6.00	12.20	12.20	0.00	0.00
	3	44.50	1001.00	19.80	14.18	12.20	990.00	94.69
	4	44.50	1001.00	4.00	14.20	12.20	1000.00	95.65
	5	44.50	2002.00	4.50	16.25	12.20	2025.00	98.95
	6	44.50	2002.00	7.00	16.30	12.20	2050.00	100.17
	7	44.50	4004.00	8.00	19.60	12.20	3700.00	91.39
	8	44.50	4004.00	9.90	19.80	12.20	3800.00	93.86
	9	44.50	12880.00	4.40	37.20	12.20	12500.00	96.72
	10	44.50	12880.00	7.12	37.60	12.20	12700.00	98.26
	11	44.50	20532.40	1.20	53.60	12.20	20700.00	100.60
	12	44.50	20532.40	1.70	53.00	12.20	20400.00	99.14
Budaiya Soil 0 - 5 cm	13	44.50	0.00	4.50	15.20	15.20	0.00	0.00
	14	44.50	0.00	3.60	15.20	15.20	0.00	0.00
	15	44.50	1001.00	10.00	17.20	15.20	1000.00	95.65
	16	44.50	1001.00	14.40	17.20	15.20	1000.00	95.65
	17	44.50	2002.00	9.00	19.15	15.20	1975.00	96.51
	18	44.50	2002.00	28.80	19.25	15.20	2025.00	98.95
	19	44.50	4004.00	15.00	22.80	15.20	3800.00	93.86
	20	44.50	4004.00	27.00	22.70	15.20	3750.00	92.63
	21	44.50	12880.00	67.00	40.50	15.20	12650.00	97.87
	22	44.50	12880.00	13.20	41.00	15.20	12900.00	99.81
	23	44.50	20532.40	12.00	56.00	15.20	20400.00	99.14
	24	44.50	20532.40	8.00	56.00	15.20	20400.00	99.14
Hamala Soil 5 - 16 cm	25	44.50	0.00		12.20	12.20	0.00	0.00
	26	44.50	0.00		12.20	12.20	0.00	0.00
	27	44.50	1001.00		12.20	12.20	0.00	0.00
	28	44.50	1001.00		12.20	12.20	0.00	0.00
	29	44.50	2002.00		12.20	12.20	0.00	0.00
	30	44.50	2002.00		12.20	12.20	0.00	0.00
	31	44.50	4004.00		12.20	12.20	0.00	0.00
	32	44.50	4004.00		12.20	12.20	0.00	0.00
	33	44.50	12880.00		12.40	12.20	200.00	1.55
	34	44.50	12880.00		12.30	12.20	100.00	0.77
	35	44.50	20532.40		12.20	12.20	0.00	0.00
	36	44.50	20532.40		12.30	12.20	100.00	0.49
Budaiya Soil 5 - 16 cm	37	44.50	0.00		15.20	15.20	0.00	0.00
	38	44.50	0.00		15.20	15.20	0.00	0.00
	39	44.50	1001.00		15.20	15.20	0.00	0.00
	40	44.50	1001.00		15.20	15.20	0.00	0.00
	41	44.50	2002.00		15.20	15.20	0.00	0.00
	42	44.50	2002.00		15.20	15.20	0.00	0.00
	43	44.50	4004.00		15.30	15.20	100.00	2.47
	44	44.50	4004.00		15.50	15.20	300.00	7.41
	45	44.50	12880.00		15.20	15.20	0.00	0.00
	46	44.50	12880.00		15.20	15.20	0.00	0.00
	47	44.50	20532.40		15.30	15.20	100.00	0.49
	48	44.50	20532.40		15.35	15.20	150.00	0.73

Table-15

CADMIUM 88
(WT_1)

TRACE METAL BALANCE

TABLE - 15

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	3.25	0.00	0.24	0.20	0.20	0.00	0.00
	2	3.25	0.00	0.65	0.20	0.20	0.00	0.00
	3	3.25	1.82	0.80	0.20	0.20	0.00	0.00
	4	3.25	1.82	0.61	0.20	0.20	0.00	0.00
	5	3.25	3.64	0.64	0.20	0.20	0.00	0.00
	6	3.25	3.64	0.60	0.20	0.20	0.00	0.00
	7	3.25	7.28	0.41	0.20	0.20	0.00	0.00
	8	3.25	7.28	0.03	0.20	0.20	0.00	0.00
	9	3.25	8.26	0.41	0.20	0.20	0.00	0.00
	10	3.25	8.26	0.56	0.20	0.20	0.00	0.00
	11	3.25	135.24	1.09	0.50	0.20	150.00	108.31
	12	3.25	135.24	0.21	0.52	0.20	160.00	115.53
Budaiya Soil 0 - 5 cm	13	3.25	0.00	0.80	0.20	0.20	0.00	0.00
	14	3.25	0.00	0.70	0.20	0.20	0.00	0.00
	15	3.25	1.82	0.34	0.20	0.20	0.00	0.00
	16	3.25	1.82	0.87	0.20	0.20	0.00	0.00
	17	3.25	3.64	0.56	0.20	0.20	0.00	0.00
	18	3.25	3.64	0.67	0.20	0.20	0.00	0.00
	19	3.25	7.28	0.43	0.20	0.20	0.00	0.00
	20	3.25	7.28	0.48	0.20	0.20	0.00	0.00
	21	3.25	8.26	0.59	0.20	0.20	0.00	0.00
	22	3.25	8.26	0.92	0.20	0.20	0.00	0.00
	23	3.25	135.24	0.94	0.48	0.20	140.00	101.09
	24	3.25	135.24	0.42	0.48	0.20	140.00	101.09
Hamala Soil 5 - 16 cm	25	3.25	0.00		0.20	0.20	0.00	0.00
	27	3.25	1.82		0.20	0.20	0.00	0.00
	28	3.25	1.82		0.20	0.20	0.00	0.00
	29	3.25	3.64		0.20	0.20	0.00	0.00
	30	3.25	3.64		0.20	0.20	0.00	0.00
	31	3.25	7.28		0.20	0.20	0.00	0.00
	32	3.25	7.28		0.20	0.20	0.00	0.00
	33	3.25	8.26		0.20	0.20	0.00	0.00
	34	3.25	8.26		0.20	0.20	0.00	0.00
	35	3.25	135.24		0.20	0.20	0.00	0.00
	36	3.25	135.24		0.20	0.20	0.00	0.00
Budaiya Soil 5 - 16 cm	37	3.25	0.00		0.20	0.20	0.00	0.00
	38	3.25	0.00		0.20	0.20	0.00	0.00
	39	3.25	1.82		0.20	0.20	0.00	0.00
	40	3.25	1.82		0.20	0.20	0.00	0.00
	41	3.25	3.64		0.20	0.20	0.00	0.00
	42	3.25	3.64		0.20	0.20	0.00	0.00
	43	3.25	7.28		0.20	0.20	0.00	0.00
	44	3.25	7.28		0.20	0.20	0.00	0.00
	45	3.25	8.26		0.20	0.20	0.00	0.00
	46	3.25	8.26		0.20	0.20	0.00	0.00
	47	3.25	135.24		0.20	0.20	0.00	0.00
	48	3.25	135.24		0.20	0.20	0.00	0.00

CADMIUM 89 TRACE METAL BALANCE **TABLE - 16**

(WT_2)

	SERIAL NUMBER	ADDED IN WATER ug	ADDED MANURE ug	LEACHING LOSS ug	AFTER CONC. ug/g	BEFORE CONC. ug/g	GAIN IN SOIL ug	% gain ug
Hamala Soil 0 - 5 cm	1	3.25	0.00	0.70	0.20	0.20	0.00	0.00
	2	3.25	0.00	0.60	0.20	0.20	0.00	0.00
	3	3.25	1.82	0.99	0.20	0.20	0.00	0.00
	4	3.25	1.82	0.20	0.20	0.20	0.00	0.00
	5	3.25	3.64	0.50	0.20	0.20	0.00	0.00
	6	3.25	3.64	1.20	0.20	0.20	0.00	0.00
	7	3.25	7.28	1.00	0.20	0.20	0.00	0.00
	8	3.25	7.28	1.32	0.20	0.20	0.00	0.00
	9	3.25	8.26	1.10	0.20	0.20	0.00	0.00
	10	3.25	8.26	0.89	0.20	0.20	0.00	0.00
	11	3.25	135.24	1.20	0.45	0.20	125.00	90.26
	12	3.25	135.24	0.15	0.40	0.20	100.00	72.21
Budaiya Soil 0 - 5 cm	13	3.25	0.00	0.90	0.20	0.20	0.00	0.00
	14	3.25	0.00	0.54	0.20	0.20	0.00	0.00
	15	3.25	1.82	1.00	0.20	0.20	0.00	0.00
	16	3.25	1.82	1.08	0.20	0.20	0.00	0.00
	17	3.25	3.64	2.00	0.20	0.20	0.00	0.00
	18	3.25	3.64	1.98	0.20	0.20	0.00	0.00
	19	3.25	7.28	1.08	0.20	0.20	0.00	0.00
	20	3.25	7.28	1.20	0.20	0.20	0.00	0.00
	21	3.25	8.26	1.20	0.20	0.20	0.00	0.00
	22	3.25	8.26	1.65	0.20	0.20	0.00	0.00
	23	3.25	135.24	0.90	0.48	0.20	140.00	101.09
	24	3.25	135.24	0.37	0.48	0.20	140.00	101.09
Hamala Soil 5 - 16 cm	25	3.25	0.00		0.20	0.20	0.00	0.00
	26	3.25	0.00		0.20	0.20	0.00	0.00
	27	3.25	1.82		0.20	0.20	0.00	0.00
	28	3.25	1.82		0.20	0.20	0.00	0.00
	29	3.25	3.64		0.20	0.20	0.00	0.00
	30	3.25	3.64		0.20	0.20	0.00	0.00
	31	3.25	7.28		0.20	0.20	0.00	0.00
	32	3.25	7.28		0.20	0.20	0.00	0.00
	33	3.25	8.26		0.20	0.20	0.00	0.00
	34	3.25	8.26		0.20	0.20	0.00	0.00
	35	3.25	135.24		0.20	0.20	0.00	0.00
	36	3.25	135.24		0.20	0.20	0.00	0.00
Budaiya Soil 5 - 16 cm	37	3.25	0.00		0.20	0.20	0.00	0.00
	38	3.25	0.00		0.20	0.20	0.00	0.00
	39	3.25	1.82		0.20	0.20	0.00	0.00
	40	3.25	1.82		0.20	0.20	0.00	0.00
	41	3.25	3.64		0.20	0.20	0.00	0.00
	42	3.25	3.64		0.20	0.20	0.00	0.00
	43	3.25	7.28		0.20	0.20	0.00	0.00
	44	3.25	7.28		0.20	0.20	0.00	0.00
	45	3.25	8.26		0.20	0.20	0.00	0.00
	46	3.25	8.26		0.20	0.20	0.00	0.00
	47	3.25	135.24		0.20	0.20	0.00	0.00
	48	3.25	135.24		0.20	0.20	0.00	0.00
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FIELD EXPERIMENT SOIL ANALYSIS RESLUTS

