LAND APPLICATION OF TREATED PAPER BOARD MILL EFFLUENT ON SOIL – WATER – PLANT – ECOSYSTEM

Thesis submitted in part fulfillment of the requirements for the degree of Doctor of Philosophy in Soil Science and Agricultural Chemistry to the Tamil Nadu Agricultural University, Coimbatore - 3

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2002

CERTIFICATE

This is to certify that the thesis entitled " **LAND APPLICATION OF TREATED PAPER BOARD MILL EFFLUENT ON SOIL - WATER - PLANT ECOSYSTEM"** submitted in part fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the Tamil Nadu Agricultural University, Coimbatore is a bonafide record of research work carried out by **Mr. M. ELAYARAJAN** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar popular journal of magazine.

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M. Elayaraja

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Abstract

ABSTRACT

LAND APPLICATION OF TREATED PAPER BOARD MILL EFFLUENT ON SOIL – WATER – PLANT ECOSYSTEM

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Treated paper board mill effluent irrigation as a method of waste water disposal is considered as an alternative approach, since this being economical, energy conserving and capable of providing recycle benefits. Beside these, paper board mill solid wastes can also be successfully used for soil conditioning and also for enhancement of soil nutrients. The present study was carried out to evaluate the impact of waste paper mill effluent and solid wastes on quality of soil - water - plant ecosystem.

Laboratory analysis of raw and treated effluent from waste paper board mill, Ballarpur Industrial Packaging Company Limited (Bilt-IPCL), Thekkampatti, Tamil Nadu brought out varying values of physical, chemical and biological properties which were well within the limits of State Pollution Control Board regulations for land application.

Bioassay experiments conducted to evaluate the effect of treated effluent at different concentrations on fish fingerlings revealed that the survival per cent was increased in *Cyprinus rogu* with increasing concentrations of water in treated effluent and decreased in *Catla catla* and *Mrigal,* which were sensitive to treated paper board mill effluent.

Laboratory germination studies conducted to determine the effect of raw and treated effluent on field crops (rice, maize, sunflower, groundnut, blackgram, greengram and soybean) and vegetable crops (amaranthus, bhendi, tomato, chilli, bittergourd, snakegourd and moringa) revealed that seed germination per cent, shoot length, root length and vigour index of the seedlings were higher in treated effluent than in raw effluent. The growth parameters of the above field crops increased upto 75 per cent concentration of treated effluent except in rice. Vegetable crops performed better under river water than at different concentrations of raw and treated effluent. Under both the effluents, the vigour index of the seedlings decreased as the concentration of the effluent increased.

Nursery experiments with *Acacia auriculiformis, Azadirachta indica* and *Eucalyptus tereticornis* revealed better sapling growth in terms of shoot length, root length, collar diameter and dry matter production (DMP) in FYM + FA (fly ash) with effluent irrigation and the performance was comparable with FYM with effluent irrigation. *A. auriculiformis* completely withered under sludge application. The FYM + FA along with effluent irrigation increased the soil EC, OC, available nutrients and exchangeable cations, and the increase was comparable with FYM alone. Marked differences in the rhizosphere microflora of tree saplings were observed under amendments irrigated with treated effluent rather than under river water except with FA, which had an adverse effect on soil microflora irrespective of the irrigation source. The performance of nursery seedlings was better under effluent irrigation amended with FYM + FA compared to FA alone. Therefore the Bilt-IPCL solid wastes could safely be used along with FYM as a nursery mix.

The soil and ground water quality parameters *viz.*, pH, EC, OC, available N, P, K, exchangeable cations, ESP, SAR and microbial load in and around the factory area increased due to continuous effluent irrigation at Mandaraikadu factory site compared to river water irrigated soils. The pH, EC, total hardness, carbonates, bicarbonates, chloride, sulphate, sodium, calcium, magnesium and potassium contents of ground water in and around the factory site also increased due to continuous discharge of treated effluent for irrigation at factory site. However, the over all rating of most of the ground water quality parameters tested in and around the factory area fell under C_1S_1 category as per the USDA classification (1954) and it is inferred that the ground water could be used for agricultural purposes safely.

Field trial conducted at Bilt-IPCL, Thekkampatti on the combined use of treated effluent and amendments in comparison with river water on maize and sunflower revealed that the pH, EC, organic matter, availability of major (NPK), secondary (Ca, and Mg,) and micronutrients (Cu, Fe, Mn and Zn) increased in treated effluent irrigated soil compared to river water irrigated soil. Fly ash + sludge + green manure with effluent irrigation improved the soil quality parameters than rest of the treatment combinations. Treated effluent irrigation increased the microbial population with best performance under amendments FA + S + GM and FA + GM, while under river water irrigated soil, lesser microbial load was observed. The soil enzymes viz., amylase and invertase activities also increased in treated effluent irrigated soils compared to the river water irrigated soil. The yield of maize and sunflower and the quality parameters of carbohydrate, protein and oil contents increased in treated effluent irrigated plots when compared to river water irrigated plots.

Soil column lysimeter study indicated that the surface soil recorded more changes than the sub-surface soil and the leachate had lesser pH, EC and exchangeable cations. The available major nutrients were higher in surface soil under treated effluent irrigation amended with FA + S + GM followed by FA + GM amendment.

Contents

CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	5
III	MATERIALS AND METHODS	36
IV	RESULTS	62
V	DISCUSSION	193
VI	SUMMARY AND CONCLUSION	245
	REFERENCES	252
	PLATES	274

List of Tables

Table No.	Title	Page No.
1	Colour changes in Bilt-IPCL effluent at periodical intervals	63
2	Odour changes in Bilt-IPCL effluent at periodical intervals	63
3	Total dissolved solids (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	63
4	Suspended solids (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	64
5	Total solids (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	64
6	pH changes in Bilt-IPCL effluent at periodical intervals	64
7	EC (dSm^{-1}) changes in Bilt-IPCL effluent at periodical intervals	66
8	Organic carbon per cent changes in Bilt-IPCL effluent at periodical intervals	66
9	Dissolved oxygen (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	66
10	BOD (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	67
11	COD (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	67
12	Bicarbonates (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	67
13	Ammoniacal nitrogen (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	69
14	Phosphorus (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	69
15	Pottasium (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	69
16	Calcium (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	70
17	Magnisium (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	70

conti...

Table.No.	Title	Page No.
18	Sodium (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	70
19	Chloride (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	71
20	Sulphate (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	71
21	Total phenol (mg L^{-1}) changes in Bilt-IPCL effluent at periodical intervals	71
22	Na per cent changes in Bilt-IPCL effluent at periodical intervals	72
23	SAR changes in Bilt-IPCL effluent at periodical intervals	72
24	Bacterial population (x 10^6 ml^{-1} CFU) changes in Bilt-IPCL effluent at periodical intervals	72
25	Fungal population (x 10^4 ml^{-1} CFU) changes in Bilt-IPCL effluent at periodical intervals	74
26	Actinomycetes population (x 10^3 ml^{-1} CFU) changes in Bilt-IPCLeffluent at periodical intervals	74
27	pH of soil samples in and around the factory area	75
28	EC (dS m-1) of soil samples in and around the factory area	75
29	Organic Carbon per cent of soil samples in and around the factory area	75
30	Available N (kg ha^{-1}) of soil samples in and around the factory area	77
31	Available P (kg ha^{-1}) of soil samples in and around the factory area	77
32	Available K (kg ha^{-1}) of soil samples in and around the factory area	77
33	Exchangeable Na (cmol (+) kg^{-1}) of soil samples in and around the factory area	78
34	Exchangeable Ca (cmol (+) kg^{-1}) of soil samples of in and around the factory area	78

conti...

Table.No.	Title	Page No.
35	Exchangeable Mg (cmol (+)kg^{-1} of soil samples in and around the factory area	78
36	Exchangeable K (cmol (+) kg^{-1}) of soil samples in and around the factory area	79
37	ESP of soil samples in and around the factory area	79
38	Per cent Chloride of soil samples in and around the factory area	79
39	CEC (cmol (+) kg^{-1}) of soil samples of in and around the factory area	81
40	SAR of soil samples of in and around the factory area	82
41	Bacterial population(X $10^6 g^{-1}$) of soil samples of in and around the factory area	82
42	Fungal population (X$10^4 g^{-1}$) of soil samples of in and around the factory area	82
43	Actinomycetes population(X $10^3 g^{-1}$) of soil samples in and around the factory area	82
44	pH of water samples in and around the factory area	83
45	EC of water samples in and around the factory area (dS m-1)	83
46	TDS in water samples collected in and around the factory area (mg L^{-1})	85
47	Total Hardness in water samples collected in and around the factory area (mg L^{-1})	85
48	BOD in water samples collected in and around the factory area (mg L^{-1})	86
49	COD of water samples in and around the factory area (mg L^{-1})	86
50	CO_3 in water samples collected in and around the factory area (mg L^{-1})	87
51	HCO_3 in water samples collected in and around the factory (mg L^{-1})	87
52	Cl^- in water samples collected in and around the factory area (mg L^{-1})	88

conti...

Table.No.	Title	Page No.
53	SO_4 in water samples collected in and around the factory area (mg L^{-1})	88
54	Na in water samples in and around the factory area (mg L^{-1})	90
55	Ca in water samples collected in and around the factoryarea (mg L^{-1})	90
56	Mg in water samples collected in and around the factory area (mg L^{-1})	91
57	Pottasium in water samples in and around the factory area (mg L^{-1})	91
58	Per cent Na in water samples collected in and around the factory area	92
59	Potential Salinity values in water samples collected in and around the factory area (cmol L^{-1})	92
60	SAR values in water samples collected in and around the factory area	93
61	RSC values in water samples collected in and around the factory area (mg L^{-1})	93
62	Initial characterstics of treated effluent and river water used for irrigation	95
63	Initial soil analysis used for the experiment	97
64	Initial amendment analysis used for the experiment	98
65	Impact of effluent on survival of fingerlings at different different dilutions	100
66	Effect of raw and treated effluent on growth characters of rice (CO-47)	103
67	Effect of raw and treated effluent on growth characters of maize (CO-1)	103
68	Effect of raw and treated effluent on growth characters of sunflower (K-1)	105
69	Effect of raw and treated effluent on growth characters of groundnut (VRI-2)	105

conti...

Table.No.	Title	Page No.
70	Effect of raw and treated effluent on growth characters of blackgram (T-9)	108
71	Effect of raw and treated effluent on growth characters of greengram (Vamban-2)	108
72	Effect of raw and treated effluent on growth characters of soybeen (Vamban-2)	110
73	Effect of raw and treated effluent on growth characters of moringa (PKM-2)	110
74	Effect of raw and treated effluent on growth characters of amaranthus (CO-4)	113
75	Effect of raw and treated effluent on growth characters of tomato (CO-3)	113
76	Effect of raw and treated effluent on growth characters of bhendi (Arka annamica)	116
77	Effect of raw and treated effluent on growth characters of chilli (CO-1)	116
78	Effect of raw and treated effluent on growth characters of bittergourd (CO-1)	118
79	Effect of raw and treated effluent on growth characters of snakegourdgourd (CO-1)	118
80	Effect of effluent and amendments on root Length(cm) of forest nursery seedlings	121
81	Effect of effluent and amendments on shoot Length(cm) of forest nursery seedlings	121
82	Effect of effluent and amendments on collar diameter(mm) of forest nursery seedlings	124
83	Effect of effluent and amendments on dry matter production of forest nursery seedlings (g $seedling^{-1}$)	124
84	Effect of effluent and amendments vigour index of forest nursery seedlings	129

conti...

Table.No.	Title	Page No.
85	Effect of effluent and amendments volume index of forest nursery seedlings	129
86	Effect of effluent and amendments on soil pH of forest nursery seedlings	133
87	Effect of effluent and amendments on soil EC (dS m^{-1}) of forest nursery seedlings	133
88	Effect of effluent and amendments on soil Organic carbon percent of forest nursery seedlings	136
89	Effect of effluent and amendments on soil available N (kg ha^{-1}) of forest nursery seedlings	138
90	Effect of effluent and amendments on soil available P (kg ha-1) of forest nursery seedlings	138
91	Effect of effluent and amendments on soil available K (kg ha^{-1}) of forest nursery seedlings	138
92	Effect of effluent and amendments on soil exchangeable Ca (cmol (+) kg ha^{-1}) of forest nursery seedlings	141
93	Effect of effluent and amendments on soil exchangeable Mg (cmol (+) kg ha^{-1}) of forest nursery seedlings	141
94	Effect of effluent and amendments on soil exchangeable Na (cmol (+) kg ha^{-1}) of forest nursery seedlings	144
95	Effect of effluent and amendments on soil bacterial population (10^6 g^{-1}) of forest nursery seedlings	144
96	Effect of effluent and amendments on soil actinomycetes population ($10^3 g^{-1}$) of forest nursery seedlings	147
97	Effect of effluent and amendments on soil fungal population (10^4 g^{-1}) of forest nursery seedlings	147
98	Effect of effluent and amendments on soil bulk density (Mg dm^{-3}) of maize and sunflower	150
99	Effect of effluent and amendments on soil reaction of maize and sunflower	150

conti...

Table.No.	Title	Page No.
100	Effect of effluent and amendments on soil EC (dS m^{-1}) of maize and sunflower	152
101	Effect of effluent and amendments on soil organic carbon per cent of maize and sunflower	152
102	Effect of effluent and amendments on soil available N (kg ha^{-1}) of maize and sunflower	155
103	Effect of effluent and amendments on soil available P (kg ha-1) of maize and sunflower	155
104	Effect of effluent and amendments on soil available K (kg ha^{-1}) of maize and sunflower	157
105	Effect of effluent and amendments on soil exchangeable calcium per cent of maize and sunflower	157
106	Effect of effluent and amendments on soil exchangeable magnesium per centof maize and sunflower	159
107	Effect of effluent and amendments on soil DTPA copper (ppm) of maize and sunflower	159
108	Effect of effluent and amendments on soil DTPA iron (ppm) of maize and sunflower	162
109	Effect of effluent and amendments on soil DTPA manganese (ppm) of maize and sunflower	162
110	Effect of effluent and amendments on soil DTPA zinc (ppm) of maize and sunflower	164
111	Effect of effluent and amendments on amylase (mg reducing sugars g^{-1} soil 24 $hours^{-1}$) of maize and sunflower	164
112	Effect of effluent and amendments on invertase (mg reducing sugars g^{-1} soil 24 $hours^{-1}$) of maize and sunflower	167
113	Effect of effluent and amendments on cellulase (mg reducing sugars g^{-1} soil 24 $hours^{-1}$) of maize and sunflower	167
114	Effect of effluent and amendment on bacterial population (x 10^6 $g^{-1}$of dry soil) of maize and sunflower	167

conti...

Table.No.	Title	Page No.
115	Effect of effluent and amendment on actinomycetes population of (x 10^3 $g^{-1}$of dry soil) maize and sunflower	169
116	Effect of effluent and amendment on fungal population of (x 10^4 $g^{-1}$of dry soil) maize and sunflower	171
117	Effect of effluent and amendment on *acetobacter* population (x 10^2 $g^{-1}$of dry soil) of maize and sunflower	171
118	Effect of effluent and amendment on *azospirillum* population (x 10^4 $g^{-1}$of dry soil) of maize and sunflower	174
119	Effect of effluent and amendment on *rhizobium* population (x 10^3 $g^{-1}$of dry soil) of maize and sunflower	174
120	Effect of effluent and amendments on germination per cent and vigour indices of maize and sunflower	177
121	Effect of effluent and amendments on plant height (cm) of maize and sunflower	178
122	Effect of effluent and amendments on yield parameters of maize and sunflower	180
123	Effect of effluent and amendments on carbohydrate and protein content in maize and oil and protein content in sunflower	181
124	Effect of effluent and amendments on reaction,EC (dSm^{-1})and OC per cent of soil collected from column lysimeter	184
125	Effect of effluent and amendments on exchangeable cations (cmol p(+) kg^{-1}) of soil collected from column lysimeter	184
126	Effect of effluent and amendment on available nutrient status (kg ha^{-1}) of soil collected from column lysimeter	187
127	Effect of effluent and amendment on biological properties of soil collected from column lysimeter	187
128	Effect of effluent and amendments on total solids (mg L^{-1}) pH and EC (dS m^{-1}) of leachates collected from column lysimeter	189
129	Effect of effluent and amendments on OC per cent, BOD and COD (mg L^{-1}) of leachates collected from of column lysimeter	189
130	Effect of effluent and amendments on exch.Ca,Mg,Na (cmol L^{-1}) and SAR of leachates collected from of column lysimeter	191

List of Figures

Fig.No.	Title	Page No.
1	Waste water sources in the pulp and paper industry	7
2	Map of Tamil Nadu	38
3	Schematic diagram of effluent treatment plant at Bilt-IPCL	39
4	Map showing the location of Bilt-IPCL factory area	43
5	Sampling locations in and around the factory area	45
6	Field lay out	58
7	Column lysimeter	59
8	Logrithimic probability of mortality in fish fingerlings at different dilutions of effluent	100
9	Total solids (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals	195
10	pH of Bilt-IPCL effluent at periodical intervals	195
11	EC (dS m^{-1}) of Bilt-IPCL effluent at periodical intervals	195
12	BOD (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals	197
13	Chloride (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals	197
14	Sulphate (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals	200
15	pH of soil in and around the factory area	200
16	EC (dS m^{-1}) of soil samples in and around the factory area	200
17	OC per cent soil samples in and around the factory area	200
18	Exchangeable Na (cmol (+) $kg^{-1}$of soil samples in and around the factory area	203
19	ESP of soil samples in and around the factory area	203
20	SAR of soil samples of in and around the factory area	203
21	pH of water samples in and around the factory area	205
22	EC of water samples in and around the factory area (dS m^{-1})	205
23	Na of water samples in and around the factory area (mg L^{-1})	205
24	Cl^- of water samples collected in and around the factory area (mg L^{-1})	207
25	SO_4 of water samples collected in and around the factory area (mg L^{-1})	207

conti…

Fig.No.	Title	Page No.
26	Per cent Na of water samples collected in and around the factory area	207
27	Effect of raw and treated effluent on root length (cm) of some important field crops	211
28	Effect of raw and treated effluent on shoot length (cm) of some important field crops	211
29	Effect of raw and treated effluent on root length (cm) of some important vegetable crops	214
30	Effect of raw and treated effluent on shoot length (cm) of some important vegetable crops	214
31	Effect of effluent and amendments on DMP of A.auriculiformis. (g seedling^{-1})	219
32	Effect of amendments on OC per cent of soil on A.auriculiformis.	219
33	Effect of amendments on pH of soil on A.auriculiformis.	219
34	Effect of effluent and amendments on soil reaction under maize and sunflower	227
35	Effect of effluent and amendments on soil EC (dS m^{-1}) under maize and sunflower	227
36	Effect of effluent and amendments on soil bacterial population (x 10^7 g^{-1}of dry soil) under maize and sunflower	231 232
37	Effect of effluent and amendments on soil *acetobacter* population (x 10^2 g^{-1}of dry soil) under maize and sunflower	232
38	Effect of effluent and amendment on soil *azospirillum* population (x 10^4 g^{-1}of dry soil) under maize and sunflower	232
39	Effect of effluent and amendment on soil *rhizobium* population (x 10^3 g^{-1}of dry soil) under maize and sunflower	
40	Effect of effluent and amendments on yield parameters under maize and Sunflower	237
41	Effect of effluent and amendments on maize carbohydrate and protein per cent	239
42	Effect of effluent and amendments on sunflower protein and oil per cent	239

List of plates

Fig.No.	Title	Page No.
1	Panoramic view of paper board mill	274
2	Treated effluent irrigation	274
3	Bio assay studies with fingerlings of *Catla catla*	275
4	Bio assay studies with fingerlings of *Cyprinus rogu*	276
5	Treated and raw effluent on germination and growth of field crops seedlings	277
6	Treated and raw effluent on germination and growth of vegetable seedlings	278
7	Effluent and solid wastes on nursery tree saplings	279
8	General view of nursery Experiment	280
9	General view of nursery field experiment	280
10	Field experiment with Maize (CO-1)	281
11	Field experiment with Sunflower (CO-4)	281
12	TNAU officials visit to experimental sites of Bilt-IPCL	282
13	Discussion with General Manager (Technical)	282

Introduction

CHAPTER I

INTRODUCTION

The sustainability of environmental quality is an accepted national goal. The major efforts to maintain and sustain environmental quality are in controlling industrial pollution, treating liquid wastes, disposal of solid wastes, etc. Agriculture, is also faced with a number of constraints. Since the concept of totally unimpaired or totally polluted environment is not meaningful, feasible compromises must be obtained between agricultural production and environmental quality control to assure adequate food supply for the nation, adequate profit for the farmers and an acceptable environment for the public.

Water pollution is a worldwide phenomenon and is one of the most serious problems confronting mankind today. The problem is accentuated by rapid urbanisation and industrialisation which are fast transferring air, water and soil into natural reservoirs of pollutants. Among the major industries in India, pulp and paper industry being highly water intensive is regarded as a major pollutant of soil and water resources. They rank third in terms of fresh water withdrawal after primary metal and chemical industries in the world (Kallas and Munter, 1994).