TABLE - 17

Grain Size

	Soil No	FARM NO	FARM NAME	Soil depth cm	Sand %	Silt %	Clay %	Texture
Chicken Manure Area	1	1	Yateem Garden	0-5cm	89.0	8.00	3.00	sandy
	2			5-25cm	86.8	10.0	3.20	sandy
	3			25-50cm	88.00	10.00	2.00	sandy
	4	2	Mohamed Daif	0-5cm	90.00	8.00	2.00	sandy
	5			5-25cm	61.60	30.40	8.00	s.loam
	6			25-50	61.00	30.00	9.00	s.loam
	7	3	Ebrahim Yousif Saleh	0-5cm	87.00	10.00	3.00	sandy
	8			5-25cm	65.60	24.20	10.20	s.loam
	9			25-50cm	68.00	25.00	7.00	s.loam
	10	4	Ebrahim Hassan Al-Majid	0-5cm	80.00	10.00	10.00	l.sand
	11			5-25cm	68.40	14.10	17.50	s.loam
	12			25-50cm	72.40	10.40	17.20	s.loam
	13	5	Hassan Makki Asoor	0-5cm	92.00	7.20	0.80	sandy
	14			5-25cm	72.40	10.40	17.20	s.loam
	15			25-50cm	72.00	11.00	17.00	s.loam
	16	6	Ali Yousif Al-Malah	0-5cm	90.00	8.80	1.20	sandy
	17			5-25cm	90.00	8.50	1.50	sandy
	18			25-50cm	90.00	8.60	1.40	sandy
Cow Manure Area	19	7	Al-Marooge Farm	0-5cm	84.00	13.00	2.60	l.sand
	20			5-25cm	84.40	12.00	3.60	l.sand
	21			25-50cm	69.20	25.00	5.80	s.loam
	22	8	Al-Marooge Farm	0-5cm	91.00	7.00	2.00	sandy
	23			5-25cm	85.00	10.00	5.00	l.sand
	24			25-50cm	82.00	12.00	6.00	l.sand
	25	9	Al-Akr-1 near well 1/134	0-5cm	95.44	2.18	2.38	sandy
	26			5-25cm	91.34	5.30	3.36	sandy
	27			25-50cm	89.04	6.24	4.72	sandy
	28	10	Al Akr-2 near well 1/137	0-5cm	94.84	2.36	2.80	sandy
	29			5-25cm	80.20	12.76	7.02	l.sand
	30			25-50cm	61.50	34.54	3.96	s.loam
	31	11	Al-Akr-3 near well 1/35	0-5cm	76.66	13.88	9.46	s.loam
	32			5-25cm	62.36	18.72	18.92	s.loam
	33			25-50cm	58.20	20.60	21.20	s.loam
Sludge Area	34	12	Al-Areen (5 years)	0-5cm	93.60	5.40	1.00	sandy
	35			5-25cm	93.00	6.00	1.00	sandy
	36			25-50cm	93.00	6.00	1.00	sandy
	37	13	Al-Areen (2years)	0-5cm	92.00	7.00	1.00	sandy
	38			5-25cm	92.00	7.00	1.00	sandy
	39			25-50cm	91.00	7.50	1.50	sandy
	40	14	Al-Areen (1 year)	0-5cm	91.00	7.50	1.50	sandy
	41			5-25cm	87.00	10.00	3.00	l.sand
	42			25-50cm	91.00	7.50	1.50	sandy
	43	15	Al Areen (6 months)	0-5cm	91.00	8.00	1.00	sandy
	44			5-25cm	89.00	9.20	1.80	sandy
	45			25-50cm	91.00	8.00	1.00	sandy
	46	16	Hamala experimental (5 years)	0-5cm	79.50	20.00	0.50	s.loam
	47			5-25cm	81.60	17.60	0.80	s.loam
	48			25-50cm	80.00	19.50	0.50	s.loam
	49	17	Hamala experimental (3 years	0-5cm	79.00	20.50	1.00	s.loam
	50			5-25cm	82.00	14.00	4.00	l.sand
	51			25-50cm	81.60	17.60	0.80	s.loam
	52	Control	HAMALA experimental	0-5cm	95.20	4.00	0.80	sandy
	53	Control	Al-Areen	0-5cm	92.60	6.40	1.00	sandy
	54	Control	Al-Marooge	0-5cm	81.00	10.00	9.00	l.sand

TABLE - 18

FIELD EXPERIMENT SOIL ANALYSIS RESLUTS

	Soil No	FARM NO	FARM NAME	Soil depth cm	Conductivity μS /cm	Soluble salts (1:5) %	pH
Chicken Manure Area	1	1	Yateem Garden	0-5cm	2.92	0.24	7.60
	2			5-25cm	2.91	0.24	7.50
	3			25-50cm	3.22	0.25	7.60
	4	2	Mohamed Daif	0-5cm	4.25	0.29	7.40
	5			5-25cm	5.35	0.34	7.60
	6			25-50	3.28	0.22	7.60
	7	3	Ebrahim Yousif Saleh	0-5cm	10.20	0.67	7.50
	8			5-25cm	3.36	0.30	7.40
	9			25-50cm	4.72	0.34	7.70
	10	4	Ebrahim Hassan Al-Majid	0-5cm	10.60	0.69	7.50
	11			5-25cm	2.98	0.23	7.60
	12			25-50cm	2.93	0.23	7.80
	13	5	Hassan Makki Asoor	0-5cm	5.17	0.33	7.40
	14			5-25cm	2.84	0.20	7.60
	15			25-50cm	2.98	0.23	7.70
	16	6	Ali Yousif Al-Malah	0-5cm	0.95	0.06	7.80
	17			5-25cm	0.61	0.04	7.80
	18			25-50cm	3.15	0.24	7.50
Cow Manure Area	19	7	Al-Marooge Farm	0-5cm	3.35	0.23	7.40
	20			5-25cm	2.92	0.20	7.40
	21			25-50cm	3.19	0.23	7.40
	22	8	Al-Marooge Farm	0-5cm	0.99	0.06	7.40
	23			5-25cm	3.08	0.26	7.50
	24			25-50cm	3.53	0.26	7.40
	25	9	Al-Akr-1 near well 1/134	0-5cm	1.00	0.05	7.72
	26			5-25cm	0.70	0.03	7.78
	27			25-50cm	0.96	0.04	7.80
	28	10	Al Akr-2 near well 1/137	0-5cm	0.51	0.02	7.82
	29			5-25cm	1.15	0.05	7.86
	30			25-50cm	1.38	0.07	7.78
	31	11	Al-Akr-3 near well 1/35	0-5cm	1.28	0.07	7.59
	32			5-25cm	0.96	0.04	7.83
	33			25-50cm	0.67	0.03	7.90
Sludge Area	34	12	Al-Areen (5 years)	0-5cm	3.54	0.26	7.54
	35			5-25cm	0.40	0.03	7.87
	36			25-50cm	2.64	0.22	7.42
	37	13	Al-Areen (2years)	0-5cm	2.52	0.22	7.46
	38			5-25cm	2.51	0.22	7.34
	39			25-50cm	2.56	0.22	7.32
	40	14	Al-Areen (1 year)	0-5cm	2.73	0.23	7.40
	41			5-25cm	2.76	0.23	7.26
	42			25-50cm	2.69	0.23	7.35
	43	15	Al Areen (6 months)	0-5cm	2.51	0.19	7.42
	44			5-25cm	5.16	0.39	7.43
	45			25-50cm	2.85	0.24	7.45
	46	16	Hamala experimental (5 years)	0-5cm	2.67	0.23	7.30
	47			5-25cm	3.94	0.30	7.10
	48			25-50cm	3.43	0.24	7.10
	49	17	Hamala experimental (3 years	0-5cm	2.86	0.27	7.10
	50			5-25cm	1.61	0.12	7.30
	51			25-50cm	3.02	0.26	6.98
	52	Control	HAMALA experimental	0-5cm	3.08	0.22	7.20
	53	Control	Al-Areen	0-5cm	4.27	0.28	7.20
	54	Control	Al-Marooge	0-5cm	11.60	0.64	7.20

FIELD EXPERIMENT SOIL ANALYSIS RESULTS

TABLE - 19

	Soil No	FARM NO	FARM NAME	Soil depth cm	CEC me/100g	TOC %	TKN mg/kg	Extra-PO4-P mg/kg	Avail-K mg/kg	Nitrate (1:5) NO3 mg/l
Chicken Manure Area	1	1 -	Yateem Garden	0-5cm	4.00	1.24	1456.00	83.20	113.25	21.70
	2			5-25cm	1.50	0.39	414.00	45.20	48.90	5.30
	3			25-50cm	1.20	0.43	364.00	17.40	45.70	3.10
	4	2 -	Mohamed Daif	0-5cm	3.00	1.16	1254.00	83.20	203.00	77.50
	5			5-25cm	1.40	0.46	252.00	11.40	173.70	7.97
	6			25-50	1.30	0.24	191.00	9.20	143.10	7.53
	7	3 -	Ebrahim Yousif Saleh	0-5cm	3.12	1.28	2050.00	83.60	1027.50	60.70
	8			5-25cm	1.80	0.85	280.00	10.60	84.50	5.30
	9			25-50cm	1.20	0.79	280.00	15.40	482.50	6.20
	10	4 -	Ebrahim Hassan Al-Majid	0-5cm	3.34	1.31	1120.00	25.80	865.00	159.50
	11			5-25cm	1.60	0.42	224.00	8.60	77.30	7.50
	12			25-50cm	1.20	0.44	196.00	7.00	96.50	5.30
	13	5 -	Hassan Makki Asoor	0-5cm	3.50	0.91	935.00	75.60	291.00	146.20
	14			5-25cm	1.20	0.45	269.00	34.20	71.90	6.20
	15			25-50cm	1.60	0.71	308.00	22.60	63.30	8.86
	16	6 -	Ali Yousif Al-Malah	0-5cm	2.20	0.89	840.00	56.20	94.80	8.42
	17			5-25cm	1.80	0.29	157.00	18.20	100.60	7.53
	18			25-50cm	1.00	0.39	196.00	10.20	93.95	3.54
Cow Manure Area	19	7 -	Al-Marooge Farm	0-5cm	3.00	2.03	1216.00	84.20	56.46	15.06
	20			5-25cm	1.50	1.29	353.00	21.20	82.65	6.65
	21			25-50cm	1.20	1.12	420.00	7.90	75.00	3.10
	22	8 -	Al-Marooge Farm	0-5cm	2.40	0.86	745.00	68.40	91.10	2.67
	23			5-25cm	1.20	1.17	168.00	35.80	86.90	1.77
	24			25-50cm	2.00	0.93	252.00	18.60	123.40	1.77
	25	9 -	Al-Akr-1 near well 1/134	0-5cm	3.52	2.48	1050.00	75.00	123.20	4.96
	26			5-25cm	3.44	1.13	280.00	20.10	81.95	6.15
	27			25-50cm	3.36	1.47	490.00	51.80	85.00	6.45
	28	10 -	Al Akr-2 near well 1/137	0-5cm	6.72	1.10	616.00	78.98	112.50	3.43
	29			5-25cm	4.32	1.46	658.00	38.90	112.00	10.70
	30			25-50cm	4.32	0.89	462.00	21.14	100.50	10.00
	31	11 -	Al-Akr-3 near well 1/35	0-5cm	7.28	3.56	686.00	97.33	163.50	7.81
	32			5-25cm	5.92	1.68	882.00	20.00	184.80	9.93
	33			25-50cm	5.04	0.89	714.00	37.88	180.10	4.58
Sludge Area	34	12 -	Al-Areen (5 years)	0-5cm	4.00	1.24	672.00	90.00	145.70	610.00
	35			5-25cm	1.40	0.39	196.00	10.00	57.20	186.00
	36			25-50cm	1.80	0.44	140.00	6.70	59.50	423.00
	37	13 -	Al-Areen (2years)	0-5cm	3.30	1.31	1053.00	56.40	96.95	246.00
	38			5-25cm	1.50	0.42	230.00	12.40	74.05	267.00
	39			25-50cm	1.90	0.44	250.00	4.40	75.60	118.00
	40	14 -	Al-Areen (1 year)	0-5cm	4.52	0.91	742.00	55.20	92.35	108.00
	41			5-25cm	1.50	0.45	250.00	3.52	68.25	158.00
	42			25-50cm	1.60	0.72	200.00	1.46	55.25	35.00
	43	15 -	Al Areen (6 months)	0-5cm	5.90	1.28	3399.00	92.40	248.40	189.00
	44			5-25cm	1.40	0.85	152.00	1.80	82.50	1016.00
	45			25-50cm	1.60	0.79	101.00	2.40	92.10	241.00
	46	16 -	Hamala experimental (5 years)	0-5cm	8.72	0.89	2268.00	134.30	106.95	41.00
	47			5-25cm	1.40	0.29	312.00	34.40	49.50	377.00
	48			25-50cm	1.80	0.39	180.00	35.20	42.50	142.00
	49	17 -	Hamala experimental (3 years	0-5cm	9.50	2.03	5250.00	278.50	162.50	128.00
	50			5-25cm	2.80	1.12	820.00	125.50	133.90	328.00
	51			25-50cm	1.20	0.42	720.00	100.00	114.10	677.00
	52	Control	HAMALA experimental	0-5cm	1.90	0.30	160.00	15.20	138.10	7.53
	53	Control	Al-Areen	0-5cm	1.20	0.45	210.00	2.50	90.00	10.20
	54	Control	Al-Marooge	0-5cm	1.00	1.00	145.00	18.20	167.50	60.70

FIELD EXPERIMENT SOIL ANALYSIS RESLUTS

TABLE - 20

SOLUBLE SALTS IN 1:5 SOLUTION (me/kg)

	Soil No	FARM NO	FARM NAME	Soil dept in cm	Ca me/kg	Mg me/kg	Na me/kg	K me/kg	SO4 me/kg	Cl me/kg
Chicken Manure Area	1	1 -	Yateem Garden	0-5	155.00	4.99	13.26	2.02	145.51	50.05
	2			5-25	155.00	29.91	12.67	0.74	149.79	25.03
	3			25-50	155.00	14.96	20.31	0.56	149.79	50.05
	4	2 -	Mohamed Dhaif	0-5	155.00	24.93	46.09	4.32	154.07	75.08
	5			5-25	175.00	29.91	62.39	3.20	158.35	100.11
	6			25-50	165.00	4.99	20.03	2.15	166.91	50.05
	7	3 -	Ebrahim Yousif Saleh	0-5	160.00	144.57	239.46	25.70	273.89	250.28
	8			5-25	155.00	19.94	62.50	1.44	184.03	50.05
	9			25-50	150.00	44.87	55.12	7.14	192.59	75.15
	10	4 -	Ebrahim Hassan Al-Majid	0-5	185.00	104.71	258.01	20.45	184.03	400.44
	11			5-25	160.00	14.96	12.13	1.32	124.11	50.05
	12			25-50	160.00	14.96	12.28	1.33	128.39	39.13
	13	5 -	Hassan Makki Ashoor	0-5	140.00	64.82	67.70	8.45	157.75	100.11
	14			5-25	150.00	4.99	10.70	1.03	102.71	50.05
	15			25-50	155.00	24.93	14.02	0.64	125.95	53.23
	16	6 -	Ali Yousif Al-Molah	0-5	10.00	24.93	18.64	1.36	17.12	25.03
	17			5-25	7.00	12.96	14.65	1.24	8.56	25.03
	18			25-50	145.00	19.94	21.11	1.54	129.64	50.05
Cow Manure Area	19	7 -	Al-Marooge Farm	0-5	125.00	24.93	35.52	2.43	104.20	75.08
	20			5-25	130.00	9.96	14.45	1.55	100.92	50.05
	21			25-50	150.00	14.97	20.01	1.61	120.11	50.05
	22	8 -	Al-Marooge Farm	0-5	25.00	9.96	15.67	1.57	8.56	50.05
	23			5-25	160.00	19.93	16.95	1.49	151.67	50.05
	24			25-50	150.00	24.93	26.21	1.99	146.80	50.05
	25	9 -	Al-Akr-1 near well 1/134	0-5	16.00	0.98	24.41	1.69	7.71	25.03
	26			5-25	7.00	5.00	20.62	0.97	0.00	25.03
	27			25-50	14.00	0.00	25.61	1.38	0.00	25.03
	28	10 -	Al Akr-2 near well 1/137	0-5	9.00	0.00	13.35	0.94	2.57	15.02
	29			5-25	14.00	5.99	32.88	2.39	7.71	35.04
	30			25-50	19.00	0.00	40.04	2.40	11.12	45.05
	31	11 -	Al-Akr-3 near well 1/35	0-5	34.00	2.01	26.37	1.94	27.39	25.03
	32			5-25	8.00	5.99	26.04	2.59	3.42	30.03
	33			25-50	8.00	0.98	19.42	1.37	3.42	20.02
Sludge Area	34	12 -	Al-Areen (5 years)	0-5	134.00	2.01	43.83	3.02	92.01	50.05
	35			5-25	8.00	2.01	8.46	0.90	0.52	10.01
	36			25-50	146.00	3.98	8.90	0.81	117.69	10.01
	37	13 -	Al-Areen (2years)	0-5	140.00	3.98	8.68	1.19	139.15	10.01
	38			5-25	130.00	9.96	10.42	1.45	139.15	10.01
	39			25-50	142.00	5.99	8.68	1.04	151.94	10.01
	40	14 -	Al-Areen (1 year)	0-5	150.00	6.97	12.37	1.28	156.21	10.01
	41			5-25	140.00	8.00	14.54	1.42	149.76	20.02
	42			25-50	150.00	5.99	9.11	0.90	162.66	10.01
	43	15 -	Al Areen (6 months)	0-5	116.00	10.99	15.62	1.47	111.28	20.02
	44			5-25	154.00	32.92	65.10	5.94	149.76	61.90
	45			25-50	150.00	8.98	13.67	1.05	143.42	20.02
	46	16 -	Hamala experimental (5 years)	0-5	148.00	8.98	8.25	0.77	162.66	10.01
	47			5-25	158.00	16.93	54.25	1.65	139.05	50.05
	48			25-50	154.00	13.94	17.36	0.75	131.77	50.05
	49	17 -	Hamala experimental (3 years	0-5	149.00	5.99	35.81	0.64	169.62	25.03
	50			5-25	42.00	16.93	22.13	2.59	46.49	25.03
	51			25-50	138.00	6.97	24.52	3.02	92.04	50.05
	52	Control	HAMALA experimental	0-5	155.00	5.00	35.37	2.22	106.39	50.05
	53	Control	Al-Areen	5-25	150.00	44.85	41.88	2.57	122.31	100.11
	54	Control	Al-Marooge	25-50	240.00	29.91	267.78	3.53	114.95	400.44

FIELD EXPERIMENT SOIL ANALYSIS RESLUTS

TABLE - 21

	Soil No	FARM NO	FARM NAME	Soil depth cm	EXCHANGEABLE CATIONS Ca me/kg	Mg me/kg	Na me/kg	K me/kg
Chicken Manure Area	1	1 -	Yateem Garden	0-5cm	1836.00	20.00	14.00	4.10
	2			5-25cm	3693.00	10.00	14.10	1.50
	3			25-50cm	4311.00	20.00	39.80	1.30
	4	2 -	Mohamed Daif	0-5cm	1677.00	139.90	68.30	6.50
	5			5-25cm	3673.00	70.00	100.90	5.30
	6			25-50	3413.00	79.90	32.60	4.20
	7	3 -	Ebrahim Yousif Saleh	0-5cm	3533.00	259.90	209.60	23.30
	8			5-25cm	3393.00	60.00	36.00	2.50
	9			25-50cm	3273.00	169.90	88.70	13.10
	10	4 -	Ebrahim Hassan Al-Majid	0-5cm	4411.00	209.90	230.40	19.80
	11			5-25cm	4052.00	10.00	13.70	2.50
	12			25-50cm	3992.00	70.00	13.40	2.90
	13	5 -	Hassan Makki Asoor	0-5cm	1198.00	139.90	86.00	8.60
	14			5-25cm	3154.00	20.00	12.30	2.20
	15			25-50cm	3573.00	60.00	16.40	1.70
	16	6 -	Ali Yousif Al-Malah	0-5cm	718.00	20.00	31.20	3.10
	17			5-25cm	599.00	39.90	17.70	3.00
	18			25-50cm	1357.00	49.90	22.80	2.80
Cow Manure Area	19	7 -	Al-Marooge Farm	0-5cm	1038.00	49.90	50.40	4.30
	20			5-25cm	2714.00	49.90	16.30	2.70
	21			25-50cm	4571.00	49.90	31.90	3.10
	22	8 -	Al-Marooge Farm	0-5cm	399.00	20.00	16.40	2.90
	23			5-25cm	1716.00	129.80	15.20	2.20
	24			25-50cm	4112.00	79.90	33.00	3.90
	25	9 -	Al-Akr-1 near well 1/134	0-5cm	347.30	27.99	28.26	1.93
	26			5-25cm	327.30	32.07	23.40	0.84
	27			25-50cm	334.30	16.47	24.35	1.07
	28	10 -	Al Akr-2 near well 1/137	0-5cm	331.30	24.01	14.78	1.55
	29			5-25cm	463.10	36.02	36.96	3.89
	30			25-50cm	349.30	24.67	41.74	4.30
	31	11 -	Al-Akr-3 near well 1/35	0-5cm	451.10	44.08	30.43	2.90
	32			5-25cm	419.20	44.08	30.00	3.88
	33			25-50cm	399.20	41.11	30.43	3.88
Sludge Area	34	12 -	Al-Areen (5 years)	0-5cm	535.00	16.00	80.00	3.90
	35			5-25cm	315.00	16.00	6.30	1.40
	36			25-50cm	1457.00	44.00	7.50	1.40
	37	13 -	Al-Areen (2years)	0-5cm	543.00	15.90	7.90	2.20
	38			5-25cm	766.00	12.00	9.10	2.40
	39			25-50cm	1169.00	44.10	9.60	1.40
	40	14 -	Al-Areen (1 year)	0-5cm	982.00	32.10	10.10	1.40
	41			5-25cm	1229.00	40.00	12.80	2.50
	42			25-50cm	1165.00	40.00	8.50	1.70
	43	15 -	Al Areen (6 months)	0-5cm	519.00	20.10	16.80	2.90
	44			5-25cm	854.00	12.00	95.60	6.70
	45			25-50cm	1054.00	8.10	11.80	2.00
	46	16 -	Hamala experimental (5 years)	0-5cm	1126.00	15.90	6.30	1.20
	47			5-25cm	718.00	27.90	82.60	2.70
	48			25-50cm	1301.00	8.10	26.10	1.20
	49	17 -	Hamala experimental (3 years	0-5cm	1157.00	23.80	18.30	0.90
	50			5-25cm	315.00	63.90	33.00	4.60
	51			25-50cm	407.00	63.90	24.30	4.10
	52	Control	HAMALA experimental	0-5cm	1397.00	20.00	52.80	4.20
	53	Control	Al-Areen	0-5cm	2295.00	39.90	55.40	3.60
	54	Control	Al-Marooge	0-5cm	4710.00	20.00	584.40	5.20