In India, there are about 371 paper and paper board units with an installed capacity of 37,14,043 tonnes per annum. In Tamil Nadu, there are 24 units with an installed capacity of 2,37,872 tonnes per annum (Gupta, 1995). The waste water generation is in the range of 214-350 $m^3\ t^{-1}$ of paper produced. The waste water being let out carries dissolved solids and varying amounts of suspended organic materials. The effluents are generally alkaline with high BOD and COD. Thus the untreated effluents discharged into the water stream make the water unfit for use and create health hazards.

Both urban and industrial complexes grow rapidly in the neighbourhood of rivers and lakes, as water is the basic raw material for their survival. In ancient times, conservation of water resources was considered as a basic law of self preservation; whereas, now sanitation of water resources is going from bad to worse due to population explosion, urbanization and ecologically unsound practices of development in the fields of irrigation, forestry and industrialization. Moreover, the total supply of water is limited and geographically irregular through seasons and years. The problem is more serious for India, since we have to support about 15% of the world population in only 6% of water resources on 2.5% of land area.

In recent years, the demand for waste water reuse has increased significantly worldwide. In particular, the arid and semi arid areas of the world can easily augment 15-20% of their water supply through reuse of waste water. The common and the most attractive form of waste water reuse is in the area of agriculture. Such water reuse accomplishes several purposes such as minimizing the cost of waste water treatment and disposal, providing much needed nutrients and fertilizers to the soil when used for agriculture and particularly alleviating the shortfall of water supply with a dependable continuous supply of waste water.

A number of industries produce large volumes of effluents requiring proper disposal. The quality of these wastes depends upon the nature of industry and type of treatments provided before released from industries. Lack of suitable treatment technologies and disposal facilities is a major hindrance to industrial expansion. The recycling options of industrial effluents includes land applications, use in irrigation, forestry, application to constructed wetlands or artificial marshlands. Sometimes, industries produce highly toxic effluents, which can neither be thrown into water bodies nor used for agricultural purpose as the toxic elements may enter the food chain through plants, animals and fish. However, effluents of some industries have useful characteristics and have the potential to improve soil productivity (Kansal, 1994). This effective management of wastes brings economic benefits and protects fragile ecosystems from degradation.

These effluents have varying chemical characteristics and metal contents, which may be harmful for soil environment. The industrial effluents which are non-toxic and when treated with suitable technology are useful as a good nutrient system. Land treatment should not be confused with the indiscriminate dumping of waste on land or landfills. Land treatment is the managed treatment and ultimate stabilization process that involves controlled application of a waste to a soil-vegetative system. It relies on the dynamic physical, chemical and biological processes occurring in soil, as a result of which the applied wastes are degraded, transformed or immobilized.

The Ballarpur Industrial Packaging Company Limited (Bilt-IPCL) is located at the foothills of Western Ghats at Thekkampatti village, Mettupalayam Taluk, Coimbatore District, a pioneer industry in perfecting the technology of making fine quality duplex paper and board from waste papers. The production capacity of the factory is around 300 tonnes of duplex board per day and it consumes around 2500-3000 m^3 of water and discharges around 2100 - 2600 m^3 of waste water per day. The waste water is properly treated in modernized effluent treatment plant and is being completely utilized for irrigation, in about 80 ha of virgin land owned by the factory.

Apart from liquid wastes, that are discharged into the land and rivers, a huge amount of solid wastes such as fly ash and sludge are being dumped by industries leading to accumulation of heavy metals. Total quantity of various types of solid wastes generated from Bilt-IPCL factory is about 300 tonnes per day. These wastes are reported to promote the crop growth if added below toxic level (Prasanthrajan, 2001).

Land application of industrial effluent and sludge for the crop production is an effective method of waste disposal wherein the valuable nutrients are recycled back into the ecosystem.

While reviewing the past work carried out in managing the liquid and solid wastes of paper and paper board mills, studies made so for on combined use of paper mill effluent either with soil amendments or paper mill solid wastes for growth of field crops are limited. Also studies on the effect of natural organic manures like cattle manures and green manure alleviating the harmful effects of treated paper board mill effluent as a source of irrigation are very meager. To make further evaluations on these aspects, this present investigation has been undertaken with the following objectives.

Objectives:

1. Characterization of Bilt-IPCL effluent for its physical and biochemical properties.
2. Monitoring the soil and ground water qualities in and around the premises of the factory
3. Assessment of the impact of different concentrations of raw and treated effluents on the growth characters of certain field and vegetable crops.
4. Assessing the usefulness of the treated effluent and solid wastes for raising forest nursery and field crops viz., maize and sunflower.
5. Evaluating the interaction between the various factors viz., effluent-soil - microbes-plants in agricultural fields irrigated with treated effluent

CHAPTER II

REVIEW OF LITERATURE

The literature on various aspects related to the present study is reviewed here in different topics, as it is indispensable to have a comprehensive knowledge about the subject.

i. Characteristics of effluent from paper and board mill.
ii. Effect of effluent irrigation on soil quality.
iii. Effect of effluent irrigation on soil microbial properties.
iv. Impact of effluent irrigation on ground water quality.
v. Effect of effluent irrigation on growth, yield and quality of plant produce.
vi. Characteristics of solid wastes.
vii. Effect of solid wastes on soil quality.
viii. Effect of solid wastes on growth, yield and quality of plant produce.
ix. Combined use of effluent with solid wastes, and their effects on soil, plant and microbial activities.
x. Movement of nutrient elements in soil.

In India there are about 371 paper mills with an installed capacity of 37.14 lakh tonnes (Gupta, 1995). The waste water generated per tonne of paper produced was in the range of 214-350 m^3 (Trivedi and Gurdeep, 1992).

In paper mills, the advanced treatment processes follow a conventional primary treatment, *i.e.* sedimentation or flotation assisted by addition of coagulation agents. Usually the effluent after mechanical primary treatment has low concentrations of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) but not always having quality sufficient for discharge into surface water (Mobius and Tolle, 1994).

Improved external treatment of waste water has become necessary for paper mills in view of stringent regulations governing the protection of receiving waters (German Federal Government, 1992). Until about a decade ago effluent treatment in the pulp and paper industry was done via mechanical methods or with conventional aerobic systems like aerated lagoons and activated sludge plants (Driessen and Wasenius, 1994).

Anaerobic treatment must be a pretreatment process since BOD and COD efficiencies are often not enough to meet stringent limits for discharge into surface bodies. Anaerobic treatment alone is not a substitute for aerobic treatment. Aerobic post - treatment is necessary to remove the residual organic pollution in the discharged effluent. The combination of anaerobic and aerobic treatments, however, can be an attractive alternative for waste water purification. (Drissen and Habets, 1992). The sources of waste water in the pulp and paper manufacturing process (Sierra-Alvarez, 1990) are as shown below:

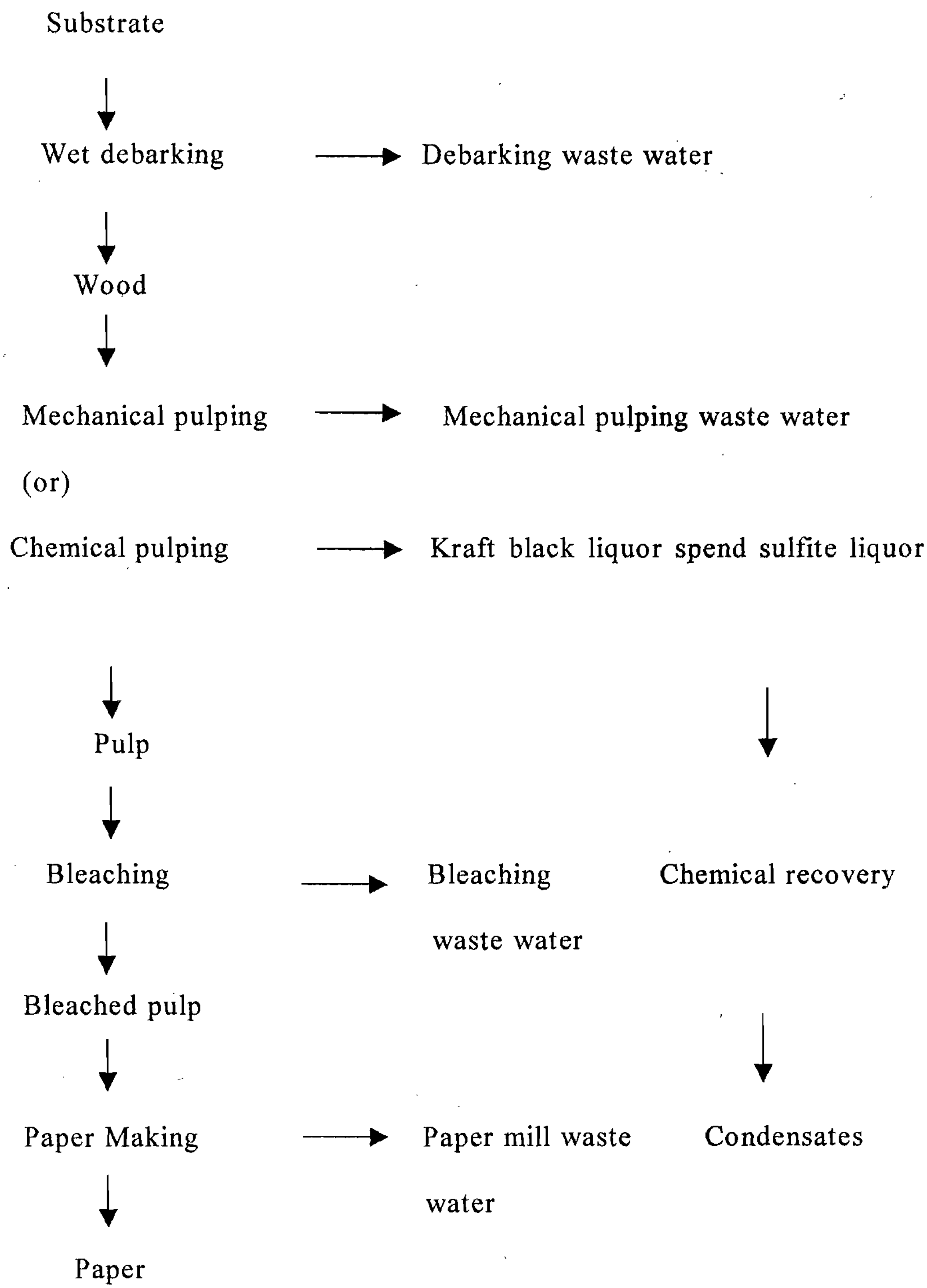


Fig.1.The sources of waste water in the pulp and paper manufacturing process

2.1. Characteristics of effluent from paper and board mill

2.1.1. Physico-chemical properties

In paper mill, water usage worked out to 400 m^3 per tonne of paper produced and the amount of waste water let out was about 330 m^3 per tonne of paper produced per day (Sastry *et al.*, 1977). The estimated total annual world capacity of pulp production in 1992 was around 261 million tonnes and that of paper and paper board production was 196 million tonnes (FAO, 1988). Nearly 75 to 95 per cent of fresh water used in the paper and pulp mill was discharged as effluent containing organic and inorganic pollutants and colouring materials.

The colour of the raw pulp and paper mill effluent was normally dark brown (Hameed, 1997; Alfred, 1998; Srinivasachari *et al.*, 1999). Colour of the waste water was due to the presence of lignin and lignin derivatives, which were not easily biodegradable and hence account for high BOD to COD ratio (Sharma and Bandhyopadhyay, 1991). The colour due to lignin compound persists in water body for longer distances (Subrahmanyam *et al.*, 1984).

The presence of colouring matter in the pulp mill waste water had a very serious impact on the aesthetic value of the consumer (Upathyaya and Singh, 1991). The presence of colouring matter varies depending upon the raw material used and mainly attributed to lignin degradation products formed during pulping and bleaching operations (Ramanathan and Parabrahmam, 1982; Subrahmanyam *et al.*, 1984; Sharma and Bandhyopadhyay, 1991; Mittar *et al.*, 1992). The brown colour in debarking water was due to oxidation products of tanning agents (Niemelae and Vaeaetaenen, 1982). Nearly 80 to 90 per cent of colour originates from bleaching (Virkola and Honkanen, 1985). Another principal problem associated with colour was foaming which was induced by surface-active nature of some of the organic materials extracted from the raw material (Holderby and Maggio, 1960).

The disagreeable phenolic odour of the effluent might be due to the presence of hydrogen sulphide, which was evident from the higher sulphate content of the effluent sample (Srinivasachari *et al.*, 1999).

The suspended and dissolved solids content in raw paper factory effluent were 3010 mg L^{-1} and 1765 mg L^{-1} respectively (Palaniswami and SreeRamulu, 1994). The dissolved and suspended solid content in the paper machine waste water were 840.0 and 568.5 mg L^{-1} (Verma *et al.*, 1974). Dissolved solids in treated pulp and paper mill effluent from Tamil Nadu Newsprint and Papers Limited (TNPL) ranged from 650 to 787 mg L^{-1} and suspended solids ranged from 102 to 104 mg L^{-1} (Alfred, 1998). The effluent from the paper mill contain rich organic carbon (Rajannan and Oblisami, 1979) due to the presence of varying quantities of suspended and dissolved organics in the effluent. The organic carbon content ranged from 0.82 to 0.87 per cent (Srinivasachari *et al.*, 1998).

Wilber and Thomas (1969) reported that after discharging from pulp and paper mills, the concentration of oxygen dissolved in the water falls to a low level as a result of breakdown of various organic materials. Rajannan and Oblisami (1979) reported that no dissolved oxygen was present in the combined effluent from paper and pulp industry. Presence of reduced levels of dissolved oxygen in the combined effluent was reported by Verma *et al.* (1974) and Somashekar *et al.* (1984).

Pollutants that generally arise from the industry include wood sugars, cellulose fibre, lignin and other spent chemicals, which impart BOD, COD, colour etc. Effluent streams in the industry are categorized as black liquor, white liquor, machine waste water and sanitary wastes (Sharma and Bandhyopadhyay, 1991).

The undiluted effluent of the paper mill had slightly alkaline pH, high BOD, COD and EC with appreciable quantities of Cl^-, SO_4^{2-} and HCO_3^- of Ca, Mg and Na and varying amounts of micronutrients (Srinivasachari *et al.*, 1999).

The BOD and COD of the treated paper mill effluent (TNPL) were around 5.2-10.0 mg L^{-1} and 420 mg L^{-1} respectively (Hameed, 1997; Malathi, 2001). The dissolved oxygen content ranged from 0.87 to 12.1 mg L^{-1} . The treated paper factory effluent had N and P content of 34.6 and 1.23 ppm respectively (Udayasoorian *et al.*, 1999a). The water stream receiving waste water from paper and pulp industry had an increase in salinity, low in sodium hazard with absence of Residual Sodium Carbonate (RSC). (Narashimha Rao and Narashimha Rao, 1992).

The BOD from small paper mill was about 400 to 2000 mg L^{-1} (Sastry *et al.*, 1977). Brown stock showed a BOD and COD of 310 and 1440 mg L^{-1} respectively (Dave, 1982). The BOD and COD in paper machine waste water were 153 and 393 mg L^{-1} respectively for the volume of 216 m^3 waste water. Verma *et al.* (1988) reported that the paper mill effluent had BOD of 28.6 ± 1.4 and COD of 310 ± 2.3 mg L^{-1}.

The combined waste water from a paper and pulp mill had pH values ranging from 7.0 to 9.4 (Paliwal and Mehta, 1970; Sastry *et al.*, 1974; Saxena *et al.*, 1979). Dave (1982) reported that pulp mill brown stock had a pH of 8.6. The paper mill effluent was having a pH of 8.1 ± 2.1 (Verma *et al.*, 1988). The pH of the treated TNPL effluent was ranged between 7.5-8.3 and EC ranged between 1.28-1.36 dS m^{-1} (Hameed, 1997).

The combined waste water had BOD: Nitrogen: Phosphorus in the proportion of 100:2:0.7 which indicate that the waste water was deficient in nitrogen and phosphorus for aerobic treatment (Saxena *et al.*, 1979). Fifty per cent of the particulate phosphorus in both kraft and paper mill effluent was potentially available for algae (Priha, 1994). Oblisami and Palanisami (1991) concluded that the combined effluent from all the sampling points were low in nutrient content, with considerable amounts of chloride, sulphate and polyphenols. The higher concentration of calcium, magnesium, sodium, chloride, sulphate and bicarbonate were reported by a number of workers (Rajannan and Oblisami, 1979; Reddy *et al.*, 1981; Gomathi and Oblisami, 1992).

Effluent samples had appreciable quantities of Cl^-, SO_4^{2-} and HCO_3^- of Ca^{2+}, Mg^{2+} and Na and varying amounts of micronutrients (Gomathi and Oblisami, 1992; Dhevagi, 1996; Alfred, 1998; Srinivasachari *et al.*, 1999; Udayasoorian *et al.*, 1999c). The pulp mill waste water had high concentration of soluble sodium (21.5 cmol L^{-1}) as compared to calcium (2.4 cmol L^{-1}). Alkalinity due to CO_3^{2-} and HCO_3^- ions were 5.8 coml. L^{-1} and 10.2 coml. L^{-1} respectively (Jaywalker and Subrahmanyam, 1987). The chloride content of the treated effluent varied from 207.4 to 358.1 mg L^{-1} and it was well within the limit (600 mg L^{-1}) of the State Pollution Control Board (Udayasoorian *et al.*, 1999a).

The treated paper mill effluent contained variable amounts of micronutrients like Fe, Cu and toxic metals. (Somashekar *et al.*, 1984; Srinivasachari *et al.*, 2000). Manikya Reddy and Venkateswaralu (1985) concluded that the concentration of heavy metals in the effluent was in the order of Zn>Cu>Pb>Ni>Co>Mn. The concentration of heavy metals like Fe, Mn and Zn were less than 1.0 ppm as reported by Udayasoorian and Jothimani (1998).

Many waste waters from the forest-based industry contain toxic substances. An important fraction of toxicity was derived from organic compound like wood resin (Walden *et al.*, 1986); tannins (Walden *et al.*, 1986; Temmink *et al.*, 1989) and chlorophenol (Walden *et al.*, 1986). The predominant toxicants were resin acids and isopimaric substances which together account for 60 to 90 per cent of the overall toxicity study (Leach and Thakare, 1976).

Waste water from bleaching process contained chlorinated non bleach products, hemicellulose, monosaccharides, resins and other substances extracted from the fibre (Bharathi and Krishnamoorthy, 1988). According to Norup (1972) considerable amounts of toxic substances were discharged from paper and pulp industry and among that pentachlorophenol was very common. Waste water from the forest-based industry contains toxic substances. The effluent contained methyl mercaptan, pentachlorophenol and pentachlorophenate, which were highly toxic (Udayasoorian and Jothimani, 1998).

2.1.2. Biological properties

Knowles *et al.* (1974) isolated nitrogen fixing Azotobacter and Klebsiella from paper mill effluent. Of 129 isolates of Klebsiella from pulp mill waste water, 32 per cent had nitrogen fixing ability and it was increased by the addition of 0.5 to 3.0 per cent glucose. Chuang (1985) reported the presence of nitrogen fixing bacteria, Azotobacter and studied the effects of nutrients on waste water treatment.

The combined effluent from paper and pulp industry had considerable population of bacteria, actinomycetes, fungi, Azotobacter and yeast (Kannan and Oblisami, 1990). Oblisami and Palanisami (1991) reported that the microbial load of the effluent was higher for bacteria and considerable number of the actinomycetes, fungi, Azotobacter and yeasts were present. The number of yeasts in the effluent disposed reached 10 lakh cells per litre and *Rhodotorula* spp. was commonly isolated. Most of the ascoporogenous yeasts found were *Hansenula oxpichia* (Spencer *et al.*, 1974).

Datta Roy and Malty (1984) recorded significant numbers of *Salmonella* present in the paper mill effluent, which was discharged into the Hoogly River. Nielson and Allard (1985) recorded reduction of Enterobacteiaceae population in the paper mill process water.

Despite the unfavourable nature of waste water from paper mill on the growth and multiplication of algae, 26 species belonging to 14 genera were recorded. Blue green algae was abundant followed by diatoms (Verma *et al.*, 1988).

soils irrigated with mechanically treated waste water, which got purified by microbial degradation. There was no appreciable decrease in the rate of infiltration in soil treated with effluent. It could be attributed to the very coarse texture of soil along with the presence of non-expanding type of clay mineral and the retention of lignin from the waste water, precipitated as calcium lignate - a structure stabilising compound, which played an important role in the formation of stable aggregates (Subrahmanyam *et al.*, 1984). The retention of moisture necessary for growing sugarcane in sandy soil under effluent irrigation was attributed to the constant humification and mineralisation of organic matter (Reddy *et al.*, 1981).

Increase in soil pH was observed when irrigated with undiluted paper factory effluent (Somasheker *et al.*, 1984; Juwarkar and Subrahmanyam, 1987; Kannan and Oblisami, 1989; Oblisami and Palanisami, 1991). Hence the combined effluent might be of great use in reclaiming the acidic soils (Ghose, 1966; Rajannan and Oblisami, 1979).