FIELD EXPERIMENT SOIL ANALYSIS RESLUTS TABLE -22

	Soil No	FARM NO	FARM NAME	Soil dept in cm	ACETIC ACID EXTRACTABLE METALS				TOTAL TRACE METALS			
					Cd mg/kg	Pb mg/kg	Zn mg/kg	Cu mg/kg	Cd mg/kg	Pb mg/kg	Zn mg/kg	Cu mg/kg
Chicken Manure Area	1	1	- Yateem Garden	0-5	0.06	0.39	2.44	0.12	0.20	5.41	6.87	5.97
	2			5-25	0.05	0.35	1.77	0.22	0.22	3.58	7.61	4.74
	3			25-50	0.03	0.30	0.62	0.44	0.19	2.50	7.55	5.00
	4	2	- Mohamed Dhaif	0-5	0.08	0.40	9.32	0.18	0.25	1.58	12.77	4.44
	5			5-25	0.09	0.35	0.52	0.36	0.23	1.97	9.63	5.92
	6			25-50	0.06	0.30	0.24	0.60	0.20	2.00	8.50	5.10
	7	3	- Ebrahim Yousif Saleh	0-5	0.07	0.50	18.74	0.10	0.19	1.94	21.69	7.38
	8			5-25	0.07	0.50	2.66	0.60	0.29	0.85	15.40	4.95
	9			25-50	0.05	0.40	0.16	0.60	0.20	1.50	10.20	5.10
	10	4	- Ebrahim Hassan Al-Majid	0-5	0.08	0.48	8.30	0.44	0.31	0.88	20.79	6.36
	11			5-25	0.06	0.35	1.60	0.60	0.33	0.95	9.00	4.29
	12			25-50	0.05	0.35	0.10	0.44	0.30	1.05	10.20	5.00
	13	5	- Hassan Makki Ashoor	0-5	0.05	0.50	4.26	0.28	0.24	6.83	13.31	7.37
	14			5-25	0.08	0.40	0.30	0.74	0.34	4.24	8.14	5.13
	15			25-50	0.06	0.40	0.12	0.88	0.35	4.50	8.10	5.10
	16	6	- Ali Yousif Al-Molah	0-5	0.08	0.36	3.38	0.88	0.24	7.62	14.29	3.32
	17			5-25	0.07	0.36	3.34	0.70	0.41	8.91	21.82	5.47
	18			25-50	0.06	0.30	0.34	0.84	0.25	8.10	13.50	5.60
Cow Manure Area	19	7	- Al-Marooge Farm	0-5	0.08	0.55	11.00	0.46	0.27	6.94	30.58	7.85
	20			5-25	0.10	0.60	2.40	0.30	0.37	5.52	11.92	3.79
	21			25-50	0.10	0.50	1.68	0.46	0.31	5.10	11.26	3.86
	22	8	- Al-Marooge Farm	0-5	0.09	0.40	23.00	0.50	0.29	7.82	38.48	4.08
	23			5-25	0.10	0.35	0.48	0.45	0.46	5.94	5.10	3.02
	24			25-50	0.07	0.35	0.12	0.36	0.35	5.15	5.60	4.50
	25	9	- Al-Akr-1 near well 1/134	0-5	0.04	3.28	8.86	0.42	0.19	6.55	76.90	6.46
	26			5-25	0.08	0.20	0.44	0.04	0.27	1.45	10.42	1.75
	27			25-50	0.04	0.80	0.80	0.10	0.20	1.45	10.50	2.10
	28	10	- Al Akr-2 near well 1/137	0-5	0.02	1.20	7.58	0.28	0.22	1.44	44.69	6.34
	29			5-25	0.02	3.80	0.82	0.24	0.13	6.44	27.26	5.91
	30			25-50	0.02	1.80	0.85	0.25	0.20	2.45	10.80	2.50
	31	11	- Al-Akr-3 near well 1/35	0-5	0.20	8.68	9.76	2.78	0.44	51.29	73.44	63.24
	32			5-25	0.02	0.20	1.66	0.84	0.25	13.80	41.96	22.10
	33			25-50	0.02	1.00	0.85	0.25	0.20	3.50	15.85	10.10
Sludge Area	34	12	- Al-Areen (5 years)	0-5	0.28	3.80	7.80	1.20	0.83	5.21	25.94	5.04
	35			5-25	0.18	1.60	1.20	0.80	0.42	2.39	9.51	3.37
	36			25-50	0.12	1.31	1.80	0.80	0.42	4.00	7.96	1.34
	37	13	- Al-Areen (2years)	0-5	0.08	1.27	11.20	1.80	1.22	4.80	35.90	12.90
	38			5-25	0.28	2.20	1.80	1.60	0.42	4.70	12.49	5.99
	39			25-50	0.20	1.20	0.60	1.80	0.44	4.80	10.28	4.89
	40	14	- Al-Areen (1 year)	0-5	0.30	4.40	11.20	2.00	0.44	9.62	100.60	55.56
	41			5-25	0.30	1.27	3.40	1.60	0.60	3.20	36.50	6.15
	42			25-50	0.42	1.20	1.80	1.40	0.44	3.80	10.74	4.99
	43	15	- Al Areen (6 months)	0-5	0.80	4.60	32.00	4.60	1.10	6.74	81.31	50.69
	44			5-25	0.10	2.47	1.40	1.20	0.94	4.40	7.62	1.63
	45			25-50	0.28	1.17	0.40	1.40	0.83	4.40	9.12	1.71
	46	16	- Hamala experimental (5 years)	0-5	0.10	3.80	42.20	4.80	2.24	7.07	87.30	42.23
	47			5-25	0.28	1.25	9.99	3.20	0.40	3.20	28.00	7.49
	48			25-50	0.10	1.25	9.00	3.00	0.45	3.00	12.00	4.95
	49	17	- Hamala experimental (3 years	0-5	0.16	4.60	51.20	5.80	1.73	39.10	139.69	163.50
	50			5-25	0.20	4.00	9.00	3.00	0.45	5.50	10.64	13.95
	51			25-50	0.22	3.00	9.00	2.80	0.50	6.80	10.65	6.85
	52	Control	HAMALA experimental	0-5	0.18	0.30	1.20	0.50	0.38	7.61	6.66	3.08
	53	Control	Al-Areen	5-25	0.10	0.35	0.32	0.20	0.25	5.00	7.30	5.10
	54	Control	Al-Marooge	25-50	0.07	0.39	0.34	0.18	0.33	4.94	7.67	5.63

TABLE - 23

FERTILIZER STUDY, FIELD ANALYSIS RESULTS
RESULT OF SOIL ANALYSIS (0 - 5 cm LAYER)

FARMS	SAND	SILT	CLAY	pH	AGGRAGATE STABILITY%	AVERAGE BULK DENSITY	W.H.C %	SOLUBLE SALTS%	COND. 25C µs/cm	T.O.C.%	EXT-P ug/g	CEC me/100g	TKN ug/g
YATEEM GARDEN	89.00	8.00	3.00	7.60	2.50	1.45	10.60	0.24	2.92	1.24	83.20	4.00	1456.00
MOHAMED DHAIF	90.00	8.00	2.00	7.40	2.30	1.48	10.00	0.29	4.25	1.16	83.20	3.00	1254.00
EBRAHIM YOUSIF SALEH	87.00	10.00	3.00	7.50	2.50	1.45	10.20	0.67	10.20	1.28	83.60	3.12	2050.00
EBRAHIM HASSAN MAJID	80.00	10.00	10.00	7.40	2.20	1.50	10.60	0.69	10.60	1.31	25.80	3.34	1120.00
HASSAN MAKKI ASHOOR	92.00	7.20	0.80	7.40	2.20	1.50	10.10	0.33	5.17	0.91	75.60	3.50	935.00
ALI YOUSIF AL-MULLA	90.00	8.80	1.20	7.80	2.20	1.45	10.60	0.06	0.95	0.89	56.20	2.20	840.00
AVEREAGE	88.00	8.67	3.33	7.52	2.32	1.47	10.35	0.38	5.68	1.13	67.93	3.19	1275.83
S.D	3.87	1.05	3.09	0.15	0.13	0.02	0.26	0.23	3.58	0.17	21.15	0.55	400.56
CONTROL	81.00	10.00	9.00	7.20	0.00	1.40	10.00	0.64	11.60	1.00	18.20	1.00	145.00
AL-MAROOGE	84.00	13.00	3.00	7.40	1.60	1.45	10.00	0.23	3.35	2.03	84.20	3.00	1216.00
AL-MAROOGE	91.00	7.00	2.00	7.40	1.50	1.52	10.10	0.06	0.99	0.86	68.40	2.40	745.00
AL-AKR-1	95.44	2.18	2.38	7.72	1.80	1.50	10.20	0.05	1.00	2.48	75.00	3.52	1050.00
AL-AKR-2	94.84	2.36	2.80	7.82	2.00	1.46	9.80	0.02	0.51	1.10	78.98	6.72	616.00
AL-AKR-3	76.66	13.88	9.46	7.59	2.00	1.48	10.10	0.07	1.28	3.56	97.33	7.28	686.00
AVEREAGE	88.39	7.68	3.93	7.59	1.78	1.48	10.04	0.09	1.43	2.01	80.78	4.58	862.60
S.D	7.14	5.02	2.79	0.17	0.20	0.03	0.14	0.07	0.99	0.98	9.75	2.01	230.58
CONTROL	81.00	10.00	9.00	7.20	0.00	1.40	10.00	0.64	11.60	1.00	18.20	1.00	145.00
AL-AREEN-5YRS	93.60	5.40	1.00	7.54	2.60	1.50	10.20	0.26	3.54	1.24	90.00	4.00	672.00
AL-AREEN-2YRS	92.00	7.00	1.00	7.46	2.20	1.45	10.30	0.22	2.52	1.31	56.40	3.30	1053.00
AL-AREEN-1YR	91.00	7.50	1.50	7.40	1.50	1.48	10.20	0.23	2.73	0.91	55.20	4.52	742.00
AL-AREEN-6MTS	91.00	8.00	1.00	7.42	2.60	1.49	10.50	0.19	2.51	1.28	92.40	5.90	3399.00
HAMALA-5YRS	79.50	20.00	0.50	7.30	2.20	1.60	10.20	0.23	2.67	0.89	134.30	8.72	2268.00
HAMALA-3YRS	79.00	20.50	1.00	7.10	2.20	1.50	10.20	0.27	2.86	2.03	278.50	9.50	5250.00
AVEREAGE	87.68	11.40	1.00	7.37	2.22	1.50	10.27	0.23	2.81	1.28	117.80	5.99	2230.67
S.D	6.03	6.31	0.29	0.14	0.37	0.05	0.11	0.03	0.35	0.38	76.60	2.35	1659.08
CONTROL	92.60	6.40	1.00	7.20	0.00	1.40	10.00	0.28	4.27	0.45	2.50	1.20	210.00

TABLE - 24

	EXCHANGEABLE CATIONS(me/kg)				SOLUBLE SALTS (1:5)SOLN											
FARMS	Ca	Mg	Na	K	Ca me/Kg	Mg me/Kg	Na me/Kg	K me/Kg	SO4 me/Kg	Cl me/Kg	NO3 me/Kg	NO3 mg/l	Ca/Mg	Ca/CATIONS	Mg/CATIONS	Cl/SO4
YATEEN GARDEN	1836.00	20.00	14.00	4.10	155.00	4.99	13.26	2.02	145.51	50.05	1.75	21.70	31.06	0.88	0.03	0.34
MOHAMED DAIF	1677.00	139.90	68.30	6.50	155.00	24.93	46.75	4.32	154.07	75.08	6.25	77.50	6.22	0.67	0.11	0.49
EBRAHIM YOUSIF SALEH	3533.00	259.90	209.60	23.30	160.00	144.57	239.46	25.70	273.89	250.28	4.89	60.70	1.11	0.28	0.25	0.91
EBRAHIM HASSAN NAJJID	4411.00	209.90	230.40	19.80	185.00	104.71	258.91	20.45	184.03	400.44	12.86	159.50	1.77	0.33	0.18	2.18
HASSAN MAKKI ASOOR	1198.00	139.90	86.00	8.60	140.00	64.82	67.70	8.45	157.75	100.11	11.76	146.20	100.11	0.50	0.23	0.63
ALI YOUSIF AL-MALAH	718.00	20.00	31.20	3.10	10.00	24.93	18.54	1.36	17.12	25.03	0.68	8:42	0.40	0.18	0.45	1.46
AVEREAGE	2228.83	131.60	106.58	10.90	134.17	61.49	107.19	10.38	155.40	150.16	6.37	79.00	23.44	0.47	0.21	1.00
S.D	1308.10	89.11	83.75	7.80	57.11	49.41	101.92	9.38	75.37	133.22	4.61	57.15	35.90	0.24	0.13	0.64
CONTROL	4710.00	20.00	584.40	5.20	240.00	29.91	267.78	3.53	114.95	400.44	4.89	60.70	8.02	0.44	0.06	3.48
AL-MAROOZE	1038.00	45.90	50.40	4.30	125.00	24.93	35.52	2.43	104.20	75.08	1.21	15.06	5.01	0.67	0.13	0.72
AL-MAROOZE	399.00	20.00	16.40	2.90	25.00	9.96	15.57	1.57	8.56	50.05	0.22	2.67	2.51	0.48	0.19	5.85
AL-AKR-1	347.30	37.99	28.26	1.93	16.00	0.98	24.41	1.69	7.71	25.03	0.40	4.96	16.33	0.37	0.02	3.25
AL-AKR-2	331.30	24.01	14.78	1.55	9.00	0.00	13.75	0.94	2.57	15.02	0.28	3.43		0.39	0.00	5.84
AL-AKR-3	451.10	44.06	30.43	2.90	34.00	2.01	26.37	1.94	27.39	25.03	0.63	7.81	16.92	0.53	0.03	0.91
AVEREAGE	513.34	33.20	28.05	2.72	41.80	7.58	23.06	1.71	30.09	38.04	0.55	6.79	5.52	0.49	0.08	3.31
S.D	265.68	11.69	12.78	0.95	42.44	9.37	7.36	0.49	38.00	21.84	0.36	4.50		0.11	0.07	2.25
CONTROL	4710.00	20.00	584.40	5.20	240.00	29.91	267.78	3.53	114.95	400.44		60.70	8.02	0.44	0.06	3.48
AL-AREEN-5YRS	535.00	16.00	80.00	3.90	134.00	2.01	43.83	3.02	92.01	50.05	49.17	610.00	66.67	0.73	0.01	0.54
AL-AREEN-2YRS	543.00	15.90	7.90	2.20	140.00	3.98	8.68	1.19	139.15	10.01	19.83	246.00	35.18	0.91	0.03	0.07
AL-AREEN-1YR	982.00	32.10	10.10	1.40	150.00	6.97	12.37	1.28	156.21	10.01	8.70	108.00	21.52	0.88	0.04	0.06
AL-AREEN-6MTS	519.00	20.10	16.80	2.90	116.00	10.99	15.62	1.47	111.28	20.02	15.23	189.00	10.56	0.81	0.08	0.18
HAMALA-5YRS	1126.00	15.90	6.30	1.20	148.00	8.98	8.25	0.77	162.66	10.01	3.30	41.00	16.48	0.89	0.05	0.06
HAMALA-3YRS	1157.00	23.80	18.30	0.90	149.00	5.99	35.01	0.64	169.62	25.03	10.32	128.00	24.87	0.78	0.03	0.15
AVEREAGE	810.33	20.63	23.23	2.08	139.50	6.49	20.76	1.40	138.49	20.86	17.76	220.33	29.21	0.83	0.04	0.18
S.D	283.27	5.89	25.76	1.05	11.94	2.98	13.89	0.78	28.19	14.28	14.96	185.65	18.38	0.06	0.02	0.17
CONTROL	2295.00	39.90	55.40	3.60	150.00	44.85	41.28	2.57	122.31	100.11		10.20	3.34	0.63	0.19	0.82

TABLE - 25

FARMS	EXTRACTABLE TRACE METALS				TOTAL TRACE METALS			
	Cd ug/g	Pb ug/g	Zn ug/g	Cu ug/g	Cd ug/g	Pb ug/g	Zn ug/g	Cu ug/g
YATEEM GARDEN	0.06	0.39	2.44	0.12	0.19	5.41	6.87	5.97
MOHAMED DHAIF	0.06	0.40	9.32	0.18	0.25	1.58	12.77	4.44
EBRAHIM YOUSIF SALEH	0.07	0.50	18.74	0.10	0.19	1.94	21.69	7.38
EBRAHIM HASSAN MAJID	0.08	0.48	8.30	0.44	0.31	0.88	20.79	6.36
HASSAN MAKKI ASHOOR	0.05	0.50	4.26	0.28	0.24	6.83	13.31	7.37
ALI YOUSIF AL-MULLA	0.08	0.36	3.38	0.88	0.24	7.62	14.29	3.32
AVEREAGE	0.07	0.44	7.74	0.33	0.24	4.04	14.95	5.81
S.D	0.01	0.06	5.52	0.27	0.04	2.67	5.04	1.49
CONTROL	0.07	0.39	0.34	0.18	0.33	4.94	7.67	5.63
AL-MAROOGE	0.08	0.55	11.00	0.46	0.27	6.94	30.58	7.85
AL-MAROOGE	0.09	0.40	23.00	0.50	0.29	7.82	38.48	4.08
AL-AKR-1	0.04	3.28	8.86	0.42	0.19	6.55	76.90	6.46
AL-AKR-2	0.02	1.20	7.58	0.28	0.22	1.44	44.69	6.34
AL-AKR-3	0.20	8.68	9.76	2.78	0.44	51.29	73.44	63.24
AVEREAGE	0.09	2.82	12.04	0.89	0.28	14.81	52.82	17.59
S.D	0.06	3.10	5.59	0.95	0.09	18.38	18.82	22.85
CONTROL	0.07	0.39	0.34	0.18	0.33	4.94	7.67	5.63
AL-AREEN-5YRS	0.28	3.80	7.80	1.20	0.83	5.21	25.94	5.04
AL-AREEN-2YRS	0.06	1.27	11.20	1.80	1.22	4.80	35.90	12.90
AL-AREEN-1YR	0.30	4.40	11.20	2.00	0.44	9.62	100.60	55.56
AL-AREEN-6MTS	0.80	4.60	32.00	4.60	1.09	6.74	81.31	50.69
HAMALA-5YRS	0.10	3.80	42.20	4.80	2.24	7.07	87.30	42.23
HAMALA-3YRS	0.16	4.60	51.20	5.80	1.73	39.10	139.69	163.50
AVEREAGE	0.29	3.75	25.93	3.37	1.26	12.09	78.46	54.99
S.D	0.24	1.16	16.85	1.76	0.59	12.18	38.50	52.00
CONTROL	0.10	0.35	0.32	0.20	0.25	5.00	7.30	5.10