Different organic amendments with effluent irrigation to tomato decreased the bulk density of the soil, slightly increased the pH and organic carbon content. (Sandana, 1995).

The electrical conductivity (EC) of the soils also showed an increase due to continuous irrigation with effluent (Kannan and Oblisami, 1990). Subrahmanyam *et al.* (1984) conducted studies with anaerobically treated pulp mill waste water from a 250 TPD paper mill in Maharashtra and reported that the effluent had an EC of 2225 to 2600 micromhos per cm which on irrigation increased the soil EC due to the greater accumulation of salts. Continuous irrigation with treated pulp and paper mill effluent resulted in increased soluble salts in sandy loam soil (Udayasoorian *et al.*, 1999b).

Increase in soil organic matter content was observed due to effluent irrigation from paper factory (Juwarkar and Subrahmanyam., 1987; Kannan and Oblisami, 1990).

Extensive documentation supported the presence of bacteria belonging to the family Enterobacteriaceae in effluent from the paper manufacturing industry (Huntley *et al.*, 1976; Nielson and Sparell, 1976; Caplenas *et al.*, 1981). Rivers receiving paper and pulp industry effluent had members of Bacillariphyceae and members of *Oscillatoria, Arthrospira* and *Spirulina* (Bharathi and Krishnamoorthy, 1988). Paper mill effluent can be used for bioproduction of nitrogen fixing blue green algae - *Scytonema schmidlei, Anabaena cylindrica, Clotheix marchica, Gloeatrichia echinulata* and high protein containing *Spirulina platensis* (Patnaik *et al.*, 1995). In paper factory effluent, a low population of actinomycetes, fungi and appreciable number of bacteria were observed (Srinivasachari *et al.*, 1999).

2.2 Effects of effluent on soil quality

In the paper industry, the treatment of waste water generated during paper production produces several kinds of residues, which constitute a disposal problem. However, most of the paper factories have attempted to dispose off the lignin rich coloured effluent through waterways and on lands. Land application of waste water is preferred as an alternative for its disposal since soil is believed to have a capacity for receiving and decomposing the wastes and pollutants (Young *et al.*, 1981) where organic materials are stabilized through the activity of microbial flora in the soil. The removal of different constituents is accomplished by physical, chemical and microbial interaction with the soil matrix and a cover crop (or) plant uptake.

2.2.1 Effect of effluent on soil physico-chemical properties

There was no appreciable decrease in hydraulic properties when soils were irrigated with paper and pulp mill waste water for over three years (Palaniswami and Sree Ramulu, 1994). Hansbrix (1987) noticed stabilisation of hydraulic conductivity in wetland

Continuous irrigation with treated TNPL effluent increased organic matter content in garden land (Dhevagi,1996), paddy soils (Alfred, 1998 and Udayasoorian and Jothimani, 1998), grassland ecosystem (Ponnaiya,1990), forest ecosystem, (Hameed, 1997 ; Kannapiran, 1995).

Available nutrient status of the soil was increased due to effluent irrigation. The higher amount of available nitrogen, phosphorus, potassium, zinc and copper, organic carbon, calcium carbonate, cation exchange capacity (CEC), exchangeable cations, and exchangeable sodium per cent were found in soils irrigated with effluent for over three years (Palaniswami, 1989; Alfred *et al.,* 1998; Udayasoorian *et al.,* 1999c).

Pushpavalli (1990) reported that the sodium adsorption ratio (SAR) values in the effluent ranged from 5.52 to 8.99 meq L^{-1} and in the category of `good' as the values were below 10.0 meq $L^{-1}$. She also reported that the sodium percentage in the effluent ranged from 57.9 to 62.3, thus falling under the category `permissible limit' as reported by Eaton (1950).

The exchangeable Na content of soil was higher under effluent irrigation at all the stages in both the crops owing to the contribution from the irrigation sources which could be gauged from the higher sodium content of effluent as compared to the well water (Malathi, 2001).

Continuous irrigation with treated effluents had increased the soil pH, EC, OC, available NPK, ESP, exchangeable Ca, Mg, N and K. (Udayasoorian *et al.*, 1999a) and DTPA-extractable Fe, Mn, Zn and Cu (Srinivasachari *et al.*, 1999).

The DTPA extractable Zn, Cu, Fe and Mn largely accumulated in the upper 15 cm soil depth and the extent of their accumulation was increased with increased time of application (Srinivasachari *et al.*, 2000).

2.3. Effect of effluent on soil microbial properties

Higher population of bacteria, fungi and actinomycetes were recorded in paper (Anita *et al.*, 1997a) and paper board mill effluent irrigated soil (Prasanthrajan, 2001). The enrichment in the nutrient content of the soil due to the effluent irrigation also enhanced the microbial population (Somashekar *et al.*, 1984).

The increase in organic matter content of the soil due to effluent irrigation accelerated the microbial activity, which in turn accelerated the substrate decomposition with the release of carbondioxide. Effluent irrigation over a period of 15 years had maximum population of bacteria, actinomycetes, fungi, *Rhizobium, Azotobacter* and yeast (Kannan and Oblisami, 1990). Diluted effluent was found to increase the microbial population and fertility of soil (Chauhan and Kaur, 1991).

Application of pulp and paper mill effluent to sugarcane tended to increase soil enzymes activities like amylase, invertase, cellulase, dehydrogenase and phosphatase. (Anita *et al.*, 1997b; Udayasoorian *et al.*, 1999b). The activities of cellulase and invertase were greater under paper mill effluent irrigation in submerged soils than in garden land soils (Kannan and Oblisami, 1990). The enzyme urease activity was more near the effluent channel, and at 15 m away from the channel, and this was confirmed by higher organic matter content which might have increased the microbial activity in both the soils (Palaniswami and Sree Ramulu, 1994).

2.4. Effect of effluent on water quality

Reuse of waste water for irrigation is very common in these days due to various reasons. Recycling and reuse of waste water in agriculture is not only helpful for conserving the plant nutrients and water for irrigation but also offers a low cost technology for the disposal of waste water from the view point of environmental pollution abatement.

If the waste water from paper and pulp industry could successfully be used for irrigation, it is possible to prevent river water pollution also to augment already scarce irrigation water resources (Jivendra and Jain, 1982; Oblisami and Palanisami, 1991).

Eutrophication due to nutrient loading is still present in many recipients of pulp and paper industry. This is due to the addition of nutrients, phosphorus and nitrogen to reduce the BOD (Wartiovaara and Heinonen, 1991). Ronald (1977) reported that the growth rate of young rainbow troud exposed to a lignosulphonate concentration of greater than 160 mg L^{-1} was slower than that of control. Paper mill effluents may be useful only for hatching purpose of a major carp *Labeo rohita* at diluted concentrations (10% to 25%) but may pose danger for the survival values of hatching when maintained in the undiluted effluent (Patra *et al.*, 1990). Impact of pulp and paper mill effluents on the river Kallada in Kerala indicated the harmful effects of kraft pulp bleaching effluents on the fishes, copepods and other aquatic forms (Nampoothery *et al.*, 1976). In another study the 96 hr LD_{50} values of various constituents of pulp and paper mill effluents on the *Crustacea, Daphnia* and *Cyclops* were found to be 2 to 55 mg L^{-1} (MaCleay, 1979).

The groundwater within the effluent irrigated areas had less pH but high EC, total hardness, carbonates, bicarbonates, chlorides, sulphates, Na, Ca, Mg, K per cent Na, SAR and RSC than that of Cauvery river water. The EC and SAR values increased two to three times within four years continuous effluent irrigation (Udayasoorian *et al.*, 1999b).

2.5. Effect of effluent irrigation on the growth, yield and quality of plant produce

Effluent irrigation provides farmers with a nutrient enriched water supply and society with a reliable and inexpensive systems for waste water treatment and disposal

(Feigin *et al*., 1991). Waste water emanating from bagasse based pulp and paper industry had been successfully tried as a source of irrigation for sugarcane, cereals, millets, pulses, vegetable crops, plantation crops and tree species by several research workers (Kannapiran, 1995; Sandana, 1995; Dhevagi, 1996; Hameed, 1997; Alfred, 1998; Udayasoorian *et al*., 1999a; Malathi, 2001).

a. Effect of effluent on seed germination

The germination and vigour index (VI) of rice was significantly poor in undiluted paper mill effluent when compared to well water and it increased with the decrease in the concentration of the effluent (Sandana, 1995; Alfred, 1998; Dixit *et al*., (1986). Inhibition in germination of rice seeds with increasing concentrations of cardboard factory effluent was also observed by Dixit *et al.,* 1986.

Kannan and Oblisami (1992) observed that irrigation with combined raw effluent from paper and pulp mill reduced the germination and VI of groundnut, sunflower, cowpea and horse gram. The paper factory effluent reduced the germination, root length and shoot length of *Phaseolus aureus*. Paper mill effluent diluted with well water at the ratio of 1:3 did not affect the germination and VI of groundnut, ragi, cowpea and cotton while irrigation with combined raw effluent from paper and pulp mill reduced the germination and VI of maize, wheat, and ragi (Oblisami and Palanisamy, 1991).

Better germination per cent, shoot length, root length and VI of seedlings at 75, 50 and 25 per cent of treated effluent were observed in maize, blackgram, greengram and soybean (Dhevagi, 1996; Udayasoorian *et al.*1999a). The treated paper mill effluent significantly increased the germination percentage, root length, shoot length and VI of bhendi, brinjal, chilli, tomato, amaranthus, bittergourd, beetroot and moringa.

However the raw effluent decreased the germination and VI of the above vegetable crops as the concentration of effluent increased (Malathi, 2001).

Misra and Behera (1991) showed that the percentage of germination, water imbibing capacity, growth, pigment, carbohydrates and protein content showed a decreasing trend with an increase in effluent concentration and time.

Use of sulphite mill waste water had no adverse effect on germination of sunflower seeds (Spulnik, 1949). However, significant reduction in germination and root and shoot length of sunflower at higher concentration of effluent was recorded by Doraisamy (1978).

b. Forest Nursery

Gomathi and Oblisami (1992) used pulp mill waste for irrigation by mixing with water for germination of tree seeds *viz.*, neem, pungam and tamarind and found that there was no inhibitory effect at lower concentration of effluent. Kannapiran (1995) and Udayasoorian *et al.* (1999a) observed better seed germination at higher concentration of effluent (75 and 100%) for *Acacia leucophloea, Albizia lebbeck* and *Leuceana leucocephala*, whereas in *Cassia hybrida* seed germination was affected with increased effluent concentration.

Hansen *et al.* (1980) suggested that kraft mill waste water could be safely used for poplar plantation. Neelay and Dhondizal (1985) reported that the effluent from pulp and paper mill was used for irrigating *Eucalyptus camadulensis*, *Pungamia pinnata, Acacia auriculiformis, Leucaena leucocephala* and *Dendrocalanus strictus*. The treated pulp and paper mill effluent did not cause any adverse effect on *Eucalyptus tereticornis* growth (Hameed and Udayasoorian, 1997).

c. Field crops

Waste water emanating from pulp and paper industry has been tried as a source of irrigation for cereals, millets, oil seeds, pulses, vegetable crops, fodder grasses, and plantation crops by several workers (Dhevagi, 1996; Alfred, 1998; Udayasoorian and Jothimani., 1998; Malathi, 2001).

In rice, the grain yield was increased due to effluent irrigation by 25 per cent than that of well water irrigation. Effluent tends to decrease the calcium uptake of rice in neutral soil and increased the Na uptake in acid soil. The soil amendments had a favorable effect on the P and K uptake of rice in acid soil. The use of 50 per cent diluted classified effluent was found superior to raw effluent irrigation more particularly in neutral soil (Velu *et al.*, 1998). Under effluent irrigation, rice varieties TRY-1, CO-43 and IR -20 performed better than white ponni. The grain yield increase was around 20 to 25 per cent under treated paper mill effluent irrigation than that of well water irrigation (Alfred *et al.*, 1998).

The kraft mill waste water could be safely used to grow crops like paddy, wheat, maize and barley on coarse textured soils (Khambatta and Ketkar, 1977; Prasad *et al.*, 1977; Subrahmanyam *et al.*, 1984). Somashekar *et al.* (1984) reported that the diluted effluent showed favourable effect on seedling growth of maize, cotton and paddy. Narashimha Rao and Narashimha Rao (1992) reported that the effluent from paper factory could be safely used for irrigating rice and cotton on alluvial soil having loamy to sandy loam texture. Positive effect on growth parameter of sorghum, maize and sunflower due to paper mill effluent irrigation was observed by Dhevagi (1996).

Fodder grasses like bermuda, sudan and hay could safely be grown on coarse textured soils using paper factory effluent (Nesteron *et al.*, 1968; Yakusherko *et al.*, 1971). Ponniah (1990) observed that cumbu napier hybrid and buffalo grass were found to be tolerant to pulp and paper mill effluent and the fodder yield increased 35 to 50 per cent under continuous paper mill effluent than well water irrigation. Irrigation of paper mill effluent had shown encouraging results on the growth of oats and orchard grass (Hashimoto and Yokoto, 1965).

The use of paper factory effluent for irrigating sugarcane was reported by several workers (Pushpavalli, 1990; Oblisami and Palanisami, 1991; Anita, 1997a).

The yield of sugarcane was more in effluent irrigated fields to the tune of about 5.13, 3.53, 3.27 and 2 per cent over the well water irrigated crop for the varieties CoC 92061, CoC 671, CoC 6304 and CoC 91061 respectively. A positive effect was observed with pressmud, daincha and farm boon applied soils (Udayasoorian *et al.*, 1999b).

An increase in jaggery yield was observed when sugarcane was grown with pulp and paper waste water (Subrahmanyam *et al.*, 1984). Gopalakrishnan *et al.* (1999) concluded that the yield of paper mill irrigated sugarcane was higher by about 10 per cent when compared to those irrigated with the fresh water (100 to 125 t ha^{-1}).

Nesteron *et al.* (1968) and Yakusherko *et al.* (1971) revealed that pulp and paper mill waste water could be used to irrigate vegetables like beans, cabbage, carrot, tomato, squash, cucumber and melons and fodder grasses like Bermuda, Sudan and Hay on coarse texture soils.

Number of fruiting clusters, fruit weight and fruit yield were also increased due to the application of amendments such as bioearth pressmud and farmyard manure along with the effluent irrigation. (Sandana, 1995).

The quality of amaranthus greens and bhendi fruits was not affected by irrigating the crop with treated effluent and by the incorporation of various amendments (Malathi, 2001). The application of composted paperboard mill solid wastes and effluent irrigation positively influenced the pod yield as well as pod formation of cowpea (Prasanthrajan, 2001).

2.6. Characteristics of solid wastes

Land application of solid wastes provides an effective and environmentally acceptable option of waste disposal, which also recycles valuable nutrients into the soil plant system (Chatterjee and Bhargava, 1982). Applying paper mill sludges to agricultural land as a soil amendment or as a source of lime may be a more desirable alternative to land fill (Gabriels, 1998; Ritter *et al.*, 1992). Due to high content of organic matter (Cellulose) in paper sludges, composting and land application have become attractive alternatives method of disposal (Udayasoorian *et al.*, 1999b).

a. Nutrient content of solid wastes

Sludge contains considerable amount of macro and micronutrients and it can be substituted with commercial mineral fertilizer (Johnson *et al.*, 1987). Primary sludge consisted of organic matter mainly in the form of cellulosic paper or wood fibre and had low N contents *i.e.* 0.1 to 0.25 per cent on dry weight basis (Bellamy *et al.*, 1995). Several studies had shown that applying paper mill sludge with a high C:N ratio to agricultural land will initially cause a net immobilisation of nitrogen (Watson and Hoitink, 1984 ; Honeycutt *et al.*, 1988).

Sandana (1995) reported that raw bagasse pith contains the lowest nutrient of N, P, K, Ca and Mg viz., 0.1[illegible], 0.69, 0.98, 0.95 and 0.28 per cent respectively, and low level of micronutrients and high carbon to nitrogen ratio. The bagasse based pulp and paper mill (TNPL) sludge contains 0.95 per cent N, 1.7 per cent P, 0.42 per cent K, 1.60 per cent Ca and 3.10 per cent Mg and very narrow range (20.5) of carbon to nitrogen ratio (Dhevagi, 1996). Fly ash was found to be poor in available N and P but, with sufficient amount of

Ca, Mg and K (Kannapiran, 1995). The performance of P and K in fly ash and the fineness of the material made its addition to acid soil to benefit crop growth by increasing the availability of nutrients.

Due to high content of organic matter in paper mill sludges, composting and land application are attractive alternatives for disposal. Comparative analysis of biocompost from bagasse pith showed a marked reduction in OC content invariably in all treatments ranging from 14 per cent in activated sludge alone to 26 per cent in treatment bagasse pith + activated sludge + ETP sludge at 2:1:1 ratio combinations. Significant reduction in C/N ratio was observed invariably in all the treatments at the end of composting period (Mini *et al.*, 1999).

Mixing bagasse pith with activated sludge and effluent treatment plant (ETP) sludge in the ratio of 2:1:1 produced a better quality compost. Among the amendments, ETP sludge had comparatively higher plant nutrients than FYM while fly ash and bagasse pith were low in nutrient. The TNPL lime sludge had higher concentration of Ca and Mg recording 8.6 and 11.0 per cent respectively but essential nutrient status was very low in lime sludge (Hameed, 1997).

b. Toxic constituents of solid wastes

The heavy metals in the soil were subjected to various chemical and physical interactions with soil organic matter, hydrous oxides of iron and manganese and soil reactions. Redox potential and aeration were some of the factors deciding the fate of metals in the soil. To mitigate the toxic effects, these sludges could be precomposted in an appropriate manner with elite microbial inoculants and the final product could be used as manure.

Concentration of heavy metals like lead, zinc, chromium, nickel and selenium was higher than cadmium in sewage sludge (Srikanth *et al.*, 1992). Bhoyar *et al.* (1992)

observed that solid waste might affect the soil properties especially when it contained higher concentration of metals and toxic constituents. Boron in fly ash was readily available to plants as reported by Townsend and Gillham (1975). Boron, considered being a major limiting factor for successful cropland utilization of ashes.

2.7. Effect of solid wastes on soil quality

2.7.1. Physical properties

Solid wastes had a favourable effect on soil physical conditions and tilth due to their high organic matter content. Physical characters of soil can best be maintained using small yearly application or a single large application of sludge (Wei *et al.*, 1985). Bhoyar *et al.* (1992) reported that waste amendments should be applied at low level. At high level of application, soil properties are likely to be impaired due to the presence of high concentration of metals and toxic constituents. Improvement in soil structure and water holding capacity due to sludge application was reported by Zhang *et al.* (1993). Soil amended with sewage sludge usually showed a reduction in bulk density, an increase in water retention and hydraulic conductivity (Kladivko and Nelson, 1979).

The bulk density and particle density of soil decreased with increasing levels of fly ash application. The maximum reduction was seen when fly ash applied with composted coir pith (Ramasubramoniam and Chandrasekar, 2001).

The maximum water holding capacity of the soil increased significantly when fly ash was applied at the rate of 10 Mg ha^{-1}. This may be due to increase in organic matter content. The porosity and hydraulic conductivity were increased, while the bulk density decreased due to fly ash application (Sahoo and Kar, 1998). Kumar *et al.* (2000b) reported that fly ash amendment to a variety of agricultural soils tend to decrease the bulk density. It also improves the water holding capacity of the soil.

Application of paper mill sludge to mine spoiled areas increased the soil aggregations which inturn enhanced the stability, water retention and served as a nutrient reservoir (Feagly *et al.*, 1994). Improved soil structure and total porosity due to paper mill sludge application was observed by Sun and Lie (1992).

The addition of appropriate quantities of fly ash can alter the soil texture. Fly ash addition @ 70 t/ha has been reported to alter the texture of sandy and clayey soil to loamy (Fail and Wochock, 1977).

2.7.2. Chemical properties

Application of pulp mill sludge to soil resulted in a significant increase in soil pH and organic matter content (Vasconcelos and Cabrel, 1993). Among the amendments, TNPL sludge added treatments recorded higher pH values (8.31 to 8.52) followed by pressmud and fortified press mud. The carbohydrate, protein and oil contents were increased slightly in solid wastes received plots (Dhevagi, 1996).

The response of fly ash along with amendments *viz.* lime, composted coirpith increased the soil pH, EC and CEC values and organic carbon content. Addition of fly ash improved the N, P, K, Ca and Mg content of the lateritic soil (Ramasubramoniam *et al.*, 2001).

Increase in the available P in the soil due to sewage sludge treatment was reported by Mine and Graveland (1972). Available phosphorus concentration and pH were increased in the 0 to 15 cm layer of agricultural land due to sewage sludge treatments (King *et al.*, 1974).

The ETP sludge had comparatively higher available NPK content than FYM while fly ash and lime sludge were inferior to the above. (Hameed, 1997). Fly ash, which is alkaline in reaction, increases the soil pH besides it adds essential plant nutrients to the soil (Kumar *et al.*, 2000b).