TABLE - 26

NUTRIENTS IN GROUND WATER IN BAHRAIN

Sr. No.	GROUND WATER BORE HOLE LOCATION	Bore Hole Location	Date Sampled	NUTRIENTS (µg/L)				Conductivity at 25° C mmhos/cm	Salinity °/₀₀	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K
				NO_2-N	NO_3-N	NH_4-N	PO_4-P										
1		9/2	22-5-89	0.0	2400	0.4	6.7	4.3	2.83	7.4	204	1030	605	236	92	595	31.8
2		9/3		0.0	4500	13.3	4.3	9.6	6.42	7.4	216	2570	1385	436	233	1470	62.4
3		9/4		0.0	2600	14.7	118	4.2	2.73	7.4	204	970	597	230	92	560	30.9
4		9/14		0.0	2400	3.8	76.9	4.6	2.97	7.4	204	1090	641	242	98	630	33.3
5		9/15		0.0	2400	7.4	0.0	4.3	2.8	7.4	210	1010	609	235	93	585	26.9
6		9/54		0.0	2900	0.0	2.5	3.6	2.36	7.3	207	830	500	216	77	465	27.2
7		9/59		0.0	3200	1.6	2.1	3.7	2.38	7.3	211	850	492	212	77	480	27.0
8		9/60		56.1	2800	9.1	0.0	9.8	5.95	7.2	206	2570	1052	382	200	1435	62.3
9		9/70		0.0	3300	5.8	1.0	3.7	2.23	7.0	210	795	445	205	73	440	25.7
10		9/78		0.0	1700	1688	0.0	5.5	3.38	7.3	327	110	932	332	133	660	53.6
11		9/79		0.0	2900	0.0	0.0	7.0	4.26	7.2	202	1820	713	284	145	1000	50.5
12		9/87		0.0	3500	2.5	0.0	3.6	2.19	7.4	222	790	420	203	73	425	25.6
13		9/90		0.0	3400	4.1	0.0	3.60	2.2	7.3	221	790	422	206	73	425	26.0
14		9/92		0.0	3400	11.2	0.0	3.2	2.2	7.2	219	800	420	207	72	425	26.2
15		9/95		0.0	3400	4.7	1.3	3.9	2.23	7.4	217	825	439	209	75	445	26.5
16		9/103		0.0	2900	0.0	0.0	4.1	2.49	7.4	223	890	5.0	222	83	495	27.6
17		9/104		0.0	3300	575	10	4.0	2.49	7.4	218	915	492	215	88	500	29.2
18	Hassan Bokhamas Garden			0.0	3400	7.0	5.2	3.6	2.1	7.4	220	816	413	200	75	388	25.5
19	A.K. Almoayyed Garden Hidd			0.0	3200	5.1	2.5	5.4	3.24	7.4	171	1384	530	248	105	673	31.9
20	Y.K. Almoayyed Garden Hidd			0.0	5800	5.1	28.3	6.2	3.75	7.4	98	1598	699	340	122	763	42.3
21	Shk.Abdulla Al-Faud Gallali			52.5	3200	2.6	8.5	4.0	2.45	7.3	171	959	418	200	88	546	25.9
22	Um Nakhila Farm Gallali			0.0	3300	1.8	13.2	3.8	2.28	7.3	195	905	446	220	80	441	24.8

TABLE - 26

NUTRIENTS IN GROUND WATER IN BAHRAIN

	Sr. No.	GROUND WATER BORE HOLE LOCATION	Bore Hole No.	Date Sampled	NUTRIENTS (μg/L) NO$_2$-N	NO$_3$-N	NH$_4$-N	PO$_4$-P	Conductivity at 25° C mmhos/cm	Salinity °/..	pH	HCO$_3$	Cl	SO$_4$	Ca	Mg	Na	K
	23		11/12	22-5-89	416.1	1900	391.2	0.0	6.9	4.52	7.3	274	1880	789	362	152	980	51.4
	24		11/12		0.0	3000	0.0	16.6	5.1	3.20	7.3	239	1220	641	272	107	650	43.9
/	25		13/147		0.0	2800	515.7	7.9	5.8	3.73	7.4	294	1450	686	325	115	770	45.9
/	26		13/151		0.0	2700	3.7	5.1	5.4	3.33	7.3	229	1300	627	288	104	690	38.4
/	27		13/152		0.0	2600	5.9	8.1	4.6	2.74	7.3	220	1110	450	228	85	570	31.5
/	28		13/153		0.0	2100	0.0	14.9	5.20	3.32	7.4	265	1280	611	290	102	690	40.2
	29		13/157		0.0	2600	5.4	112.0	4.8	2.80	7.4	219	1130	465	234	86	600	32.3
	30		13/160		0.0	2500	7.7	159.9	5.0	2.92	7.3	223	1160	491	244	90	620	34.0
	31		13/161		0.0	2300	7.9	9.9	5.4	3.31	7.4	244	1310	616	288	104	680	38.2
	32		13/183		0.0	3100	835.9	31.7	6.7	4.68	7.4	370	1555	1181	461	148	850	64.6
*	33	Yateem Garden Budaiya		27-5-89	0.0	3300	10.0	9.8	4.1	2.55	7.0	134	888	400	192	75.4	452	29.6
*	34	Shaikha Muneera Farm Jasra			0.0	2900	0.5	0.0	8.5	5.53	6.8	171	2130	867	308	176	1141	57.9
*	35	Ebrahim Yousif Saleh Farm			0.0	2500	5.4	1.4	4.6	2.96	7.5	207	976	606	232	97	514	31.6
*	36	Dumistan			36.1	2300	12.4	12.1	4.6	2.90	7.2	183	976	630	224	73	589	32.2
*	37	Shaikh Mohamed Farm Karzakhan			0.0	1300	0.0	6.8	2.3	1.40	7.5	134	497	239	108	36.5	247	16.1
*	38	Malchiya			22.6	2200	0.0	0.0	13.8[illegible]	8.29	7.0	171	4083	785	536	216	2025	69.2
–	39	Al-Marooza Farm Zallaq			0.0	2900	8.8	0.8	10.4[illegible]	6.20	7.4	207	2540	1278	516	199	1300	59.6
x	40	Al-Areen Sanctuary			0.0	1400	11.2	8.7	7.0	3.50	7.3	148	1349	932	328	134	725	37.5
	41	Hamala Agricultural Farm			0.0	2900	0.6	16.8	4.4	2.50	7.3	195	941	568	236	85	500	30.3

/	Control area
*	Chicken manure area
–	Cow manure area
x	Sewage sludge area

TABLE - 26

NUTRIENTS IN GROUND WATER IN BAHRAIN

		Date Sampled	NUTRIENTS (µg/L)				Conductivity at 25° C mmhos/cm	Salinity °/oo	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K	F
			NO_2-N	NO_3-N	NH_4-N	PO_4-P											
42	West Rifaa	25-5-89	0.0	3200	0.0	10.0	4.6	2.69	7.4	217	970	565	230	88	555	34.8	
43	Hamala Town		0.0	2900	0.0	8.50	4.5	2.73	7.4	215	1000	555	229	88	570	33.9	
44	Salmaniya - P_2		0.0	2700	0.0	20.9	5.4	3.08	7.4	219	1320	443	248	100	680	38.0	
45	Mahooz - P_2		0.0	2800	0.0	7.90	4.9	2.81	7.0	207	1170	432	212	99	615	34.3	
46	Hoora - P_1		0.0	2800	0.8	6.30	4.9	2.85	7.3	198	1200	436	216	98	630	34.5	
47	Muharraq - P_4		0.0	3000	2.7	160	4.6	2.62	7.3	198	1060	435	216	90	555	32.9	
48	Sitra		0.0	2700	3.4	0.0	8.2	4.55	7.3	205	2130	556	256	156	1140	51.0	
49	Al-Akr 1/35		0.0	6900	99.8	170.3	7400	4.49	7.2	231.8	2065.5	648.5	326	159.3	1000	65.0	
50	Al-Akr 1/50		0.0	23300	14.9	21.03	13900	9.3	6.8	235.0	4807.5	1385	636	313.73	2165	110	
51	Al-Akr 1/105		0.0	18600	14.9	70.5	9100	6.1	8.25	251.3	2840	872.4	416	216.7	1400	80	
52	Al-Akr 1/109		0.0	11900	14.9	10.17	11200	7.01	6.85	236.7	3088.5	1267.4	492	251.7	1600	79	
53	Al -Akr 1/131		0.0	18300	14.9	24.42	9100	5.8	6.85	238.0	2739.0	861.0	404	198.21	1361	80	
54	Al-Akr 1/132		0.0	9200	139.8	374.4	7600	4.9	6.7	255.0	2236.5	703.0	352	148.35	1129	68	
55	Al-Akr 1/134		41	22500	1658	159.4	11300	8.15	7.2	317.2	3869.0	1102.8	470	306.4	1970	100	
56	Al-Akr 1/137		9.5	5300	233.7	14.9	7000	4.15	7.1	262.0	2059.0	647.0	306	149.57	1052	60	
57	Al-Akr 1/139		2.7	3100	14.9	8.14	7700	5.29	7.0	280.0	2414.0	759.0	384	154.432	1233	68	

Table-27

Trace metals in Ground waters of Bahrain.

Bore hole location	Cd	Pb	Zn	Cu
	<-----------	ug L-1	-----------	>
1. 9/2	1.18	3.70	8.53	3.50
2. 9/3	1.25	4.20	10.23	3.10
3. 9/4	0.85	3.26	12.10	3.50
4. 9/14	0.45	3.50	10.20	3.65
5. 9/15	0.68	3.63	9.85	4.12
6. 9/52	0.45	3.95	10.70	3.65
7. 9/59	0.65	3.28	10.10	3.85
8. 9/60	0.82	3.24	10.20	3.25
9. 9/70	0.86	3.75	10.16	4.10
10. 9/78	0.85	3.65	10.20	3.85
11. 9/79	0.85	3.26	9.98	3.15
12. 9/87	0.29	4.20	8.85	3.28
13. 9/90	0.38	4.10	10.15	3.05
14. 9/92	0.85	4.05	10.20	3.85
15. 9/95	0.45	3.75	10.10	3.15
16. 9/103	0.28	3.28	10.02	3.02
17. 9/104	0.28	3.24	9.95	3.86
18. H. Bokhamas garden	0.85	3.90	9.05	3.16
19. A.K. Almoyyed garden	0.85	3.56	10.12	3.22
20. Y.K. Almoyyed garden	0.29	3.26	10.16	3.16
21. Shk. Abdulla Al-Faud garden	0.30	3.55	10.00	3.75
22. Um Nakhila farm, Galali.	0.35	3.65	9.95	4.00
23. 11/12	0.35	3.45	8.53	4.02
24. 11/13	0.42	3.46	10.10	3.05
25. 13/147	0.46	2.76	12.15	3.86
26. 13/151	0.85	3.26	10.20	4.10
27. 13/152	0.45	3.16	9.65	3.86
28. 13/153	0.42	3.85	10.10	3.95
29. 13/157	0.28	3.28	10.25	4.02
30. 13/160	0.35	3.52	10.15	3.96
31. 13/161	0.38	3.22	9.98	3.92
32. 13/183	0.28	3.36	10.12	3.96
33. Yateem garden, Budaiya	0.28	3.46	10.12	4.00
34. Shaika Muneera farm.	0.35	3.20	9.65	4.00
35. Ebrahim Yousif Saleh farm	0.35	3.81	9.86	3.96
36. Dumistan farm	0.65	3.62	14.12	3.96
37. Sh. Mohamed farm, Karzakhan	0.35	3.72	10.12	3.96
38. Malchiya farm	0.35	3.65	10.65	3.85
39. Al-Marooge farm, Zallaq.	0.62	3.28	8.90	3.25
40. Al-Areen farm	0.65	3.65	12.50	3.86
41. Hamala agri. farm	0.65	3.85	10.50	4.00

TABLE - 27 (Continued)

Trace metals in Ground waters of Bahrain.

Bore hole location	Cd	Pb	Zn	Cu
	<-----------	ug L-1	----------->	
42. West Riffa	1.20	3.70	10.13	5.16
43. Hamad Town	1.11	3.97	8.53	3.50
44. Salmaniya-P-2	1.12	4.64	12.43	4.56
45. Mahooz-P-2	0.46	4.20	10.23	3.80
46. Hoora-P1	0.37	3.26	9.86	3.65
47. Muharraq-P-4	0.30	3.50	14.46	3.65
48. Sitra	0.29	2.27	9.67	3.16
49. Al--Akr 1/35	0.12	3.50	8.65	5.10
50. Al- Akr 1/50	0.15	4.20	5.00	5.21
51. Al-Akr 1/105	0.05	4.00	5.50	5.65
52. Al-Akr 1/109	0.02	3.20	6.10	5.20
53. Al-Akr 1/131	0.10	1.20	5.50	5.10
54. Al-Akr 1/132	0.10	1.80	5.25	5.10
55. Al-Akr 1/134	0.50	1.90	5.10	5.00
56. Al-Akr 1/137	0.22	3.50	9.80	3.85
57. Al-Akr 1/139	0.50	3.60	8.88	5.10
Average ($\bar{x}$)	0.51	3.47	9.77	3.92
S.D.	0.31	0.59	1.77	0.65

TABLE - 28

NUTRIENTS IN RAIN WATER RUN-OFF IN BAHRAIN

No		Date Sampled	NUTRIENTS (µg/L)				Conductivity at 25° C mmhos/cm	Salinity °/₀₀	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K
			NO_2-N	NO_3-N	NH_4-N	PO_4-P										
1	Yateem Garden Drainage	30-3-89	14.7	3969	664.2	40.5	7.4	6.0	7.5	238	1846	1999.9	680	219	1020	55
* 2	Yateem Garden run-off		10000	25570	1140	21.5	10.1	8.0	7.5	280	2911	1935.7	492	389	1468	225
3	Yateem Garden run-off		84.9	1700	1287	28.8	1.3	0.8	8.1	150	120	50	50	20	50	5
4.	Yateem Garden accumulated Water		50.5	1414	3655	21.3	11.9	8.0	7.8	260	3182	2000	725	320	1530	200
* 5	Jasra - Ali Moh'd Daif Garden (H.E. Jawad Al-Arayed)		86.5	3300	1483	7.1	5.4	4.0	8.2	230	1600	1000	610	210	480	41.2
6	" Location II		174.1	900	50000	243.3	27.6	20.0	6.6	280	9985	4500	800	410	6780	450
7	" Location III		6419	21900	20000	0	34.3	26.0	7.8	260	14500	4820	788	400	9990	280
* 8	Ebrahim Yousif Saleh Demistan (Shk.Khalifa bin Moh'd Al-Kh.)		10000	96270	4344	0	56.1	50.0	7.4	213	21371	4010	890	480	13774	450
* 9	Ebrahim Yousif Saleh Drainage 2		303.5	19100	5137	19.8	13.8	11.0	8.0	258	3976	2800	700	385	2400	100
10	" Location 3		111.4	0	78000	398.7	66.2	58.0	7.95	280	29678	6975.7	880	390	20650	500
11	" Location 4		6402	12100	40000	19.1	31.2	22.0	7.5	300	11715	3005.6	776	516	7180	270
12	" Location 5		1680	46200	1713	26.6	6.2	5.0	8.1	285	2250	1900	610	400	1005	65
13	" Location 6		8373	96100	3328	208.0	28.4	22.0	7.2	260	10100	4002	780	410	6650	400
14	" Location 7		10000	69800	2583	0	14.0	10.0	7.8	282	3900	2100	725	320	2163	100
15	Karzakan. Ebrahim Hassan Al-Majid (HE. P.M.) Location		94.1	100	30000	0	44.8	37.0	6.95	210	17111	3900	616	1010	10100	510
* 16	" Garden " 2		8281	8900	2918	0	41.5	32.0	7.0	280	15407	6442.5	592	851	10800	210
17	" " " 3		103.5	300	13745	50.5	58.0	49.0	6.5	268	26500	7100	690	1300	16990	680
18	" " " 4		415.1	4331	14245	736.1	81.5	74.0	7.5	278	34100	8155	600	1108	22750	952
19	" " " 5		300.4	2040	20000	803.5	57.8	52.0	7.5	282	27100	7005	750	880	18350	258
* 20	Karzakhan: Sh.Mo'd (Hassan Maki Asoor/A.Hussain Ali Al-H)		105.5	600	537	115.2	37.2	28.0	7.3	280	15425	2800	900	625	9070	298
21	Karzakhan: Location 2		19.7	200	3358	0.16	33.4	24.0	7.7	320	12100	3816	770	500	7880	150
22	Malchiya Ali Yousif Al-Malah Drainage I		82.7	1100	702	10.1	17.2	13.0	7.6	300	6674	2600	610	480	3990	100
23	" " Location II		292.1	3700	814	9.7	18.8	14.5	7.8	318	6288	2462.4	968	511	3200	112

TABLE - 28

NUTRIENTS IN RAIN WATER RUN-OFF IN BAHRAIN

	DRAINAGE	Date Sampled	NUTRIENTS (μg/L)				Conductivity at 25° C mmhos/cm	Salinity ‰	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K	F	
			NO_2-N	NO_3-N	NH_4-N	PO_4-P												
24	Malchiya. Ali Yousif Al-Malah Drainage Location III		28.3	600	509	290.8	16.5	13.0	7.8	295	6020	2612	700	380	3690	105		
X 25	Hamala Agricultural Garden Location 1		65.6	284	984	109.0	2.0	0.8	8.2	282	200	240	71	32	186	17		
/ 26	Location 2		10000	185.3	25720	0	47.9	32	8.5	290	15400	6000	710	610	10650	550		
27	Location 3		14.24	280	166.2	24.5	2.6	1.8	8.5	320	250	500	70	30	350	20		
28	Location 4		49.2	290	295.8	0	3.8	2.5	8.2	280	350	310	98	58	250	28		
29	Location 5		59.1	180	278.1	0	2.6	1.8	8.0	280	258	285	71	25	285	18.5		
	Average	$\bar{x}$	2538.28	14531.49	11296.77	109.80	26.88	21.59	7.67	271.00	10355.76	3287.13	605.31	457.55	6694.86	246.54		
	Standard Deviation	σ	3952.39	27503.9	18267.87	208.49	22.26	19.58	0.50	35.78	9836.34	2312.72	267.73	323.01	6652.09	232.37		
	Range		14.24 - 10100	0 - 69800	278.1 - 50000	0 - 803.5	1.3 - 81.5	0.8 - 74.0	6.5 - 8.5	150 - 320	120 - 34100	50 - 8155	50 - 968	20 - 1300	50 - 22750	5 - 952		

/	Control area
✱	Chicken manure area
—	Cow manure area
X	Sewage sludge area

Table-29

Trace Metals in Rain water run-off in Bahrain

Sample location		Cd	Pb	Zn	Cu
		<		ug L-1	>
1. Yateem Garden-1		2.50	10.05	100.25	15.60
2. Yateem Garden-1	*	10.12	20.15	55.20	12.85
3. Yateem Garden-3		10.15	22.16	22.20	15.20
4. Yateem Garden-4		1.50	20.60	20.10	15.60
5. Jasra-Ali Mohd Daif garden-1	*	1.50	100.15	25.60	18.60
6. ,, ,, -2		1.50	150.15	60.20	20.00
7. ,, ,, -3		1.20	200.20	15.80	22.15
8. Ebrahim Yousif Saleh Farm -1	*	2.20	25.05	28.60	16.50
9. ,, ,, -2	*	2.20	100.10	30.50	18.20
10. ,, ,, -3		1.50	120.20	20.10	20.00
11. ,, ,, -4		1.60	160.50	32.60	18.00
12. ,, ,, -5		1.82	180.10	35.60	18.00
13. ,, ,, -6		1.82	25.10	50.00	16.15
14. ,, ,, -7		1.82	100.80	12.00	20.00
15. Ebrahim Hassan Al- Majid farm -1		2.50	110.10	50.00	21.00
16. ,, ,, -2	*	1.50	50.10	42.00	20.00
17. ,, ,, -3		0.95	28.68	30.00	16.15
18. ,, ,, -4		0.85	50.18	12.00	17.10
19. ,, ,, -5		1.10	15.85	30.00	18.20
20. Hassan Makki Asoor farm -1	*	1.50	16.10	16.65	25.10
21. ,, ,, -2		2.00	100.10	18.00	26.20
22. Ali Yousif Maleh. -1		1.50	25.20	25.00	20.50
23. ,, ,, -2	-	1.50	28.20	25.00	16.20
24. ,, ,, -3		1.50	18.80	60.20	15.00
25. Hamala Agri. Farm -1	x	1.60	22.00	28.60	12.00
26. ,, ,, -2	/	0.80	15.00	32.20	16.00
27. ,, ,, -3		0.80	17.50	30.00	28.60
28. ,, ,, -4		1.00	18.00	28.60	12.00
29. ,, ,, -5		1.50	17.00	20.20	20.20
Average ($\bar{x}$)		2.14	60.97	33.01	18.59
S.D.		2.26	57.41	18.63	3.70