2.7.3. Biological properties:

Sludge amendments quickly increased the number and activity of microorganisms, resulting in the increased availability of plant nutrients and development of a soil environment, which is condusive for continued plant growth (Sopper and Seakar, 1987). Application of decomposed paper mill waste at the rate of 10 to 20 t ha^{-1} improved the biological activity (Ilyaltdinov *et al.*, 1990). Pichtel and Hayes (1990) reported that the combined application of fly ash with sewage sludge increased the microbial numbers but the bacterial, actinomycetes and algal counts on the soil typically decreased with increase in ash content. Kannapiran (1995) observed that soil amendment with fly ash appears to result in decreased microbial activity and numbers.

2.8. Effect of solid wastes on the growth, yield and quality of plant produce

2.8.1. Forest crops

A significant improvement in growth of forest trees like *Acacia auriculiformis, Eucalyptus teriticornis, Casuarina equisetifolia* and *Acacia mangium* was observed at a fly ash concentration of 18-24 per cent (Kumar *et al.*, 2000b). Horton and McMinn (1977) reported that several tree species established on ash basin exhibited some growth abnormalities such as reduced vigour, chlorosis, necrosis, purpling etc.

The basal diameter and dry matter production of *Eucalyptus tereticornis, Acacia nilotica* and *Casuarina equisetifolia* decreased with increased rate of fly ash application (Kannapiran *et al.*, 1997). Better shoot length, root length, collar diameter and dry matter production, were observed under FYM and ETP sludge whereas seedlings completely withered in case of *Acacia nilotica* and *Casuarina equisetifolia* due to lime sludge application (Hameed, 1997). Growth parameters of *Eucalyptus* *tereticornis* were marginally affected in paper mill sludges *viz.*, fly ash, bagasse pith and lime sludge (Hameed and Udayasoorian, 1997).

2.8.2. Field crops

In the paper industry, the treatment of waste water generated during paper production produced several kinds of residues, which constitute a disposal problem. Most of the paper factories have attempted to dispose off the lignin rich coloured effluent through water ways on lands. Land application of waste water was preferred as an alternative for its disposal since soil was believed to have the capacity for decomposing the wastes and pollutants where organic materials were stabilized by the activities of soil microbes (Young *et al.*,1981).The removal of different constituents was accomplished by physical, chemical and microbial interaction with the soil matrix and a cover crop or plant uptake.

Pressmud and ETP sludge were identified as effective ameliorants for paddy crop (Alfred *et al.*, 1998). Bagasse pith and activated sludge @ 1:1 ratio with 100 per cent NPK increased the growth parameter of groundnut and performed better than FYM with 100 per cent NPK (Udayasoorian *et al.*, 1999b). Pressmud applied @ 5 t/ha increased the nodulation of soybean. Enriched pressmud @ 10 t/ha increased the number of millable canes in sugarcane (Rakkiappan *et al.*, 1999).

Sunflower was increased by about 25 per cent in red soil under rainfed as well as irrigated conditions when fly ash was applied @ 60 t/ha along with 20 t/ha FYM. The yield of maize also increased by about 35 per cent when fly ash was applied @ 30 t/ha along with FYM @ 20 t/ha at Raichur. Similarly paddy, wheat and groundnut yields also increased due to addition of fly ash. (Kumar *et al.*, 2000a).

The fly ash @ 10 t/ha along with paper factory sludge @ 15 t/ha and chemical fertilizer (CF) applied to rice and only CF to potato increased grain yield of rice and tuber yield of potato respectively over CF applied to both crops in rice-potato cropping sequence at Kharagpur. Tomato, brinjal, potato, pea and cabbage recorded more yield around 30 – 50 per cent when fly ash was applied at the rate of 25 per cent to the soil (Kumar *et al.*, 2000a).

Higher paper mill sludge application (10% by weight of soil) diminished the growth of oats (Dolar *et al.*, 1972; Aitken *et al.*, 1998). A drastic reduction in growth of soybean was observed when fly ash was applied at higher levels (>16% fly ash).

Soil fertility and crop growth had been improved with the use of paper mill sludge as an organic amendment. The paper mill sludge could be used to add organic carbon to mine soils and obtains efficient growth of *Cyanodon dactylon* (Feagley *et al.*, 1994). Fodder grasses like cumbu napier hybrid. guinea grass and buffalo grass performed better with pressmud followed by FYM, farm boon, TNPL sludge and control (Ponniah and Ramasamy, 1999). Ritter *et al.* (1992) reported that mixtures containing equal parts of sludge, fly ash and soil gave better results on plant height of oats, red fescue and white clover. Brady and Feagley (1992) reported that the treatments receiving paper mill sludge plus twice the amount of recommended rate of fertilizer produced the highest yield of Bermuda grass (*Cyanodon dactylon*) on mine spoiled land.

The quality of amaranthus greens and bhendi fruits were not affected by irrigating the crop with treated effluent and by the incorporation of various amendments. The quality parameters like protein, carbohydrate, vitamin C, phosphorus and calcium were improved due to the effluent irrigation and amendments addition (Malathi, 2001).

2.9. Combined use of effluents and solid wastes and their effects on soil, plant and microbial activities.

Combined use of industrial effluents along with amendments might provide a soil with enough nutrients and with better physical and microbiological environment, thus improving the soil fertility.

2.9.1. Soil quality.

2.9.1.1. Physico-chemical properties

Soil pH and organic matter content were increased following the addition of paper mill sludge (Vasconcelos and Cabrel, 1993; Palaniswami and Sree Ramulu, 1994). On the contrary a slight reduction in pH due to pressmud addition was reported by Raja and Raj (1981). The soil pH was maximum under lime sludge application followed by fly ash, bagasse pith and ETP sludge whereas soil EC was much higher under lime sludge amended soils (Hameed, 1997). Several studies had shown that applying paper mill sludge with a high C:N ratio will initially cause a net immobilization of nitrogen (Honeycutt *et al.*, 1988).

Sandana (1995) showed that different organic amendments along with effluent irrigation to tomato revealed considerable decrease in bulk density of the soil, slight increase in pH, EC and organic carbon content.

Continuous use of paper mill sludge over a period of 15 years to sandy soil increased soil EC, exchangeable Na, Ca, Mg and K, available P, K, Fe, Mn, Zn and Cu and activity of urease and phosphatase enzymes (Palaniswami and Sree Ramulu, 1994). Rodella *et al.* (1995) reported that paper mill sludge resulted in the increase in soil Cation Exchange Capacity. Available Phosphorus and organic carbon content of soil were increased due to the application of press mud.The improvement in the available P status of the soil by the addition of fly ash was reported by Kunchanwar *et al.* (1994) and Sahoo and Kar (1998).

Continuous use of paper mill waste water for one year resulted in the accumulation of DTPA extractable Zn, Cu, Fe and Mn in soil to levels that may cause imbalances of nutrients in the soil (Srinivasachari *et al.*, 2000)

2.9.1.2. Microbiological properties

The CO_2 evolution, which is an index of the biological activity of the soil, was higher in pressmud treated soils (Raja and Raj, 1981). Sludge amendments quickly increased the number and activity of microorganisms resulting in the increased availability of plant nutrients and development of soil environment, which was conducive for plant growth (Sopper and Seakar, 1987). Application of decomposed paper mill waste at the rate of 5-10 t ha^{-1} improved the biological activity (Ilyaltdinov *et al.,* 1990; Udayasoorian *et al.*, 1999b).

Combined application of fly ash with sewage sludge increased the microbial population but the bacterial, actinomycetes and fungal counts on the soil typically decreased with increase in ash content (Pichtel and Hayes, 1990). On the contrary, Lal *et al.* (1996) reported that microbial activity was higher in fly ash amended soils. Among the amendments, ETP sludge recorded the highest microbial population followed by FYM, bagasse pith and fly ash whereas actinomycetes and fungi were totally absent under lime sludge incorporation (Hameed, 1997). Dhevagi *et al.* (2000) observed higher population of *Azotobacter* and *Azospirillum* in pressmud amended maize field. More over invertase activity was higher in soils amended with press mud and TNPL sludge.

The increase in organic matter content of the soil due to effluent irrigation accelerated the microbial activity and inturn accelerated the substrate decomposition with the release of CO_2 (Kannan and Oblisami, 1990). Diluted effluent was found to increase the microbial population and fertility of soil (Chauhan and Kaur, 1991). The continuous effluent irrigation for sugarcane crop did not have adverse effect on the soil microflora (Anita *et al.*, 1997a). The effluent irrigation to eucalyptus seedlings enhanced the growth of rhizosphere soil bacteria, fungi and actinomycetes (Hameed, 1997).

Effluent irrigated soil over a period of 15 years had maximum population of bacteria, actinomycetes, fungi, *Rhizobium, Azotobacter* and yeast. The enrichment in the nutrient content of the soil due to the effluent irrigation enhanced the microbial population (Somashekar *et al.*, 1984).

Palaniswami (1989) and Palaniswami and Sree Ramulu (1994) reported that urease and acid and alkaline phosphatase activity were observed to be maximum in 15 years effluent irrigated soil. Oblisami and Palaniswami (1991) reported that paper factory effluent irrigation resulted in an increase in soil amylase, invertase, cellulase, dehydrogenase and phosphatase activity, which was directly proportional to the period of effluent irrigation to the soil. In effluent irrigated sugarcane crop, the soil amylase activity decreased while soil invertase activity increased (Anita *et al.*, 1997b). There was an increase in amylase, invertase and cellulase activity in the soil with effluent irrigation and this might be due to increased microbial population, which helped in mineralization and degradation of organic matter (Dhevagi *et al.*, 2000).

2.9.2. Crop growth:

2.9.2.1. Forest crops

Hansen *et al.* (1980) suggested that kraft mill waste water could be safely used for poplar plantation. Neelay and Dhondizal (1985) reported that the effluent from pulp and paper mill was used for irrigating *Eucalyptus camadulensis*, *Pungamia pinnata, Acacia auriculiformis Leucaena leucocephala* and *Dendrocalanus strictus*. The treated pulp and paper mill effluent did not cause any adverse effect on *Eucalyptus tereticornis* growth (Hameed and Udayasoorian, 1997).

Nutrient content of tree seedlings (*Acacia nilotica*, *Casuarina equisetifolia* and *Eucalyptus tereticornis*) increased due to increased nutrient status of soil by the addition of organic amendments together with effluent irrigation (Hameed, 1997).

2.9.2.2. Field crops

Rice yield was higher under pulp and paper mill effluent irrigation compared to well water. Of the three varieties tested, IR 20 and White ponni performed better than ADT 36 (Alfred *et al*, 1998). They also recorded higher grain yield (6.87 t ha^{-1}) in pressmud amended soil with effluent irrigation. The effluent irrigation did not affect the grain yield of rice (Srinivasachari *et al*., 1998). The paddy grain yield was increased by 25 per cent due to effluent irrigation (Udayasoorian *et al*., 1999a). Jivendra (1995) reported that kraft mill waste water had no adverse effect on the palatability and nutrition value of paddy.

The fodder yield increase due to effluent irrigation over well water in cumbu napier hybrid was 39.32 per cent followed by guinea grass (38.68%), congo signal (27.40%) and the least in para grass (16.50%) (Ponniah and Ramaswamy, 1999). He observed that the accumulation of lead in the grass is low when compared with the concentration detected in sludge and it is within the normal levels of 1-10 ppm. Zinc concentrations in grass was quite high (98.53 ppm) due to high mobility of this metal in sludge amended soils (Srikanth *et al*., 1992).

The yield of maize and oil seed crops was higher in treatment amended with pressmud along with effluent irrigation (Udayasoorian *et al*., 1999a). Raja and Raj (1981) inferred that there was a significant increase in grain yield of ragi with increasing levels of pressmud on lateritic and red soils. In mine soil, paper mill sludge in combination with fertilizer increased yield of clover (*Trifolium subterranean*) more than that with fertilizer alone (Feagley *et al.*, 1994). Seven per cent increase in yield was observed in wheat, barley and linseed by the application of paper mill sludge (Aitken *et al.*, 1998).

The adverse effects of the effluent from paper factory could be alleviated by resorting to the application of N, P, and K along with organic and inorganic amendments such as pressmud, farmyard manure (FYM) and gypsum (Pushpavalli, 1990). Paper mill effluent irrigation plus 20 tonne gypsum per ha recorded maximum germination, shoot length, dry weight of sugarcane setting and increase in content and uptake of N, P_2O_5 and K_2O, Mn, Zn and also the uptake of Fe and Co (Oblisami and Palanisami, 1991).

Udayasoorian *et al.* (1999a) concluded that the yield of sugarcane was more in effluent irrigated fields to a tune of about 5.13, 3.53, 3.27 and 2.00 per cent over the well water irrigated crop for the varieties COC 92061, COC 671, COC 6304 and COC 91061 respectively. An increase in jaggery yield was observed when sugarcane was grown with pulp and paper mill waste water (Subrahmanyam *et al.*, 1984). Gopalakrishnan *et al.* (1999) concluded that the yield of paper mill irrigated sugarcane were higher by about 10 per cent when compared to those irrigated with the fresh water (100 to 125 t ha^{-1}).

Better growth of plants viz., brinjal, onion, sunflower, banana and pulp wood such as Eucalyptus were observed while paper mill sludge was applied along with effluent irrigation (Veena *et al.*, 1992). Number of fruiting clusters, fruit weight, fruit yield was higher in the treatment receiving bioearth, pressmud and FYM along with effluent irrigation (Sandana, 1995).

Treated paper mill effluent with amendments like ETP sludge and pressmud can be used to fetch higher yield of amaranthus. Composted bagasse pith, ETP sludge and pressmud can be used

2.10. Leaching or Movement of elements in soil column

The movement of water and solutes by diffusion and convection within the soil profile involves a series of process, which are important to agriculture and environment.

Another major effect of such disposal is the possibility of ground water pollution, depending upon soil conditions, mobility of metals, applied dose etc. Leaching of inorganic pollutants such as chlorides, sulphates and nitrates and metals take place. Most of the metals are retained on top soil i.e., productive zone. The increase in metal content of soil decrease with respect to soil depth. Out of the metals present in soil a small amount of less than 7 per cent is taken up by the edible part of vegetation, thus introducing the metal into food chain . Plant uptake, solubility and mobility of metals in soil are influenced by soil pH, chemical form of the metals, soil CEC, soil redox potential, texture and organic matter (Anderson and Nilsson, 1974 and Iwai.*et al.,* 1975).

Waste management through land application as a method of waste water treatment and disposal is considered as an alternative approach being economical, energy conservative and capable of providing recycle and reuse benefits compared to conventional treatment technologies currently adopted. In the land application system, the soil matrix provides physical, chemical and biochemical treatments to the waste water simultaneously through various sorptive, degradative and assimilative processes occurring in the soil. The sorptive, assimilative and degradative potential of a soil vary considerably and depend on soil properties like texture, hydraulic conductivity, porosity, pH, CEC, organic matter content and microbial status. The physiological nature of biomass to be grown and the type of waste water to be applied / disposed on soil play an important role in the success of the land treatment system. The resultant effect of the land treatment system depends on the interaction between soil-plant-waste systems, which can be rapidly ascertained both in laboratory, and field using a lysimeter (Subrahmanyam and Juwarkar, 1992). Soil having high conductivity did not allow metals to easily leach out and the texture of soils plays an important role in the migration of metals. Clay soil retains high amount of metals. So metal pollution can be controlled by using high clay soil as a linear and maintaining pH above 8.3 (Olaniya *et al.,* 1992).

All constituents in leachates manifested high rates of self purification and the final concentrations were considerably lower and high temperatures and shallower depths of solid wastes seem to be responsible for high rates of self purification (Khan *et al.,* 1994).

The per cent colour reduction in the leachate was higher in clay soil along with treated effluent irrigation. The total solids, pH, EC and organic carbon were higher in sandy loam soil leachates (Dhevagi, 1996).

From the above foregoing review it is evident that the paper mill effluent and sludge could be used for irrigation in dry lands without any adverse effect on germination, yield levels, quality of crop produce and without much deterioration on ground water quality. The informations available in the use of paper mill effluent for crop production and its impact on soil, plant and groundwater quality are meagre. In this context the present investigation has been taken up to assess the possibility of using Bilt-IPCL effluent and solid waste on crop growth, quality of soil and ground water.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The present investigation on the effect of treated paper board factory effluent and solid wastes on soil characteristics, ground water quality, crop growth and quality of crop produce are carried out at the Bilt-IPCL Thekkampatti, Mettupalayam, Coimbatore District and in the Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore for field trials and lab analysis respectively during October 2000 to September 2001.

The details regarding collection of effluent, solid waste, soil, ground water and plant samples, the field trials carried out and the analytical methods followed are presented below.

Part I : Analysis of raw and treated Bilt-IPCL effluent and solid wastes

Part II : Assessing the soil characteristics and ground water quality in and around the Factory area

Part III : a) Bio-Assay test to assess impact of treated effluent on Fish-fingerlings

b) Laboratory studies to assess the impact of treated and raw effluent on germination of field crops and vegetable crops

c) Nursery experiment to assess the impact of effluent irrigation and amendments on growth of forest tree saplings. (Forest tree saplings are being cultivated in isolated pockets within the Bilt-IPCL area using both treated Bilt-IPCL effluent and river water).

Part IV : Field trial to study the impact of treated effluent irrigation and amendment incorporation on crop growth and soil quality.

Part V : Assessing the changes that occurs due to continuous effluent irrigation on soil microbiological processes.

3.1.Geography of the study area

The Bilt-IPCL is situated in Thekkampatti village, Mettupalayam, Coimbatore District (Fig.2) Coimbatore lies in 11.02° North latitude and in 77.03° East longitude. The mean annual rainfall is 700 mm. Soil is of Red loamy type and classified as Typic Ustalf. River Canals and wells are the main sources of irrigation in this region. The main cropping pattern includes sugarcane, cumbu, sunflower, banana, flowers and coconut.

3.2. Analysis of effluent and solid wastes

3.2.1. Collection of effluent samples

The raw and treated effluent samples were collected from (Bilt-IPCL), Thekkampatti, and analysed for physical, chemical and biological properties. The samples were collected at periodical interval of once in three months at three point sources *viz.* inlet (untreated), middle (aerated) and outlet (treated) and analysed for its physico-chemical properties (Fig.3).

3.2.2.Sampling of Effluent

Samples for microbiological examinations were collected in sterilized bottles. The sampling bottles were closed with a ground glass stopper having an overlapping rim. The stopper was relaxed by an intervening strip of paper to prevent breakage. The bottles were protected by covering with aluminium foil and sterilized in an autoclave at 20 psi for 15 minutes. The bottles were opened only at the time of sampling. (Fig.4.)