*	Chicken manure	area
-	Cow manure	area
x	Sewage sludge	area
/	Control	area

TABLE - 30

NUTRIENTS IN DRAINAGE WATER IN BAHRAIN

No.	DRAINAGE		Date Sampled	NUTRIENTS (µg/L)				Conductivity at 25° C mmhos/cm	Salinity °/₀₀	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K	F	B
				NO_2-N	NO_3-N	NH_4-N	PO_4-P												
/ 1.		M_1	5-4-89	1071	11000	250.1	24.5	7.6	6.0	7.3	305	1600	1800	600	194.6	938	60.2	1.44	0.27
2.		M_2		34.3	300	755.7	5.5	12.9	10.0	7.3	352	3634	2656.6	830	420	1893	156		0.52
3.	Barbar (Barbar School)	M_4		153.2	3900	641.2	8.0	5.9	4.5	7.2	210	1349	1581.8	624	155.65	666	43.3		0.26
4.		M_5		111.2	6800	294.8	0.0	7.3	6.0	7.3	280	1646	1925	630	160	973	56		0.26
5.		M_6		434.1	3600	244.8	8.9	6.4	4.0	7.8	248	1633	1324	568	170	791	45.6		0.22
6.		M_7		151.4	1900	951	8.4	9.4	8.0	7.98	270	2556	2318	640	280	1585	64.6		0.30
7.	Budaiya Farm	M_8		221.2	15400	483	1.7	5.5	4.0	7.6	280	1400	1316.8	512	204.3	645	47.7		0.27
8.	"	M_9		36.3	500	627.9	10.3	11.8	10.0	7.3	194	3300	2680	832	428.03	1658	74.9		0.99
* 9.		M_{10}		379.9	87900	1091	1.2	11.1	10.0	7.4	256	3060	2388	832	379.4	1528	77.8	1.33	0.91
* 10		M_{11}		348.3	9100	414.7	3.5	8.0	6.0	7.4	256	1562	1902.8	610	200	943	58		0.42
* 11		M_{13}		154.4	7500	992.1	0.5	6.5	5.5	7.7	230	1690	1990	716	280	753	46.9		0.32
* 12		M_{13A}		346.8	1400	1646	5.6	14.2	11.0	7.2	200	4400	2430.9	880	452	2158	110		0.66
* 13		M_{13B}		865.5	14800	2021	0	8.9	7.0	7.2	220	2414	1935.7	648	272.4	1240	86		0.46
* 14	Jasrah (Down-stream Position)	M_{14}		164.1	10600	1028	4.5	11.5	8.5	7.8	220	3550	2303	688	288	2163	75.6		0.46
15	Hamala	M_{15}		150.4	21500	1170	18.3	10.3	8.0	7.5	286	2880	2205.6	850	390	1278	69.5		0.65
16	Hamala	M_{16}		622.7	11100	1050	7.3	8.2	6.0	7.5	230	2201	1800	608	257.8	1150	57.9		0.63
x 17		M_{16B}		410.9	21800	1020	8.0	9.1	7.8	7.5	280	24142414	2078.9	720	280	1293	63.8		0.60
18	"	M_{17}		870.9	15200	1981	0	11.5	9.8	7.4	246	3195	2580.9	890	310	1778	77.2		0.73
19	Rashid bin Ebrahim North	M_{18}		61.7	7500	989.1	2.1	9.8	8.0	7.5	220	2698	2200	720	286.98	1490	62.8		0.62
20	Dumistan	M_{19}		219.0	15900	1116	0.0	12.5	10.0	7.7	300	3621	2380	800	210	2250	84.95		1.1
21	"	M_{20}		105.5	2100	875.2	8.7	13.1	10.0	7.2	210	3905	2700	760	374.5	2255	81.1	1.54	0.96
22	Hassan Haider Darwish	M_{21}		32.8	1700	1252	3.9	16.4	12.8	7.5	210	5438	2321	890	388	2890	82.5		0.52
23		M_{22}		63.4	2200	1132	1.5	13.4	11.0	7.4	200	4047	2400	990	380	1920	78.2		0.73

TABLE - 30

NUTRIENTS IN DRAINAGE WATER IN BAHRAIN

				Date Sampled	NUTRIENTS (µg/L)				Conductivity at 25° C mmhos/cm	Salinity °/₀₀	pH	HCO_3	Cl	SO_4	Ca	Mg	Na	K	F	B
					NO_2-N	NO_3-N	NH_4-N	PO_4-P												
	24		M_{24}	5-4-89	124.6	3200	1114	257.7	14.5	11	7.3	140	4710	2306	984	396	2260	77.1		0.59
	25	Al Nasr	M_{25}		51.7	1800	985.1	[illegible]6.8	17.3	14.0	7.4	210	5600	2506	910	380	2995	189		0.45
	26	A.Aziz Al-Hassan	M_{26}		62.5	2100	1027	5.3	13.4	10	7.7	206	4047	2668.2	842	310	2350	79.9		0.70
	27	Majid Al-Naimi	M_{27}		53.5	1700	927.1	29.1	11.6	10	7.7	230	3621	2064.1	830	310	1850	60.9		0.62
	28		M_{28}		135.9	9800	1065	0	13.0	10	7.8	180	4047	2100	928	340.5	1940	70.7		0.62
	29	Sahrakan Darklab	M_{29}		84.5	4700	1069	3.3	15.9	12.5	7.8	220	5183	2679	900	338	2924	185		0.98
	30	Kanoo Farmer	M_{30}		109	8700	969.1	241.5	11.4	10	7.9	230	3337	2100	818	328	1600	150		0.78
—	31		M_{31}		39.2	900	896.6	3.9	11.6	10	7.9	200	3337	2100	820	310	1630	85.5		0.69
—	32	Zallaq	M_{32}		42	500	823.8	0	10.3	8.2	7.9	240	2982	1517	712	325.9	1280	59		0.71
X	33	Wasmiya	M_{33}		70.1	2700	872.2	394	8	5	7.7	200	2485	1500	536	194.6	1372	50.1	1.05	0.35
	34	Um Nakhila Drainage	M_{34}		1278	22300	1565	5	34	26	7.8	240	13561	2082.5	728	899.8	7190	365		0.31
	35	Qualali Drainage	M_{35}		213.5	18400	1117	0	59.8	46	7.5	200	26696	3617.1	896	1624	14820	355		0.46

/ Control area

✱ Chicken manure area

— Cow manure area

X Sewage sludge area

Table-31

TRACE METALS IN DRAINAGE WATERS OF BAHRAIN

Drainage	Cd	Pb	Zn	Cu (ug/l)
1. M1 /	1.50	9.40	2.20	23.50
2. M2	1.84	12.30	2.10	21.50
3. M4	1.74	10.40	2.50	8.90
4. M5	1.83	11.40	2.30	18.40
5. M6	1.95	12.90	2.40	9.70
6. M7	1.83	27.00	2.10	24.40
7. M8	1.30	3.90	2.20	11.30
8. M9	1.83	27.00	2.50	23.80
9. M10 *	2.10	13.90	2.60	23.30
10. M11 *	2.10	27.00	2.70	13.50
11. M13 *	2.80	17.80	2.50	16.60
12. M13-A *	2.80	17.80	2.50	15.20
13. M13-B *	2.70	17.20	2.60	8.00
14. M14 *	2.20	17.80	2.30	2.10
15. M15	1.60	13.80	2.10	6.90
16. M16	1.80	7.40	2.60	9.90
17. M16-B *	2.10	7.80	3.50	10.10
18. M17	1.90	10.20	3.20	10.20
19. M18	1.80	12.20	2.00	12.50
20. M19	2.10	7.40	2.60	16.20
21. M20	2.10	7.80	2.00	17.20
22. M21	2.00	13.20	3.00	18.10
23. M22	1.90	9.60	3.50	20.00
24. M24	1.90	7.80	2.60	10.10
25. M25	2.10	10.50	2.20	9.90
26. M26	2.00	8.10	3.10	8.60
27. M27	2.20	7.50	3.80	10.10
28. M28	2.10	7.60	2.80	10.20
29. M29	2.20	10.10	2.60	9.80
30. M30	2.20	20.90	2.50	10.10
31. M31 -	2.10	10.20	3.20	10.10
32. M32 -	2.00	21.10	4.10	8.60
33. M33 x	1.80	18.20	4.00	9.20
34. M34	1.80	7.90	3.50	9.10
35. M35	5.70	10.50	2.80	13.30
Average ($\bar{x}$)	2.11	13.02	2.72	13.15
S.D.	0.69	6.04	0.57	5.56

TABLE - 32

DATA USED FOR COMPARISON

EFFECTS OF TREATMENT ON GROUNDWATER, DRAINAGE & SURFACE RUNOFF

SERIAL NO.	SAMPLE DETAILS	GROUNDWATER (mg/L)			DRAINAGE (mg/L)			RUNOFF (mg/L)			TRACE METALS (ug/L) GROUNDWATER				TRACE METALS (ug/L) DRAINAGE				TRACE METALS (ug/L) RUNOFF			
		NO3-N	PO4-P	K	NO3-N	PO4-P	K	NO3-N	PO4-P	K	Cd	Pb	Zn	Cu	Cd	Pb	Zn	Cu	Cd	Pb	Zn	Cu
1	CHICKEN MANURE TREATMENT AREA	3.30	0.01	29.60	87.90	0.01	77.80	25.60	0.02	225.00	0.28	3.46	10.12	4.00	2.10	13.90	2.60	23.30	10.12	20.15	55.20	12.85
2	CHICKEN MANURE TREATMENT AREA	2.90	0.01	57.90	9.10	0.01	58.00	3.30	0.01	41.20	0.35	3.20	9.65	4.00	2.10	27.00	2.70	13.50	1.50	100.20	25.60	18.60
3	CHICKEN MANURE TREATMENT AREA	2.50	0.01	31.60	7.50	0.01	46.90	96.30	0.01	450.00	0.35	3.81	9.86	3.96	2.80	17.80	2.50	16.60	2.20	25.10	28.60	16.50
4	CHICKEN MANURE TREATMENT AREA	2.30	0.01	32.20	1.40	0.01	110.00	19.10	0.02	100.00	0.65	3.62	14.12	3.96	2.80	17.80	2.50	15.20	2.20	100.10	30.50	18.20
5	CHICKEN MANURE TREATMENT AREA	1.30	0.01	16.10	14.80	0.01	86.00	8.90	0.01	210.00	0.35	3.72	10.12	3.96	2.70	17.20	2.60	8.00	1.50	50.10	42.00	20.00
6	CHICKEN MANURE TREATMENT AREA	2.20	0.01	69.20	10.60	0.01	75.60	0.60	0.10	298.00	0.35	3.65	10.65	3.85	2.20	17.80	2.30	2.10	1.50	16.10	16.65	25.10
7	COW MANURE TREATMENT AREA	2.90	0.01	59.60	0.90	0.01	65.50	3.70	0.01	112.00	0.62	3.28	8.90	3.25	2.10	10.20	3.20	10.10	1.50	28.20	25.00	16.20
8	COW MANURE TREATMENT AREA				0.50	0.01	59.00								2.00	21.10	4.10	8.60				
9	COW MANURE TREATMENT AREA	22.50	0.20	100.00							0.50	1.90	5.10	5.00								
10	COW MANURE TREATMENT AREA	5.30	0.01	60.00							0.22	3.50	9.80	3.85								
11	COW MANURE TREATMENT AREA	6.90	0.20	65.00							0.12	3.50	8.65	5.10								
12	SLUDGE TREATMENT AREA	1.40	0.01	38.00	2.70	0.39	50.10	0.20	0.10	17.00	0.65	3.65	12.50	3.86	1.80	18.20	4.00	9.20	1.60	22.00	28.60	12.00
13	SLUDGE TREATMENT AREA				21.80	0.01	63.80	0.20	0.10	17.00				3.86	2.10	7.80	3.50	10.10				
14	CONTROL AREA	2.80	0.01	45.90	11.00	0.01	60.20	0.20	0.01	550.00	0.46	2.76	12.15	3.86	1.50	9.40	2.20	23.50	0.80	15.00	32.20	16.00
15	CONTROL AREA	2.70	0.01	38.40							0.85	3.26	10.20	4.10								
16	CONTROL AREA	2.60	0.01	31.50							0.45	3.16	9.65	3.86								
17	CONTROL AREA	2.10	0.01	40.20							0.42	3.85	10.10	3.95								