FIG.2. MAP OF TAMIL NADU

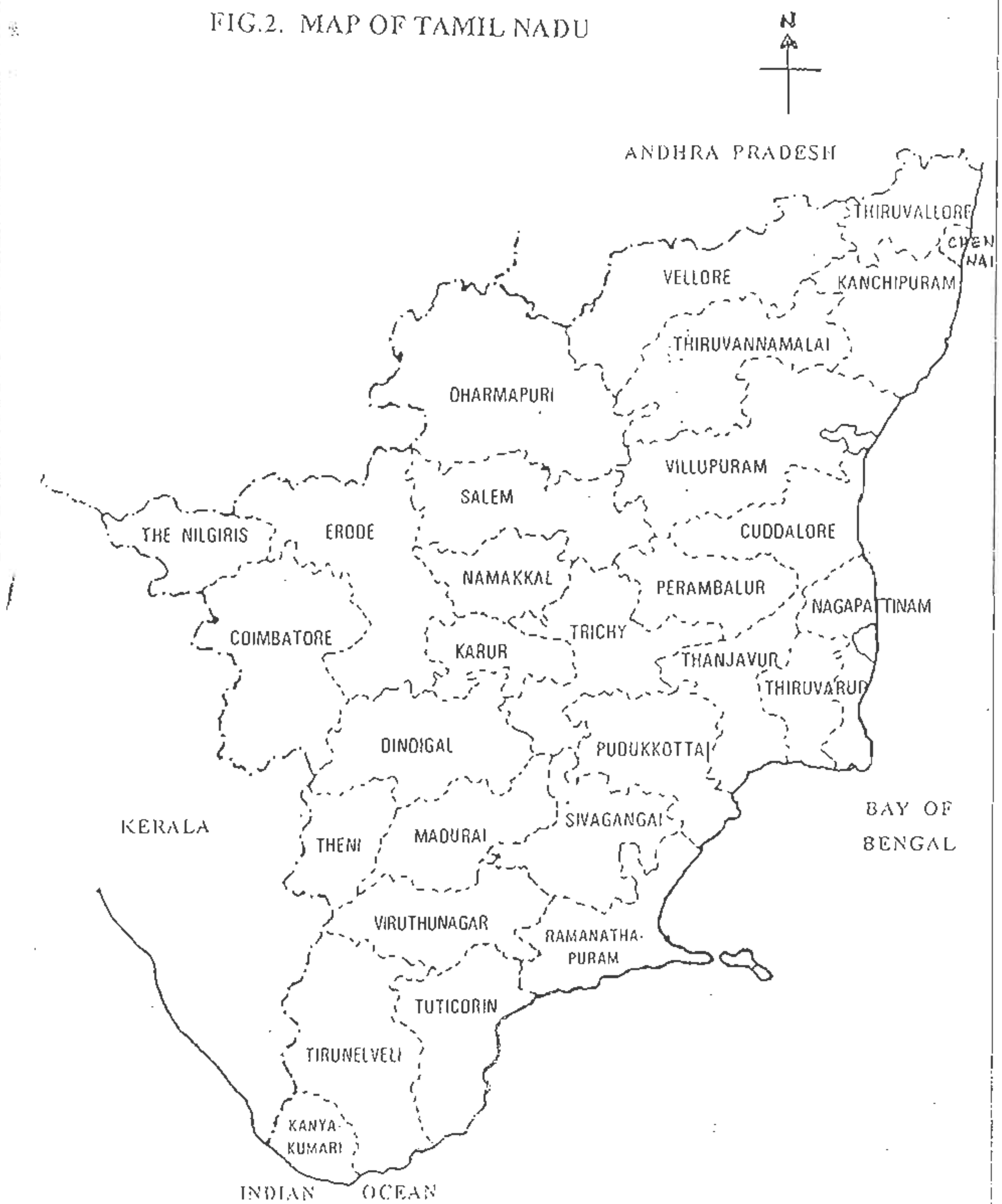
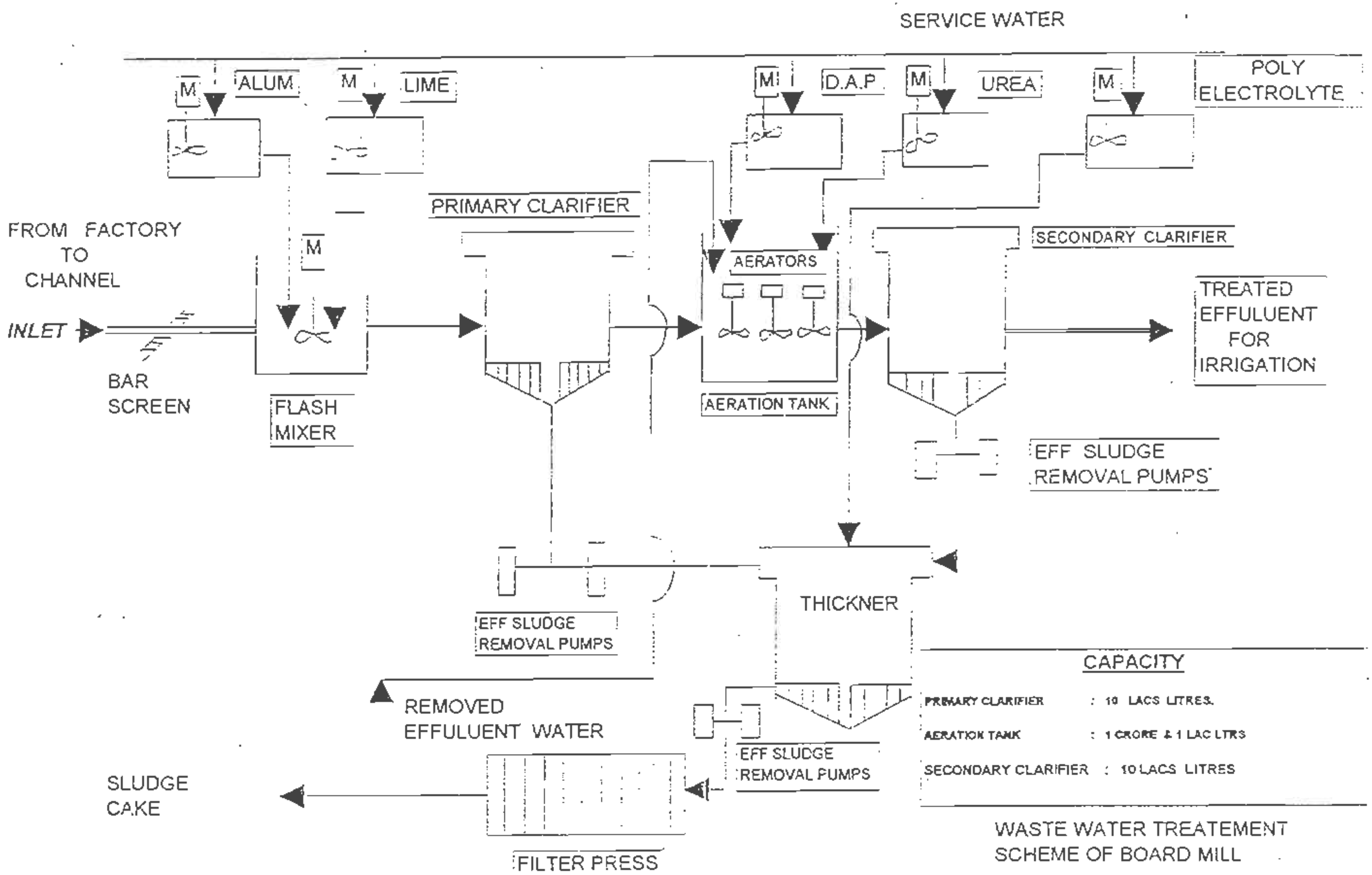


Fig.3. Schematic diagram of Effluent Treatment Plant at Bilt-IPCL



3.2.3.Preservation of Samples

The samples for the analysis of dissolved oxygen (DO) were added with one ml of manganese sulphate solution and one ml of alkaline potassium iodide solution as given under the procedure for the estimation of dissolved oxygen. Samples for the determination of Biochemical Oxygen Demand (BOD) were preserved by adding five ml of washed chloroform (Chloroform and distilled water were taken in a separating funnel, shaken well and the water layer was discarded) per litre of the sample (Anon., 1989).

3.2.4 Analysis of effluent samples

The physical, chemical and biological characteristics of the effluent samples were analysed as per the methods detailed in Standard Methods for the Examination of Water and Waste Water (Anon., 1989).

3.2.4.1. Physical properties

i. Color and foam : Assessed by visual comparison with distilled water.

ii. Suspended solids : A known quantity of the effluent was filtered using Whatman No. 1 filter paper and the residue was dried at 105°C to a constant weight.

iii. Dissolved solids : The filtrate obtained from the suspended solids was evaporated, dried at 105°C to a constant weight.

iv. Total solids : The addition of suspended and dissolved solids gave the total solids.

3.2.4.2. Chemical properties

i. pH

The pH of the effluent was measured using a pH meter with glass electrode (Jackson, 1973).

ii. Electrical conductivity (EC)

The EC of the effluent was measured by using a conductivity bridge (Jackson, 1973).

iii. Dissolved oxygen (DO)

The dissolved oxygen in the effluent was determined by azide modification of iodometric method (Anon., 1989).

iv. Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand was determined as per the standard procedure (Anon., 1989).

v. Chemical Oxygen Demand (COD)

The chemical oxygen demand of the effluent was determined as detailed in Anon. (1989).

vi. Organic carbon

The organic carbon content of the effluent was estimated by the wet digestion method of Walkley and Black as described by Piper (1966).

vii. Ammoniacal nitrogen (NH_4-N)

The ammoniacal nitrogen content of the sample was estimated by Bremner method (Jackson, 1973).

viii. Phosphorus

This was estimated colorimetrically as described by Olsen *et al.* (1954).

ix. Potassium

This was estimated by EEL flame photometer (Jackson, 1973).

x. Calcium

The calcium content was estimated by Versenate titration method as detailed by Jackson (1973).

xi. Magnesium

The magnesium content was estimated by the difference between the value of calcium plus magnesium and calcium estimation in the Versenate titration method (Jackson, 1973).

xii. Sodium

The sodium content of the effluent sample was determined by using EEL flame photometer with sodium filter as described by Jackson (1973).

xiii. Chloride

The chloride content of the effluent sample was determined by Mohr's method as described by Jackson (1967)

xiv. Sulphate

The Sulphate content of the effluent sample was determined by Turbidimetric method using spectrophotometer at 420nm.

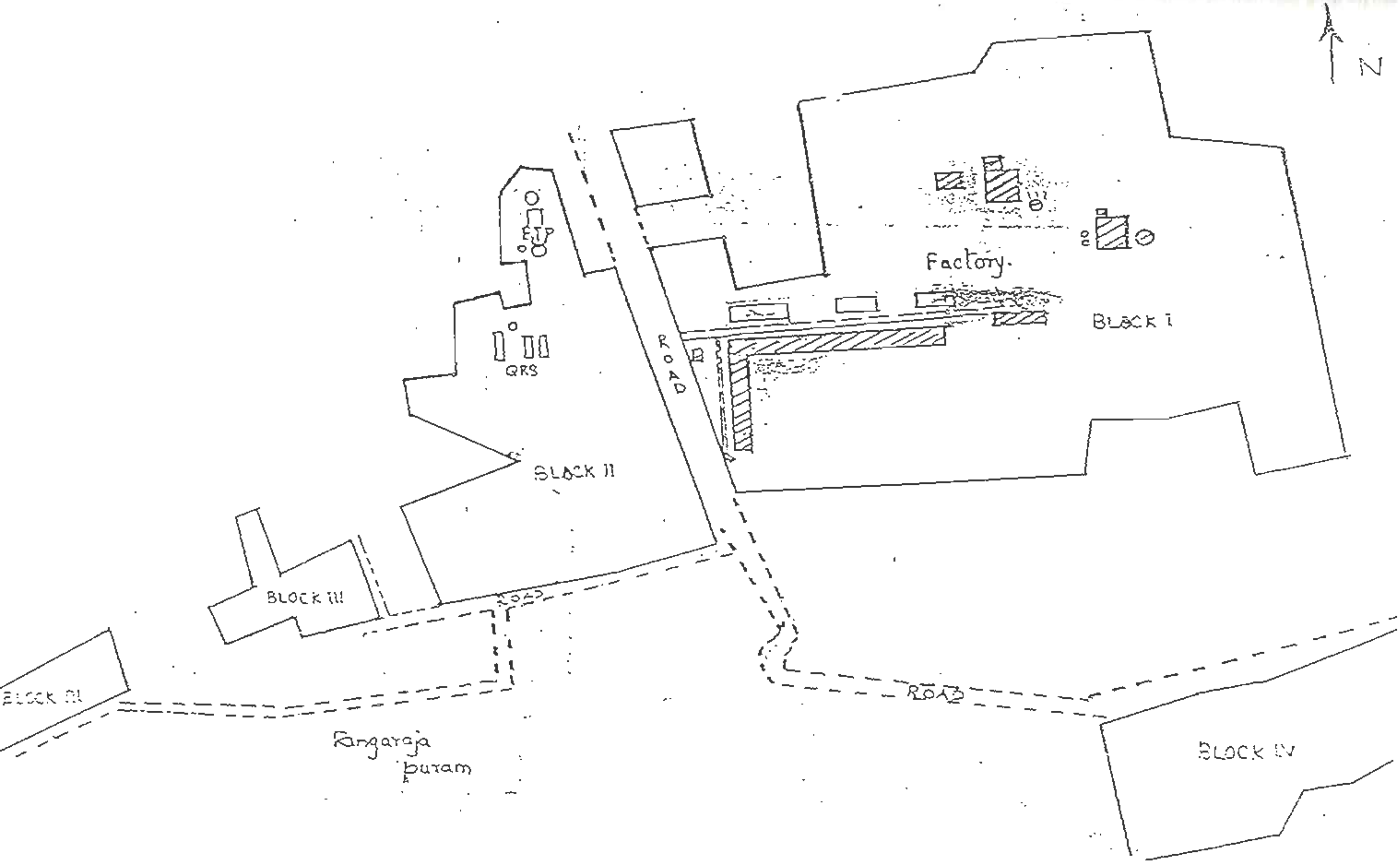
xv. Total Phenols

The Total Phenols content of the effluent sample was determined by Folin Ciocalteau reagent and measuring in spectrophotometer at 650nm by Bray and Thorpe (1954)

3.2.4.3. Microbial properties

Particulars	Remarks	Author
Enumeration of bacteria, actinomycetes and fungi	Serial dilution and plating method	Jenson (1968)
Organism	**Media used**	
Bacteria	Nutrient glucose agar	Rangaswamy (1966)
Actinomycetes	Kenknight's agar	Rangaswamy (1966)
Fungi	Martin's rose bengal agar	Martin (1950)

Fig.4. Map showing the location of Bilt-IPCL



3.3. Field Survey

Field survey involved collection and analysis of thirty-five numbers of soil and ground water samples representing in and around the factory areas covering Mandaraikadu, Devanapuram, Periya Thekkampatti, Chinna Thekkampatti, Chinna Kandiyur and Rangarajapuram villages. (Fig.5.)

3.3.1. Collection of soil samples

Five hundred grams of soil samples representing 0 – 30 cm depth were collected once in three months to assess the changes in soil quality parameters if any due to effluent contamination.

3.3.2. Collection of water samples

The water samples were also collected from Open / Bore wells to monitor the changes in the ground water quality due to effluent discharge for crop production in 35 locations of in and around of the factory area. One litre volume of water was collected in polyethylene container at monthly intervals from October 2000 to September 2001. The quality of ground water samples from different locations were compared with samples collected near intake river water (control) where the possibilities of ground water pollution due to Bilt -IPCL effluent was remote.

3.3.3. Preservation of samples

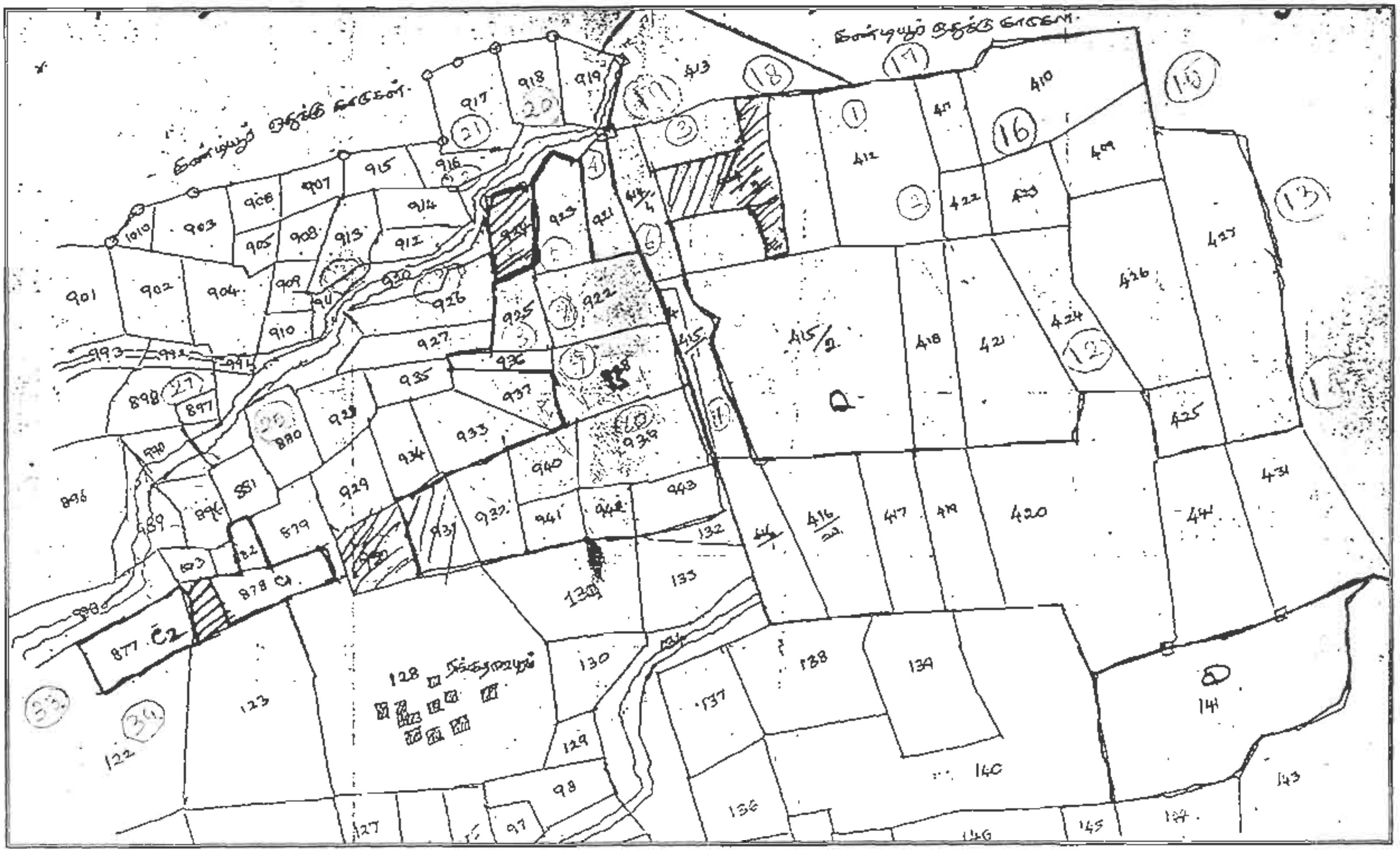
Water samples collected from the wells were kept in freezer at 4°C to avoid microbial activity whereas the collected soil samples were dried in shade for two days, powdered gently with a wooden mallet and sieved through a 0.2 to 2 mm sieve. The material, which passed through the sieve, was taken for further analysis.

3.3.4. Analysis of samples

3.3.4.1. Soil samples

3.3.4.1.1. Chemical properties

Fig.5. Sampling locations in and around the factory area



Parameters		Method	Author (s)
1.	pH	Soil : water suspension of 1 : 2.5	Jackson (1973)
2.	EC	Soil : water suspension of 1 : 2.5	Jackson (1973)
3.	OC	Wet digestion method of Walkley and Black (1934)	Piper (1966)
4.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
5.	Available P	Photoelectric colorimeter at 660 nm	Olsen *et al.* (1954)
6.	Available K	Ammonium acetate extract (Flame photometer)	Stanford and English (1948)
7	Per cent chloride	Acidimetric titration	Baruah.and Barthakur(1997)
8.	Exchangeable Na	Ammonium acetate extract (Flame photometer)	Jackson (1973)
9.	Exchangeable Ca	Versenate titration method	Jackson (1973)
10.	Exchangeable Mg	Versenate titration method	Jackson (1973)
11.	Exchangeable K	Ammonium acetate extract (Flame photometer)	Jackson (1973)
12.	Exchangeable Sodium per cent		Saxena *et al.* (1978)
13	Sodium Adsorption Ratio (SAR)		Chopra and Kanwar (1982)
14	DTPA Cu, Fe, Mn, Zn	AAS (Atomic Absorption Spectrophotometer)	Lindsay & Norwell 1978)

3.3.4.1.2. Biological properties

The population of different groups of microorganisms was enumerated in the soil samples as described earlier for effluents **3.2.4.3.**

3.3.4.2. Water samples

Parameters		Method	Author (s)
1.	pH	Measured using a digital pH meter : 335 glass electrode	Jackson (1973)
2.	EC	Measured using a conductivity bridge – (CM 180 Elico conductivity meter)	Jackson (1973)
3.	Total hardness	Titrating with 0.01 M EDTA using erichrome black-T indicator	Jackson (1967)
4.	Carbonates	Titrating with 0.1N H_2SO_4 using phenolphthalein indicator	Piper (1966)
5.	Bicarbonates	Titrating with 0.1N H_2SO_4 using methyl orange indicator	Piper (1966)
6.	Chloride	Mohr's method	Jackson (1967)
7.	Sulphates	Turbidimetric method using spectrophotometer at 420 nm	Jackson (1967)
8.	Sodium	EEL flame photometer	Jackson (1967)
9.	Calcium	Versenate titration method	Jackson (1967)

10.	Magnesium	Versenate titration method	Jackson (1967)
11.	Potassium	EEL flame photometer	Jackson (1967)
12.	Per cent Sodium		Eaton (1950)
13.	Potential Salinity (PS)	$Cl_2 + 1/2\ SO_4$	Doneen (1965)
14.	Sodium Adsorption Ratio (SAR)		Chopra and Kanwar (1982)
15.	Residual Sodium Carbonate (RSC)	$(CO_3 + HCO_3) - (Ca + Mg)$	Eaton (1950)

3.4.Bioassay Experiment

Bioassay experiments for determining acute toxicity were carried out according to the methods recommended in American Public Health Association (APHA, 1980). To study the effect of effluent at different concentrations *viz.* 0, 25, 50, 75 and 100 per cent on survival percent of fingerlings for 96 hours.

Healthy fingerlings *viz., Catla catla, Cyprinus rogu, Mrigal* of about 4–5 cm in length and 10 g in weight were brought from Department of Fisheries, Bhavanisagar, and acclimatized in dechlorinated tap water. The fingerlings were fed with minced meat on alternate days. Excess food and water were cleared from the bottom of the aquarium periodically.

3.5. Germination studies

The effluent from paper board factory was studied for its influence on seed germination and VI of rice, maize, sunflower, groundnut, blackgram, greengram, soybean, bhendi, chilli, tomato, amaranthus, bittergourd, snakegourd, and moringa.

Germination test was carried out in a germination room maintained at a temperature of 25 ± 1.5°C and relative humidity of 95 ± 2 per cent with diffuse light (approximately 10 hrs.) during the day. Tomato (CO-3), brinjal (CO-2), bhendi (Arka anamica), chilli (CO-1), amaranthus (CO-1) and seeds were germinated in germination papers. The moringa (PKM-1) and bittergourd (CO-1) seeds were germinated in sand trays. The experiment was conducted in completely randomized design and replicated four times. Hundred seeds were sown in each replication as per the treatment given below. The observations on percentage of germination, shoot and root lengths were taken at 14 days after sowing (DAS) for tomato, chilli, bittergourd and moringa, 18 DAS for amaranthus and 21 DAS for bhendi.

Treatments:

T1- 0 percent effluent (100 per cent tap water)-control

T2- 25 per cent effluent

T3- 50 per cent effluent

T4- 75 per cent effluent

T5- 100 per cent effluent

3.5.1.Germination percentage

The counts were taken as per the ISTA rules (1993) and expressed in percentage.

3.5.2.Root length

The normal seedlings were taken at random and the distance between the collar and tip of the primary root were measured and the mean value was arrived and expressed as centimeter (cm).

3.5.3.Shoot length

The seedlings were again measured for the distance between collar and tip of the primary shoot. The mean value of the shoot length was recorded and expressed as cm.

3.5.4.Vigour index (VI)

The VI was calculated for each replication by using the formula suggested by Abdul-Baki and Anderson (1973).

VI = Germination percentage x [Root length (cm) + Shoot length (cm)]

3.6. Nursery Experiment

Nursery experiment with the fallowing forest tree saplings was carried out at Bilt-IPCL, Thekkampatti, Mettupalayam to study the effect of paper factory effluent with solid wastes on soil properties, seedling growth and microbial population.

Treatmental details

Design	: Factorial RBD
No. of replication	: Three
No. of polybags	:Twenty

Test tree saplings:

Leguminous:

1. *Acacia auriculiformis*

Non- Leguminous:

2. *Azadirachta indica*

3. *Eucalyptus tereticornis*

Irrigation:

I_1 - River water

I_2 - Treated Effluent

Ameliorants (Industrial solid wastes)

T_1 - Red Soil: Sand: FYM @2:1:1ratio

T_2 - Red Soil: Sand: FA @2:1:1ratio

T_3 - Red Soil: Sand: S @2:1:1ratio

T_4 - Red Soil: FA: FYM @2:1:1ratio

T_5 - Red Soil: S: FYM @2:1:1ratio

T_6 - Red Soil: FA: S @2:1:1ratio

(FYM – Farmyard manure, FA-Fly ash, S-Sludge, GM-Green manure -Daincha)

Thirty day old test tree saplings were transplanted in poly bags (20x10cm) containing nursery mix as per treatments above. The biometric observations, soil and plant samples were collected at 60 and 120 days after transplanting. (DAT)

3.6.1. Biometric observations

3.6.1.1. Germination percentage, Root Length, Shoot Length and (VI) were measured as described in **3.5.1., 3.5.2., 3.5.3.** and **3.5.4.** respectively.

3.6.1.2.Collar diameter

Collar diameter was measured slightly above the root collar region of the seedling with screw gauge and expressed in millimeters (mm)

3.6.1.3.Dry Matter Production (DMP)

The normal seedlings were first dried under shade for a week and then dried in a hot air oven maintained at 85^0C for 24 hrs then cooled in a desiccator and weighed. The dry matter production was expressed in grams (g)

3.6.1.4.Volume Of Index (VOI)

VOI= Diametre $(mm)^2$ X Height (cm)

3.6.2.Soil analysis

3.6.2.1.Collection and preparation of soil samples

The soil samples were collected at different growth period's viz., 60 and 120 DAT. The samples were dried in shade for two days powdered gently with a wooden mallet and sieved through a 2 mm and 0.2 mm sieve. The material, which passed through the sieve, was taken for analysis.

3.6.2.2.Physical properties

The initial soil used for preparing the nursery mix was analysed for its physical properties viz. bulk density, particle density, pore space and water holding capacity (Chopra and Kanwar, 1982).

3.6.2.2.Chemical properties

The soil chemical properties viz., pH, EC, OC, Available NPK, Exchangeable Ca, Mg, Na, K and DTPA Cu Fe, Mn, Zn were analysed as described in **3.3.4.1.1**

3.6.2.3.Biological properties

The microbial population of bacteria, actinomycetes and fungi were enumerated as described in **3.2.4.3.**

3.7.Raising of Field crops

Field trials were conducted to assess the influence of treated effluent irrigation along with suitable amendments on yield and quality of sunflower (CO-4) and maize

(CO-1). Fly ash and sludge generated from this industry either alone and / or its combinations with green manure (Daincha) were compared with FYM. The treated effluent and river water were used for irrigation. The other cultural practices were followed as per Crop Production Guide -- 1999, Tamil Nadu Agricultural University, Coimbatore.

Treatment details

Irrigation: I_1 - River water

I_2 - Treated Effluent

Ameliorants (Industrial solid wastes):

T_1 - Control

T_2 - FYM @ 12.5 t ha $^{-1}$ + N P K

T_3 - FA @ 5 t ha $^{-1}$ + NPK

T_4 - S @ 5 t ha $^{-1}$ + N P K

T_5 - FA @ 5 t ha $^{-1}$ + S@ 5 t ha $^{-1}$ + N P K

T_6 - T_3 + GM @ 6.25 t ha $^{-1}$

T_7 - T_4 +GM @ 6.25 t ha $^{-1}$

T_8 - T_5 + GM @ 6.25 t ha $^{-1}$

(NPK : 136.5: 62.5: 50 kg ha^{-1} for maize)

(NPK : 40: 20:20 kg ha^{-1} for sunflower)

(**FYM** - Farmyard manure, **FA**-Fly ash, **S**-Sludge, **GM**-Green manure (Daincha))

Location :Bilt-IPCL, Thekkampatti

Design :Factorial RBD

Plot size :4x4m

No. of replications :Three

3.7.1. Soil analysis

3.7.1.1. Collection and preparation of soil samples

The soil samples collected at initial, vegetative, flowering and reproductive stages of crop growth were dried in shade for two days, powdered gently with a wooden mallet and sieved through a 2 and 0.2 mm sieve. The material, which passed through the 0.2 mm sieve (organic carbon) and 2 mm sieve, were taken for analysis.

3.7.1.2. Physical properties

The soil physical constants *viz.,* Water holding capacity, Bulk density, Particle density, Per cent pore space, Mechanical fractionation were performed as described by Chopra and Kanwar (1982)

3.7.1.3. Chemical properties

The soil chemical properties viz., pH, EC, OC, Available NPK, Exchangeable Ca, Mg and DTPA micronutrients analysed as described in **3.3.4.1.**

3.7.1.4. Biological properties

The microbial population of bacteria, actinomycetes and fungi were enumerated as described in **3.2.4.3.**

Organism	Media used	Reference
Azotobacter	Waksman 77	Subba Rao (1988)
Azospirillum	N-free malicacid medium	Dobereiner (1980)
Rhizobium	Yeast extract mannitol agar	Subba Rao (1988)

3.7.1.5. Soil Enzyme activity

1.	Amylase	Spectrometer Galstyan (1965)
2.	Invertase	Spectrometer Galstyan (1965)
3.	Cellulase	Spectrometer Galstyan (1965)

3.7.2. Plant analysis

3.7.2.1.Collection of plant samples

The plant samples were collected during the vegetative, flowering and at harvest stages of crop growth. The samples collected were air dried for two days, then oven dried at 60°C and powdered in a Wiley mill and used for the analysis.

3.7.2.2. Chemical analysis of the plant sample

1.	Nitrogen	Diacid extract	Jackson (1973)
2.	Phosphorus	Triacid extract	Jackson (1967)
3.	Potassium	Triacid extract	Jackson (1973)

3.7.2.3. Other observations recorded

i) **Germination percentage:** Germination counts were recorded after 15 days and it was expressed as percentage of germinated seeds to the total number of seeds sown.

ii) **Plant height:** The length of the shoot from cotyledon to the tip was measured and expressed in centimeter (cm).

iii) **Plant dry weight:** The plant samples were dried in an oven for free of moisture till the constant weight was obtained and expressed as kg of dry matter ha^{-1}.

iv) **Carbohydrate:** was estimated by following the method of Dubios *et al.* (1956).

v) **Crude protein:** Crude protein (CP) was calculated by using the following formula. (Debetz and Well, 1968)

CP (per cent) = Total N (per cent) x 6.25

vi) **Oil content:** Oil content of the sunflower seed was estimated in a Nuclear Magnetic Resonance Unit (NMR) and expressed as percentage.

3.7.2.4. Post harvest observations

3.7.2.4.1. Maize

i) **Cob length**: The length of the cobs in the tagged row samples was measured and expressed in cm.

ii) **Cob weight**: The weight of the cob in each plant was weighed and recorded as cob weight (g).

iii) **Grains weight/cob**: The weight of the grains in each cob weighed and recorded as grain weight per cob (g).

iv) **1000 grain weight**: Thousand grains were counted from each cob, weighed and recorded (g).

3.7.2.4.2. Sunflower

i) **No. of grains per head:** The number of grains in each ear head counted and recorded.

ii) **1000 grain weight** : 100 grains were counted from each head and multiplied by ten , weighed and recorded.

3.7.2.5.Post harvest analysis

The plant available and exchangeable nutrients statuses were analysed as per the standard procedures mentioned earlier **3.6.2.**

3.8. Column Lysimeter study

Column lysimeters were employed for laboratory studies to evaluate the different treatment of soil with waste water. The PVC pipes were used as lysimeter (40 x 9 cm) to collect leachate samples. A layer of mixture consist of washed sand and gravel was filled initially to a height of 10 cm, then the pipe was filled with the soil by giving light tapping. The lysimeters were kept in open air for one month for natural compaction. The water and effluents were sprinkled to maintain the moisture content (Fig.7). The soil used in lysimeter represents the factory area soil with different treatments. The soils were excavated from a pit of size 2 m x 1.5 m x 2 m in the field proposed for waste water irrigation. After completion of filling, soils in columns were subjected 3-4 cycles of wetting and drying to ensure proper compaction prior to start the actual application of waste water.

3.8.1. Soil analysis

The physical, chemical and biological characteristics of the soil were analysed as per the standard procedures described earlier in **3.3.4.1.**

3.8.2. Leachate analysis

The effluent and leachate analysis was carried as per the standard procedures described earlier in **3.3.4.2.**

3.9. Statistical analysis

The experimental data were statistically analysed to find out the influence of various treatments on the soil and growth of tree seedlings as suggested by Panse and Sukhatme (1985). The critical difference was worked out at 5 per cent (0.05) probability level.

Fig.6. Field Layout

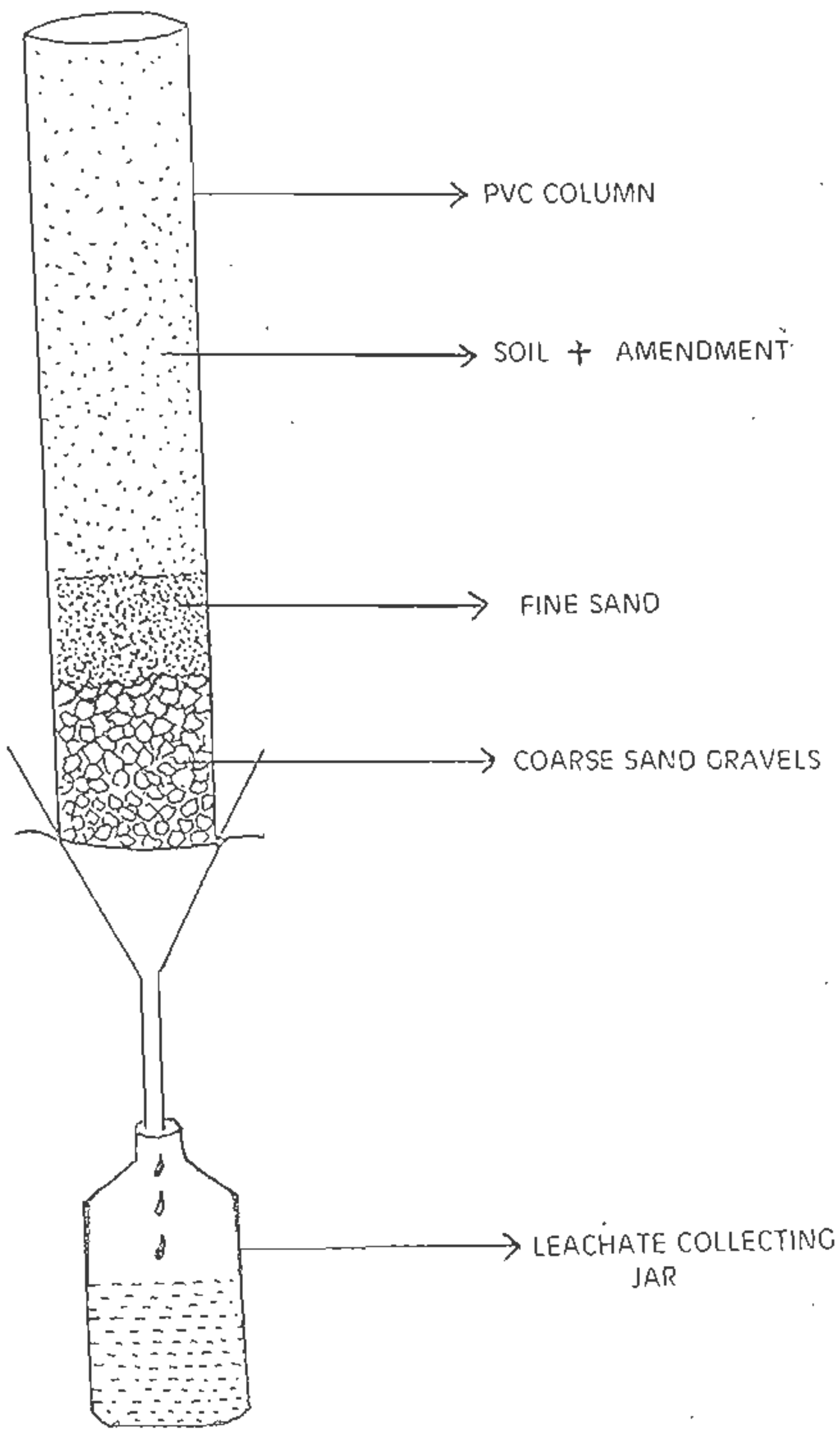
MAIZE

	River water channel (I_1)							
R1	A_2	A_4	A_6	A_1	A_8	A_3	A_5	A_7
R2	A_7	A_1	A_5	A_8	A_2	A_4	A_6	A_3
R3	A_2	A_6	A_3	A_7	A_4	A_1	A_8	A_5
Buffer channel								
R1	A_8	A_1	A_4	A_6	A_2	A_7	A_5	A_3
R2	A_3	A_7	A_5	A_8	A_1	A_4	A_6	A_2
R3	A_6	A_3	A_7	A_5	A_2	A_8	A_4	A_1
	Treated effluent channel (I_2)							

SUNFLOWER

	River water (I_1) channel							
R1	A_6	A_1	A_4	A_7	A_2	A_5	A_3	A_8
R2	A_3	A_6	A_8	A_1	A_4	A_7	A_2	A_5
R3	A_7	A_2	A_5	A_3	A_8	A_4	A_1	A_6
Buffer channel								
R1	A_1	A_7	A_4	A_2	A_6	A_5	A_3	A_8
R2	A_6	A_3	A_8	A_4	A_7	A_2	A_5	A_1
R3	A_8	A_5	A_2	A_6	A_4	A_1	A_3	A_7
	Treated effluent (I_2) channel							

Fig.7. Column Lysimeter



List of benchmark wells selected for sampling

S.No.	Location	Name of the village
	Inside Factory Area	
1	Bore well -Eastern side of Security office	Mandaraikadu
2	Bore well -Near Aerator ETP	Mandaraikadu
3	Open well -Near Aerator ETP	Mandaraikadu
4	Open well -Near Guest House	Mandaraikadu
5	Bore well -Back side of canteen	Mandaraikadu
6	Open well -Garden partner	Mandaraikadu
7	Bore well -Sugarcane field number-2	Devanapuram
8	Bore well -Sugarcane field number-1	Devanapuram
	Out side Factory Area	
9	Open well -Nachimuthu thottam	Devanapuram
10	Open well -K.Karuppusamy thottam	Devanapuram
11	Open well -N.K. Selvaraj thottam	Devanapuram
12	Odai -Pallathu odai (Near Selvaraj Thottam)	Devanapuram
13	Open well -Veeranna thottam	Devanapuram
14	Open well -Pettaiyan thottam	Periya Thekkampatti
15	Open well -R. Pettaiyan thottam	Periya Thekkampatti
16	Open well -Subbana thottam	Periya Thekkampatti
17	Open well -Pathri thottam	Periya Thekkampatti
18	Open well -Easwaran thottam	Periya Thekkampatti
19	Open well -Kalikutti thottam	Periya Thekkampatti
20	Open well -Soma sundara thottam	Periya Thekkampatti

21	Open well -Nataraju thottam	Chinna Thekkampatti
22	Open well -Rangaraju thottam	Chinna Thekkampatti
23	Open well -chinnasamy thottam	Chinna Thekkampatti
24	Odai (Near Kandasamy Thottam)	Chinna Thekkampatti
25	Open well -Kandasamy thottam	Chinna Thekkampatti
26	Open well -Nanchai thottam	Chinna Thekkampatt
27	Open well -P. Natarajan thottam	Chinna Kandiyur
28	Open well - K. Palanisamy thottam	Chinna Kandiyur
29	Open well -Annamalai thottam	Chinna Kandiyur
30	Open well -Marudhappa thottam	Chinna Kandiyur
31	Open well – K.Ramasamy thottam	Chinna Kandiyur
32	Open well -Somanur thottam-1	Rangarajapuram
33	Open well -Mysore thottam	Rangarajapuram
34	Open well -Subbaiyan thottam	Rangarajapuram
35	Intake River water (**Control**)	ChinnaThekkampatti

ABSTRACT (Total No. 35)

Villages	**No. of Sampling points**
Mandharaikadu	6
Devanapuram	7
Periya Thekkampatti	7
Chinna Thekkampatti	6
Chinna Kandiyur	5
Rangarajapuram	3
Control (Intake River water)	1
Total	**35**

Results

CHAPTER IV

RESULTS

The present work was carried out to study the cumulative effect of paper board mill effluent and solid wastes generated at Ballarpur Industrial Packaging Company Limited (Bilt-IPCL) Thekkampatti, Mettupalayam on the physico-chemical and biological properties of soil, water and plant ecosystem. The results obtained from the laboratory, nursery and field experiments are presented hereunder.

4.1. Effluent analysis

The effluent collected from the Bilt-IPCL effluent treatment plant (ETP) at three point sources viz., inlet, middle (aerated) and outlet at a periodical interval of once in three months from September 2000 to September 2001 were analysed for various physico-chemical and biological characteristics.

4.1.1. Physico-chemical characteristics

The colour of the effluent before treatment was dirty green and after aeration it changed to light yellow. The colour of the treated effluent letout for irrigation was creamy white throughout the period of analysis except March 2001 wherein the colour at the outlet was yellowish (Table 1). The effluent had phenolic odour at all point sources throughout the period of analysis (Table 2).

The total dissolved solids and suspended solids, which ranged from 1800 to 2300 and 197 to 208 mg L^{-1} respectively before the treatment process were reduced to a range of 725 to 850 and 114 to 132 mg L^{-1} at the outlet (Table 3 and 4). The total dissolved solids and suspended solids were higher in summer followed by north east monsoon and south west monsoon seasons. The total solids in the effluent at inlet

Table 1.Colour of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	Dirty green	Light yellow	Creamy white
December-2000	Dirty green	Light yellow	Creamy white
March-2001	Dirty green	Light yellow	Yellowish
June-2001	Dirty green	Light yellow	Creamy white
September-2001	Dirty green	Light yellow	Creamy white

Table 2.Odour of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	Phenolic	Phenolic	Slight phenolic
December-2000	Phenolic	Phenolic	Slight phenolic
March-2001	Phenolic	Phenolic	Slight phenolic
June-2001	Phenolic	Phenolic	Slight phenolic
September-2001	Phenolic	Phenolic	Slight phenolic

Table 3.Total dissolved solids (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	1800	1212	725
December-2000	2060	1356	826
March-2001	2300	1432	850
June-2001	1960	1238	783
September-2001	1942	1228	752
Mean	2012	1293	787
Range	1800-2300	1212-1432	725-850
SD	185.60	96.31	51.42
SE	83.00	43.07	22.99

Table 4.Suspended solids (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	197	158	114
December-2000	205	164	122
March-2001	208	152	132
June-2001	204	152	126
September-2001	198	123	116
Mean	202	150	122
Range	197 to 208	123 to 164	114 to 132
SD	4.72	15.79	7.35
SE	2.11	7.06	3.29

Table 5.Total solids (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	2004	1380	878
December-2000	2265	1596	972
March-2001	2508	1364	857
June-2001	2157	1396	940
September-2001	2140	1479	899
Mean	2215	1443	909
Range	2004 to 2508	1364 to 1596	857 to 972
SD	188.32	96.34	46.62
SE	84.22	43.08	20.85

Table 6.pH of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	6.10	6.22	6.95
December-2000	6.41	6.77	7.15
March-2001	6.43	6.84	7.21
June-2001	6.31	6.53	7.10
September-2001	6.28	6.64	7.03
Mean	6.31	6.60	7.13
Range	6.10 to 6.43	6.22 to 6.84	6.95 to 7.21
SD	0.13	0.24	0.11
SE	0.06	0.11	0.05

ranged from 2004 to 2508 mg L^{-1} and were reduced to 857 to 972 mg L^{-1} after treatment (Table 5).

The pH of the effluent at the inlet was acidic in nature (6.10 to 6.43). After aerobic treatment the pH was brought to neutral condition (6.95 to 7.21) at the outlet (Table 6). Increased pH was recorded in the month of March 2001 and the lowest in September 2000. The mean electrical conductivity (EC) values at the three point sources *viz.*, inlet, middle and outlet were found to be 1.48, 1.33 and 1.22 dS m^{-1} respectively (Table 7). The highest EC was recorded during summer (June 2001) followed by north east monsoon (December 2000). The mean Organic Carbon (OC) content of the effluent decreased from 0.66 per cent at the inlet to 0.53 per cent at the outlet (Table 8). Effluent analysis during the month of March 2001(summer) recorded the highest OC content and the least during September 2000 and 2001(south west monsoon).

The Dissolved Oxygen (DO) content of the effluent was very low at the inlet (2.0 to 3.6 mg L^{-1}) and increased after aeration at the middle (3.1 to 4.9 mg L^{-1}) and again decreased (2.1 to 3.7 mg L^{-1}) at the outlet (Table 9). The DO content was least during March 2001 and it was high during September 2000 in the effluent (outlet). Among the seasons, summer months recorded very low DO content. The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) at the inlet were found to be 166 and 1911 mg L^{-1} respectively in the paper board mill effluent. After treatment the BOD and COD were brought down to 12.5 and 107 mg L^{-1} respectively at the outlet (Table 10 and 11). High BOD and COD were recorded during the month of March 2001 at the outlet followed by December 2000. Here also the summer months recorded higher BOD and COD than north east monsoon. The carbonates in the effluent were beyond the detectable limit. The bicarbonates in the released effluent outlet ranged

Table 7.EC (dS m^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	1.41	1.30	1.18
December-2000	1.45	1.35	1.23
March-2001	1.48	1.38	1.25
June-2001	1.52	1.32	1.22
September-2001	1.52	1.32	1.20
Mean	1.48	1.33	1.22
Range	1.41 to 1.52	1.30 to 1.38	1.18 to 1.25
SD	0.05	0.03	0.03
SE	0.02	0.01	0.01

Table 8.Organic carbon per cent of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	0.62	0.61	0.51
December-2000	0.69	0.62	0.56
March-2001	0.71	0.66	0.58
June-2001	0.64	0.57	0.47
September-2001	0.63	0.61	0.51
Mean	0.66	0.61	0.53
Range	0.62 to 0.71	0.57 to 0.66	0.47 to 0.58
SD	0.04	0.03	0.04
SE	0.02	0.01	0.02

Table 9.Dissolved oxygen (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	3.6	4.9	3.7
December-2000	3.4	4.7	3.7
March-2001	2.0	3.1	2.1
June-2001	2.9	4.2	2.8
September-2001	2.5	4.4	2.5
Mean	2.88	4.26	2.96
Range	2.0 to 3.6	3.1 to 4.9	2.1 to 3.7
SD	0.61	0.80	0.67
SE	0.23	0.32	0.25

Table 10.BOD (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	168	76	11.4
December-2000	172	76	13.6
March-2001	176	86	14.5
June-2001	153	73	12.2
September-2001	162	71	10.6
Mean	166	76	12.5
Range	153-176	71-86	10.6-14.5
SD	9.01	5.77	1.59
SE	4.03	2.58	0.71

Table 11.COD (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	1232	482	78
December-2000	2145	582	123
March-2001	2200	621	128
June-2001	2042	498	92
September-2001	1936	514	114
Mean	1911	539	107
Range	1232-2200	482-621	78-128
SD	392.78	59.43	21.28
SE	175.66	26.58	9.52

Table 12.Bicarbonates (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	232	167	117
December-2000	201	140	110
March-2001	198	134	95
June-2001	192	132	94
September-2001	222	157	114
Mean	209.1	146.0	106.3
Range	192-232	132-167	94-117
SD	17.27	15.31	10.77
SE	7.72	6.85	4.82

from 94 to 117 mg L^{-1}. The bicarbonates were found to be low during the month of June 2001 (Table 12).

The ammoniacal nitrogen, phosphorus and potassium content of the effluent were high in the aerated sample (middle) followed by the released effluent used for irrigation (Outlet). The inlet sample had low quantity of the above nutrients, compared to aerated sample and the released effluent. At the outlet the mean ammoniacal nitrogen (Table 13), phosphorus (Table 14) and potassium (Table 15) were found to be 24.40, 1.26 and 18.15 mg L^{-1} respectively. The above nutrients were more during the month of March 2001, at all point sources. The calcium (Table 16) and magnesium (Table 17) content of the effluent decreased after the treatment processes, from 410.3 to 243.7and 129.7 mg L^{-1} to 73.1 mg L^{-1} respectively at the outlet. Highest calcium (263 mg L^{-1}) and magnesium (89 mg L^{-1}) content were recorded during March 2001.

The sodium, chloride and sulphates content of the effluent were reduced after treatment and the values ranged from 364 to 417 (Table 18), 298 to 338 (Table 19) and 105 to 132 mg L^{-1} (Table 20) respectively in the released effluent outlet. Similar trend of recording the highest values in the month of March 2001 was reflected in sodium, chloride and sulphates. The total phenol content at the inlet was found to be 27.17 mg L^{-1} that was reduced to 10.86 mg L^{-1} at the outlet (Table 21).

The Na per cent and sodium adsorption ratio (SAR) of the effluent were reduced after treatment and ranged from 41.9 to 37.9 (Table 22) and 7.5 to 5.7 (Table 23) respectively. The highest Na per cent and SAR were observed in March 2001 followed by December 2000.

4.1.2. Biological Characteristics

The treated effluent had considerable amount of microbial load. The microbiological analysis revealed that the population was high in the aerated sample

Table 13.Ammoniacal nitrogen (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	19.2	32.7	22.2
December-2000	22.3	34.6	25.7
March-2001	24.6	35.3	26.5
June-2001	19.6	31.5	23.3
September-2001	21.7	32.3	24.3
Mean	21.48	33.27	24.40
Range	19.2-24.6	31.5-35.3	22.2-26.5
SD	2.20	1.62	1.75
SE	0.98	0.72	0.78

Table 14.Phosphorus (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	1.02	1.26	1.22
December-2000	1.26	1.59	1.32
March-2001	1.28	1.68	1.34
June-2001	1.07	1.21	1.25
September-2001	1.12	1.35	1.19
Mean	1.15	1.42	1.26
Range	1.02-1.28	1.21-1.68	1.19-1.34
SD	0.12	0.21	0.06
SE	0.05	0.09	0.03

Table 15. Potassium (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	15.5	25.4	15.6
December-2000	18.2	26.3	19.4
March-2001	19.3	27.5	21.3
June-2001	16.3	24.5	16.6
September-2001	17.9	23.2	17.8
Mean	17.44	25.38	18.15
Range	15.5-19.3	23.2-27.5	15.6-21.3
SD	1.53	1.66	2.27
SE	0.69	0.74	1.02

Table 16.Calcium (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	396	278	253
December-2000	424	299	236
March-2001	427	308	**263**
June-2001	417	295	234
September-2001	388	275	233
Mean	410.3	290.8	243.7
Range	388-427	275-308	233-263
SD	17.70	13.97	13.53
SE	7.91	6.25	6.05

Table 17.Magnisium (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	116	84	56
December-2000	142	115	83
March-2001	142	116	**89**
June-2001	118	92	65
September-2001	130	102	72
Mean	129.7	101.8	73.1
Range	116-142	84-116	56-89
SD	12.78	14.18	13.23
SE	5.72	6.34	5.92

Table 18.Sodium (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	674	482	393
December-2000	703	502	410
March-2001	712	521	417
June-2001	680	496	402
September-2001	661	454	364
Mean	686	491	397
Range	661-712	454-521	364-417
SD	21.04	24.98	20.61
SE	9.41	11.17	9.22

Table 19.Chloride (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	605	482	313
December-2000	612	497	327
March-2001	643	509	338
June-2001	574	462	298
September-2001	631	492	320
Mean	613	488	319
Range	574-643	462-509	298-338
SD	26.50	17.67	15.02
SE	11.85	7.90	6.72

Table 20.Sulphate (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	320	152	105
December-2000	389	181	130
March-2001	401	202	132
June-2001	357	167	112
September-2001	384	184	127
Mean	370	177	121
Range	320-401	152-202	105-132
SD	32.35	18.81	11.99
SE	14.47	8.41	5.36

Table 21.Total phenol (mg L^{-1}) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	25.4	20.8	9.4
December-2000	28.1	23.5	12.5
March-2001	29.3	24.6	13.1
June-2001	27.5	21.6	10.6
September-2001	25.5	22.8	8.7
Mean	27.17	22.66	10.86
Range	25.4-29.3	20.8-24.6	8.7-13.1
SD	1.72	1.51	1.91
SE	0.77	0.68	0.85

Table 22. Per cent sodium of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	40.7	38.4	38.3
December-2000	42.6	40.3	38.5
March-2001	42.9	40.4	39.2
June-2001	41.7	39.3	37.2
September-2001	41.7	38.0	36.4
Mean	41.9	39.3	37.9
Range	40.7-42.9	38.0-40.4	36.4-39.2
SD	0.88	1.07	1.12
SE	0.2	0.3	0.3

Table 23.SAR of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	7.3	6.2	5.8
December-2000	7.6	6.5	5.8
March-2001	7.8	6.5	6.0
June-2001	7.6	6.4	5.7
September-2001	7.4	5.9	5.3
Mean	7.5	6.3	5.7
Range	7.27-7.81	5.93-6.53	5.33-5.98
SD	0.21	0.25	0.25
SE	0.05	0.06	0.06

Table 24.Bacterial population (x 10^6 ml^{-1} CFU) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	45	76	60
December-2000	42	73	53
March-2001	38	71	48
June-2001	40	70	48
September-2001	47	82	53
Mean	42.4	74.4	52.4
Range	38-47	70-82	48-60
SD	3.65	4.83	5.05
SE	1.63	2.16	2.26

followed by outlet and inlet. Bacterial population (Table 24) was high and it varied from 48 to 60 x 10^6 ml^{-1} CFU followed by fungal (4 to 8 x 10^4 ml^{-1} CFU) (Table 25) and actinomycetes population (1 to 3 x 10^3 ml^{-1} CFU) (Table 26). The microbial load was found to be least during the summer months (March 2001).

4.2. Characteristics of Soils and Well water in and around the factory area under Bilt-IPCL effluent irrigation

4.2.1. Soil analysis

The result on the physico-chemical and biological characteristics of the field soils as influenced by effluent irrigation in and around the factory area is presented in Tables 27 to 43.

4.2.1.1. Physico-chemical properties

The mean pH of the soil samples collected at periodical intervals increased from 6.69 to 6.86 due to continuous Bilt-IPCL effluent irrigation, whereas the values in river water irrigated soils ranged from 7.02 to 7.15 (Table 27). The pH was very high during the summer (March, 2001) and very less during the north east monsoon (December, 2000). Among the villages, Rangarajapuram recorded higher pH followed by C. Thekkampatti. The EC of the soil samples were high under effluent irrigation compared to river water irrigation (Table 28). The EC values ranged from increased from 0.05 to 0.10 dS m^{-1} in effluent irrigated soils against 0.04 to 0.07 in river water irrigated soils. The highest EC was recorded in the month of March 2001(summer). The soluble salt concentration decreased during the monsoon seasons (December 2000, and 2001). Rangarajapuram village recorded the highest EC. The organic carbon content was increased during the month of March 2001. High OC content in soil was recorded

Table 25.Fungal population (x 10^4 ml^{-1} CFU) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	5	11	8
December-2000	4	10	6
March-2001	4	6	4
June-2001	5	7	5
September-2001	4	8	5
Mean	4.4	8.4	5.6
Range	4-5	6-11	4-8
SD	0.55	2.07	1.52
SE	0.24	0.93	0.68

Table 26.Actinomycetes population (x 10^3 ml^{-1} CFU) of Bilt-IPCL effluent at periodical intervals

Period	Point Sources		
	Inlet	Middle	Outlet
September-2000	4	4	3
December-2000	3	3	3
March-2001	4	3	1
June-2001	3	3	2
September-2001	4	4	3
Mean	3.6	3.4	2.4
Range	3-4	3-4	1-3
SD	0.55	0.55	0.89
SE	0.24	0.24	0.40

Table 27. pH of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	6.52	6.55	6.70	6.66	6.61	6.61
Devanapuram	6.51	6.54	6.67	6.64	6.61	6.59
P.Thekkampatti	6.63	6.66	6.82	6.76	6.67	6.71
C.Thekkampatti	6.92	6.93	7.06	7.01	6.95	6.97
Chinna kandiyur	6.78	6.81	6.95	6.90	6.83	6.85
Rangarajapuram	6.95	6.99	7.16	7.08	6.95	7.03
Mean	6.69	6.71	6.86	6.81	6.74	6.76
Range	6.30-7.02	6.32-7.08	6.51-7.28	6.45-7.20	6.42-7.05	6.41-7.10
SD	0.22	0.22	0.23	0.22	0.20	0.21
SE	0.04	0.04	0.04	0.04	0.03	0.04
Control(river water)	7.02	7.15	7.10	7.05	7.10	7.08

Table 28.EC (dSm^{-1}) of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	0.05	0.06	0.10	0.08	0.06	0.07
Devanapuram	0.04	0.05	0.09	0.08	0.06	0.06
P.Thekkampatti	0.05	0.06	0.11	0.09	0.06	0.07
C.Thekkampatti	0.04	0.05	0.10	0.08	0.06	0.07
Chinna kandiyur	0.04	0.05	0.09	0.08	0.06	0.06
Rangarajapuram	0.06	0.07	0.11	0.09	0.07	0.08
Mean	0.05	0.06	0.10	0.08	0.06	0.07
Range	0.03-0.08	0.03-0.09	0.07-0.13	0.06-0.12	0.03-0.10	0.05-0.10
SD	0.01	0.02	0.02	0.02	0.01	0.01
SE	0.00	0.00	0.00	0.00	0.00	0.00
Control(river water)	0.04	0.05	0.07	0.06	0.04	0.05

Table 29.Organic Carbon per cent of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	0.49	0.50	0.58	0.55	0.53	0.53
Devanapuram	0.45	0.47	0.54	0.49	0.47	0.48
P.Thekkampatti	0.44	0.46	0.52	0.49	0.46	0.47
C.Thekkampatti	0.48	0.49	0.54	0.52	0.50	0.51
Chinna kandiyur	0.44	0.45	0.51	0.49	0.46	0.47
Rangarajapuram	0.44	0.46	0.48	0.46	0.47	0.46
Mean	0.46	0.47	0.53	0.50	0.48	0.49
Range	0.38-0.61	0.40-0.63	0.45-0.68	0.42-0.65	0.42-0.62	0.42-0.64
SD	0.05	0.05	0.05	0.05	0.05	0.05
SE	0.01	0.01	0.01	0.01	0.01	0.01
Control(river water)	0.36	0.37	0.45	0.43	0.43	0.41

Mean,Range,SD,SE represents whole number of soil samples

under effluent irrigation compared to river water irrigated soil at different intervals of analysis (Table 29).

The mean soil available N status (Table 30) showed an increasing trend due to continuous effluent irrigation (142 – 145 kg ha^{-1}) over river water irrigation (135 to 142 kg ha^{-1}). The available P was recorded higher in effluent irrigated soil than river water irrigated soil (Table 31). Continuous effluent irrigation increased the soil available K status in and around the factory region than that of river water irrigated soils (Table 32).

Exchangeable sodium content was low in the river water irrigated soils compared to effluent irrigation (Table 33). The mean exchangeable sodium was found to be 5.98, 6.50, 7.11, 6.41, and 6.68 cmol (+) kg^{-1} at September 2000, December 2000, March 2001, June 2001 and September 2001 respectively in Bilt-IPCL effluent irrigated soil in and around the factory area. The sodium content was very high in Rangarajapuram during the period of March 2001.Similar trend of increase in soil exchangeable calcium (Table 34) was observed in effluent irrigation compared to river water irrigation. The river water irrigated soils recorded higher exchangeable magnesium content than effluent irrigated soils (Table 35). The exchangeable potassium content was less in river water irrigated soil compared to effluent irrigated soil (Table 36).

The ESP of the soil samples collected in and around the factory region irrigated by Bilt-IPCL effluent was higher than that of river water irrigation (Table 37). C. Thekkampatti recorded higher ESP values invariably in all seasons except September 2000. Among the villages, the lowest ESP was recorded in C. Kandiyur. The mean per cent chloride values at different location in and around the factory area ranged from 0.012 to 0.015. It was comparatively higher than the soil samples of river water irrigation (Table 38). Among the locations, C. Thekkampatti, Rangarajapuram and

Table 30. Available N (kg ha^{-1}) of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	135	135	138	136	136	136
Devanapuram	142	140	146	142	143	142
P.Thekkampatti	145	144	148	144	146	145
C.Thekkampatti	144	142	144	145	144	144
Chinna kandiyur	153	151	151	149	143	149
Rangarajapuram	147	145	145	143	139	144
Mean	144	142	145	143	142	143
Range	115-162	112-161	112-162	106-160	111-161	111-160
SD	11.0	11.5	11.5	11.7	10.7	10.9
SE	1.9	2.0	2.0	2.0	1.8	1.9
Control(river water)	141	142	141	139	135	140

Table 31. Available P (kg ha^{-1}) of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	28.75	27.96	28.61	28.69	27.08	28.22
Devanapuram	28.53	27.94	28.22	28.09	27.38	28.03
P.Thekkampatti	29.75	28.47	29.51	29.50	28.11	29.07
C.Thekkampatti	30.48	28.97	30.30	30.29	28.45	29.70
Chinna kandiyur	31.66	30.08	31.40	30.98	29.57	30.74
Rangarajapuram	31.46	29.12	31.30	28.41	26.84	29.43
Mean	29.88	28.65	29.66	29.33	27.94	29.09
Range	25.4-33.6	24.9-31.5	25.1-33.3	23.7-32.6	23.3-30.8	25.1-32.2
SD	2.12	2.00	2.13	2.55	2.16	2.00
SE	0.36	0.34	0.37	0.44	0.37	0.34
Control(river water)	28	28	29	29	26	28

Table 32. Available K (kg ha^{-1}) of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	233	231	240	230	236	234
Devanapuram	238	235	246	233	238	238
P.Thekkampatti	220	215	233	221	226	223
C.Thekkampatti	236	233	251	239	247	241
Chinna kandiyur	229	227	234	219	228	227
Rangarajapuram	231	229	235	221	230	229
Mean	231	228	240	228	235	232
Range	208-257	206-254	221-261	205-254	217-257	216-253
SD	13.0	13.5	10.8	12.7	11.0	10.7
SE	2.2	2.3	1.8	2.2	1.9	1.8
Control(river water)	237	235	247	234	246	240

Mean,Range,SD,SE represents whole number of soil samples

Table 33.Exchangeable Na (cmol (+) kg^{-1})of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	5.94	6.52	7.07	6.77	6.55	6.57
Devanapuram	5.97	6.62	7.10	6.79	6.40	6.58
P.Thekkampatti	5.92	6.35	7.20	6.76	6.37	6.52
C.Thekkampatti	5.96	6.46	7.11	6.60	6.47	6.52
Chinna kandiyur	6.06	6.55	7.01	6.40	6.19	6.44
Rangarajapuram	6.10	6.49	7.21	6.70	6.52	6.60
Mean	5.98	6.50	7.11	6.68	6.41	6.54
Range	5.6-6.6	6.1-7.0	6.7-7.9	6.2-7.0	5.7-7.0	6.2-7.1
SD	0.28	0.29	0.25	0.26	0.31	0.23
SE	0.05	0.05	0.04	0.05	0.05	0.04
Control(river water)	5.75	6.98	6.82	6.52	6.31	6.42

Table 34.Exchangeable Ca (cmol (+) kg^{-1}) of soil samples of in and around the Factory are

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	8.47	8.54	9.42	9.46	8.77	8.93
Devanapuram	8.49	8.47	9.37	9.47	8.77	8.91
P.Thekkampatti	8.29	8.60	9.39	9.50	8.48	8.86
C.Thekkampatti	7.77	7.88	8.81	8.93	8.04	8.29
Chinna kandiyur	8.27	8.56	9.49	9.76	8.93	9.00
Rangarajapuram	7.83	8.34	9.29	9.44	8.51	8.68
Mean	8.23	8.41	9.30	9.42	8.58	8.79
Range	6.9-8.9	7.1-9.0	8.6-10.1	8.6-10.3	7.5-9.4	7.9-9.5
SD	0.47	0.46	0.44	0.44	0.47	0.41
SE	0.08	0.08	0.08	0.08	0.08	0.07
Control(river water)	7.25	7.41	8.45	8.41	7.65	8.52

Table 35.Exchangeable Mg (cmol (+)kg^{-1} of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	4.50	4.54	5.00	5.03	4.66	4.75
Devanapuram	4.51	4.50	4.98	5.03	4.66	4.74
P.Thekkampatti	4.41	4.57	4.99	5.05	4.51	4.70
C.Thekkampatti	4.13	4.19	4.68	4.74	4.27	4.40
Chinna kandiyur	4.39	4.55	5.04	5.18	4.74	4.78
Rangarajapuram	4.16	4.43	4.94	5.02	4.52	4.61
Mean	4.37	4.47	4.94	5.00	4.56	4.67
Range	3.7-4.7	3.8-4.8	4.5-5.4	4.5-5.5	4.0-5.0	4.2-5.1
SD	0.25	0.25	0.24	0.23	0.25	0.215
SE	0.04	0.04	0.04	0.04	0.04	0.04
Control(river water)	3.32	3.45	3.78	3.85	3.51	3.66

Mean,Range,SD,SE represents whole number of soil samples

Table 36 Exchangeable K (cmol (+) kg^{-1}) of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	0.067	0.073	0.094	0.082	0.076	0.078
Devanapuram	0.058	0.065	0.102	0.090	0.071	0.077
P.Thekkampatti	0.064	0.074	0.100	0.079	0.076	0.079
C.Thekkampatti	0.064	0.074	0.102	0.078	0.076	0.079
Chinna kandiyur	0.064	0.074	0.100	0.078	0.074	0.078
Rangarajapuram	0.067	0.076	0.103	0.080	0.078	0.081
Mean	0.06	0.07	0.10	0.08	0.08	0.08
Range	0.04-0.07	0.05-0.08	0.08-0.12	0.07-0.10	0.05-0.08	0.06-0.09
SD	0.01	0.01	0.01	0.01	0.01	0.01
SE	0.001	0.001	0.001	0.001	0.001	0.001
Control(river water)	0.069	0.072	0.078	0.075	0.072	0.073

Table 37.ESP of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	30.9	32.7	32.3	31.3	32.2	32.5
Devanapuram	30.9	33.3	32.5	31.3	31.7	32.5
P.Thekkampatti	31.2	32.0	32.8	31.2	32.3	32.2
C.Thekkampatti	32.8	34.3	33.9	32.0	33.9	34.1
Chinna kandiyur	31.8	32.7	31.9	29.5	30.7	31.7
Rangarajapuram	33.1	33.2	33.0	31.1	32.8	33.0
Mean	30.0	32.0	34.4	32.7	31.8	31.9
Range	27.5-33.4	28.9-35.6	31.5-37.9	29.4-36.5	28.1-35.3	29.0-35.3
SD	1.79	1.77	1.69	1.70	1.92	1.62
SE	0.31	0.30	0.29	0.29	0.33	0.28
Control(river water)	30.4	35.4	31.4	30.4	31.7	31.1

Table 38.Per cent Chloride of soil samples in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	0.012	0.013	0.015	0.013	0.013	0.013
Devanapuram	0.012	0.014	0.016	0.014	0.013	0.014
P.Thekkampatti	0.011	0.013	0.016	0.014	0.013	0.013
C.Thekkampatti	0.013	0.013	0.016	0.014	0.013	0.014
Chinna kandiyur	0.011	0.012	0.015	0.013	0.012	0.013
Rangarajapuram	0.013	0.014	0.015	0.014	0.013	0.014
Mean	0.01	0.01	0.02	0.01	0.01	0.01
Range	0.011-0.013	0.011-0.015	0.013-0.018	0.011-0.016	0.011-0.015	0.012-0.015
SD	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.00	0.00	0.00	0.00	0.00	0.00
Control(river water)	0.013	0.014	0.015	0.013	0.013	0.013

Mean,Range,SD,SE represents whole number of soil samples

Devanapuram recorded higher percent chloride than the other villages. The percent chloride was maximum during summer season (March, 2001). Similar trend was also observed in CEC of soil samples and the values ranged from 20.6-23.1 cmol (+) kg^{-1} during March, 2001 (Table 39). The mean SAR was high in the soil samples collected in the effluent irrigated soil and the SAR values ranged from 3.3 to 3.9 compared to river water irrigated soils (Table 40).

4.2.1.2. Biological properties

Soil irrigated with Bilt-IPCL effluent recorded higher microbial load than river water irrigated soil. The mean bacterial population for different periods increased from 19 to 25 x 10^6 g^{-1} of dry soil in the effluent irrigated soil while in the river water irrigation it increased from 14 to 20 x 10^6 g^{-1} of dry soil (Table 41). Considerable amount of fungi (Table 42) and actinomycetes (Table 43) were also present in effluent and river water irrigated soils. A similar trend of increase in microbial population was also noticed in fungi and actinomycetes at periodical intervals and also at different locations of in and around the factory area.

4.2.2. Well Water Analysis

The pH of the well water collected in and around the factory area irrigated by Bilt-IPCL effluent was high compared to that of river water irrigation, at different period of analysis. The mean pH of the well water increased from 7.50 to 8.58 in continuous effluent irrigation (Table 44). The pH of the water samples were high during the summer (March, April and May) and low during monsoon season (October, November and December). Among the villages, P. Thekkampatti recorded high pH followed by C. Kandiyur. The EC of the well water ranged from 0.82 to 1.02 dSm^{-1} (Table 45) and for river water from 0.09 to 0.18 dSm^{-1} at different intervals. C. Thekkampatii recorded higher EC whereas C.Kandiyur showed comparatively lower

Table 39.CEC (cmol (+) kg^{-1}) of soil samples of in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	19.2	19.9	21.9	21.6	20.3	20.6
Devanapuram	19.3	19.9	21.8	21.7	20.2	20.6
P.Thekkampatti	18.9	19.9	22.0	21.7	19.7	20.4
C.Thekkampatti	18.2	18.9	21.0	20.6	19.1	19.5
Chinna kandiyur	19.0	20.0	21.9	21.7	20.2	20.6
Rangarajapuram	18.4	19.6	21.8	21.5	19.9	20.3
Mean	18.90	19.71	21.74	21.48	19.90	20.34
Range	16.8-19.8	17.6-20.6	20.6-23.1	20.3-22.6	18.3-21.2	18.9-21.2
SD	0.66	0.67	0.60	0.60	0.66	0.57
SE	0.11	0.12	0.10	0.10	0.11	0.10
Control(river water)	16.2	16.3	16.5	16.3	16.4	16.3

Table 40.SAR of soil samples of in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	3.14	3.50	3.83	3.65	3.50	3.53
Devanapuram	3.16	3.57	3.85	3.66	3.42	3.53
P.Thekkampatti	3.17	3.39	3.90	3.64	3.47	3.51
C.Thekkampatti	3.29	3.60	3.98	3.67	3.61	3.63
Chinna kandiyur	3.25	3.50	3.77	3.39	3.28	3.44
Rangarajapuram	3.36	3.53	3.93	3.61	3.54	3.59
Mean	3.21	3.51	3.87	3.61	3.47	3.54
Range	2.9-3.6	3.1-3.9	3.5-4.4	3.2-4.1	3.0-3.9	3.3-3.9
SD	0.20	0.21	0.21	0.20	0.23	0.18
SE	0.04	0.04	0.04	0.03	0.04	0.03
Control(river water)	2.95	3.67	3.65	3.46	3.28	3.39

Table 41.Bacterial population(X 10^6 g^{-1} CFU) of soil samples of in and around the Facto

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	17	20	26	24	23	22
Devanapuram	18	21	26	24	22	22
P.Thekkampatti	19	21	27	25	24	23
C.Thekkampatti	22	24	28	27	26	25
Chinna kandiyur	21	23	27	25	24	24
Rangarajapuram	23	24	29	28	27	26
Mean	19	22	27	25	24	24
Range	15-27	17-28	24-31	21-31	19-30	19.8-29
SD	3.17	2.73	1.82	2.15	2.47	2.34
SE	0.54	0.47	0.31	0.37	0.42	0.40
Control(river water)	14	16	20	19	17	17.2

Mean,Range,SD,SE represents whole number of soil samples

Table 42.Fungal population (X 10^4 g^{-1} CFU) of soil samples of in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	4	4	5	5	6	5
Devanapuram	4	4	4	5	6	5
P.Thekkampatti	4	4	5	5	6	5
C.Thekkampatti	4	4	5	5	6	5
Chinna kandiyur	4	4	5	6	6	5
Rangarajapuram	4	5	5	6	6	5
Mean	4	4	5	5	6	5
Range	3.0-5.0	3.0-5.0	4.0-6.0	4.0-7.0	5.0-7.0	3.8-6.0
SD	0.67	0.65	0.74	0.70	0.67	0.52
SE	0.12	0.11	0.13	0.12	0.11	0.09
Control(river water)	2	3	3	4	4	3.2

Table 43.Actinomycetes population (X 10^5 g^{-1} CFU) of soil samples of in and around the Factory area

Location	Sep-00	Dec-00	Mar-01	Jun-01	Sep-01	Mean
Mandarikadu	2	2	2	3	3	2
Devanapuram	2	3	3	3	2	3
P.Thekkampatti	2	3	3	2	3	3
C.Thekkampatti	2	2	3	3	3	2
Chinna kandiyur	2	2	2	3	3	2
Rangarajapuram	1	2	2	3	3	2
Mean	2	2	2	3	3	2
Range	1.0-3.0	1.0-4.0	2.0-4.0	1.0-4.0	1.0-4.0	1.8-3.0
SD	0.73	0.68	0.66	0.97	0.80	0.35
SE	0.13	0.12	0.11	0.17	0.14	0.06
Control(river water)	1	1	2	3	2	1.8

Mean,Range,SD,SE represents whole number of soil samples

Table 44.pH of water samples in and around the factory area

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	7.48	7.53	7.53	8.30	8.25	8.38	8.37	8.41	8.26	8.32	8.33	8.35	8.12
Devanapuram	7.43	7.45	7.46	8.35	8.30	8.44	8.42	8.47	8.43	8.36	8.38	8.41	8.16
P.Thekkampatti	7.63	7.66	7.68	8.74	8.71	8.78	8.76	8.81	8.77	8.73	8.74	8.74	8.48
C.Thekkampatti	7.51	7.55	7.55	8.43	8.41	8.53	8.52	8.55	8.46	8.48	8.52	8.50	8.25
C.Kandiyur	7.50	7.50	7.51	8.65	8.62	8.66	8.64	8.67	8.65	8.61	8.62	8.64	8.36
R.Rajapuram	7.41	7.42	7.44	8.35	8.32	8.47	8.46	8.49	8.53	8.36	8.39	8.43	8.17
Mean	7.50	7.53	7.54	8.48	8.44	8.55	8.54	8.58	8.51	8.49	8.51	8.52	8.26
Range	7.10-7.85	7.14-7.92	7.15-7.85	8.05-8.98	8.00-8.91	8.14-9.02	8.13-8.97	8.17-9.02	7.76-9.14	8.05-8.94	8.07-8.98	8.10-8.94	7.96-8.63
SD	0.205	0.204	0.199	0.221	0.231	0.191	0.201	0.198	0.270	0.208	0.204	0.205	0.174
SE	0.035	0.035	0.034	0.038	0.040	0.033	0.035	0.034	0.046	0.036	0.035	0.035	0.030
Control(river water)	7.27	7.30	7.35	7.54	7.52	7.65	7.63	7.66	7.47	7.56	7.59	7.62	7.51

Table 45.EC of water samples in and around the factory area (dS m^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	0.66	0.68	0.70	1.87	0.99	1.07	1.03	1.09	1.01	0.92	0.95	0.98	1.00
Devanapuram	0.71	0.72	0.74	0.81	1.04	1.00	0.98	1.03	0.98	0.87	0.93	0.97	0.90
P.Thekkampatti	0.90	1.07	1.06	0.88	0.92	0.98	0.96	1.01	0.95	0.91	0.92	0.94	0.96
C.Thekkampatti	1.00	1.02	1.04	0.94	1.13	1.05	1.02	1.07	1.00	0.97	0.99	1.00	1.02
C.Kandiyur	0.83	0.84	0.85	0.66	0.79	0.82	0.80	0.85	0.74	0.68	0.77	0.79	0.79
R.Rajapuram	0.88	0.91	0.91	0.85	1.08	1.08	1.06	1.10	1.00	0.91	0.94	1.03	0.98
Mean	0.82	0.87	0.88	1.02	0.99	1.00	0.97	1.02	0.95	0.88	0.92	0.95	0.94
Range	0.08-1.21	0.46-1.25	0.47-1.25	0.39-7.26	0.67-1.76	0.66-1.38	0.66-1.38	0.70-1.41	0.60-1.32	0.52-1.32	0.65-1.29	0.68-1.31	0.70-1.68
SD	0.237	0.209	0.203	1.114	0.212	0.152	0.151	0.159	0.151	0.172	0.155	0.145	0.172
SE	0.041	0.036	0.035	0.191	0.036	0.026	0.026	0.027	0.026	0.029	0.027	0.025	0.029
Control(river water)	0.09	0.11	0.10	0.15	0.07	0.15	0.12	0.16	0.15	0.18	0.15	0.09	0.13

Range,Mean,SD and SE values represented whole number of water samples

EC value (0.79 dSm^{-1}). The increasing trend of EC was observed in all the villages due to continuous effluent irrigation inside the factory area for sugarcane. The highest EC of 1.00, 0.97, 1.02 dSm^{-1} was observed in March, April and May 2001 respectively, whereas October, 2000 recorded lower EC value of 0.85 dSm^{-1}.

The total dissolved solids of well water samples increased from 527 to 646 (mg L^{-1}) at periodical intervals whereas river water ranged from 58 to 178 (mg L^{-1}) (Table 46). The total hardness of well water increased from 282 to 398 mg L^{-1} (Table 47), whereas river water recorded less values of total hardness compared to observation wells in and around the factory region.

The BOD in the well water samples varied from 7.7 to 8.9 mg L^{-1} whereas river water recorded the BOD ranged from 6.2 to 7.2 mg L^{-1} (Table 48). The BOD of the water samples increased during the summer season (March, April and May) and again decreased drastically in the monsoon season. Among the villages Devanapuram recorded the highest BOD and the lowest BOD was observed in monsoon (October, 2000). The similar trend was observed in COD except the highest COD was recorded in the P.Thekkampatti village (99 mg L^{-1}). The (COD) of the well water samples were high in effluent irrigated area (67 to 111 mg L^{-1}) whereas in river water recorded very less COD in the range of 16 to 73 mg L^{-1} (Table 49).

Carbonates and bicarbonates were found to be more in well water than that of river water used for irrigation. The carbonates and bicarbonates increased from 43 to 57 mg L^{-1}(Table 50) and 268 to 305 mg L^{-1} (Table 51) respectively at periodical intervals.

The chloride (Table 52) and sulphates (Table 53) concentration were higher in the factory regions of Bilt-IPCL effluent irrigated area, whereas river water recorded very low concentration of chloride and sulphates. Chloride increased from 82.4 to 101.1 mg L^{-1} in the well water whereas river water ranged from 21.3 to 42.5 mg L^{-1}.

Table 46. TDS of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	423	434	447	965	628	672	654	690	646	585	622	632	616
Devanapuram	456	457	475	521	661	629	623	651	623	554	637	616	575
P.Thekkampatti	573	683	678	560	588	619	610	639	610	579	585	599	610
C.Thekkampatti	638	648	662	603	718	661	644	674	637	645	690	694	659
C.Kandiyur	529	537	541	424	507	516	508	536	474	429	504	493	500
R.Rajapuram	562	578	580	546	691	677	672	693	641	576	677	686	632
Mean	527	555	564	610	630	628	617	646	607	564	617	617	598
Range	51-773	293-798	301-800	250-3246	427-1123	415-868	418-875	442-891	383-843	330-838	435-843	414-1006	446-954
SD	151.7	133.1	130.0	476.7	135.5	95.6	95.4	100.5	96.7	115.4	110.0	116.7	97.9
SE	26.0	22.8	22.3	81.8	23.2	16.4	16.4	17.2	16.6	19.8	18.9	20.0	16.8
Control(river water)	58	70	64	173	45	94	76	101	96	178	96	57	92

Table 47. Total Hardness of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	301	295	302	408	433	446	415	471	456	413	445	468	404
Devanapuram	284	286	291	340	378	385	354	398	391	352	382	395	353
P.Thekkampatti	289	296	301	288	349	361	305	370	343	302	358	368	328
C.Thekkampatti	297	310	313	295	363	370	305	417	399	303	368	415	346
C.Kandiyur	226	235	237	324	365	383	339	348	336	336	380	345	321
R.Rajapuram	286	311	305	325	348	353	331	359	351	329	351	356	334
Mean	282	288	292	330	375	385	342	398	382	340	383	395	349
Range	147-392	150-403	153-404	143-751	182-784	186-810	147-754	217-817	208-765	146-752	185-808	215-806	180-657
SD	67.4	65.2	64.8	102.0	105.6	111.6	99.6	116.5	111.7	99.6	111.5	115.5	83.3
SE	11.6	11.2	11.1	17.5	18.1	19.1	17.1	20.0	19.1	17.1	19.1	19.8	14.3
Control(river water)	60	54	63	73	94	101	90	142	146	88	98	142	96

Range, Mean, SD and SE values represented whole number of water samples

Table 48.BOD of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	7.8	8.0	7.9	7.4	7.9	8.7	8.6	9.0	8.3	7.9	8.1	8.5	8.2
Devanapuram	7.7	8.3	8.4	7.8	8.4	9.1	9.0	9.2	8.5	8.4	8.8	8.8	8.5
P.Thekkampatti	7.8	8.0	8.1	8.0	7.5	8.8	8.8	9.0	8.2	8.3	8.3	8.6	8.3
C.Thekkampatti	7.7	8.0	8.2	7.7	7.9	8.7	8.5	8.8	8.2	8.1	8.3	8.3	8.2
C.Kandiyur	7.6	7.9	8.1	7.2	8.0	8.3	8.1	8.4	8.3	7.8	8.3	7.9	8.0
R.Rajapuram	7.8	8.1	8.3	7.9	7.9	8.7	8.6	8.8	8.4	8.2	8.3	8.4	8.3
Mean	7.7	8.0	8.1	7.7	7.9	8.7	8.6	8.9	8.3	8.1	8.3	8.4	8.2
Range	7.6-7.8	7.9-8.3	7.9-8.4	7.2-8.0	7.5-8.4	8.3-9.1	8.1-9.0	8.4-9.2	8.2-8.5	7.8-8.4	8.1-8.8	7.9-8.8	8.0-8.5
SD	0.07	0.13	0.17	0.31	0.30	0.27	0.28	0.27	0.11	0.23	0.23	0.30	0.17
SE	0.01	0.03	0.03	0.06	0.06	0.05	0.06	0.05	0.02	0.05	0.05	0.06	0.03
Control(river water)	6.2	6.6	6.5	6.2	6.8	6.9	7.2	7.05	6.8	7.05	7.15	7.2	6.80

Table 49.COD of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	67	69	64	117	77	112	107	120	96	98	102	108	95
Devanapuram	61	64	59	112	98	111	107	113	80	82	92	103	90
P.Thekkampatti	71	80	75	162	91	114	107	123	82	84	98	103	99
C.Thekkampatti	67	72	77	99	67	101	97	104	80	85	89	95	86
C.Kandiyur	67	70	67	131	45	96	92	100	64	66	79	83	80
R.Rajapuram	69	69	59	128	43	90	87	96	69	88	83	85	81
Mean	67	71	68	125	75	106	101	111	80	84	92	98	90
Range	32-96	48-96	48-96	48-192	32-128	43-155	38-150	51-163	48-112	50-116	55-152	39-151	59-119
SD	18.69	17.70	14.77	35.99	30.69	21.20	21.80	21.42	17.62	17.36	20.88	22.01	13.35
SE	3.20	3.04	2.53	6.17	5.26	3.64	3.74	3.67	3.02	2.98	3.58	3.77	2.29
Control(river water)	48	64	64	16	48	70	71	73	64	62	65	68	59

Range,Mean,SD and SE values represented whole number of water samples

Table 50.CO_3 of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	48	40	40	86	58	60	56	63	42	46	46	52	53
Devanapuram	43	51	57	46	45	51	48	54	57	45	45	47	49
P.Thekkampatti	57	53	57	57	63	63	60	64	57	50	52	54	57
C.Thekkampatti	38	46	48	44	50	55	53	59	48	46	48	51	49
C.Kandiyur	24	36	41	24	34	40	37	42	41	30	32	35	35
R.Rajapuram	44	40	40	48	48	48	48	54	40	42	44	46	45
Mean	43	46	48	52	50	54	51	57	49	44	45	48	49
Range	0-84	0-72	24-72	0-300	0-84	30-84	24-84	24-84	24-72	18-72	24-72	24-78	30-81
SD	21.93	17.42	15.77	48.96	20.84	14.01	14.34	13.22	14.83	13.42	12.76	12.58	13.71
SE	3.76	2.99	2.70	8.40	3.57	2.40	2.46	2.27	2.54	2.30	2.19	2.16	2.35
Control(river water)	0	36	48	0	0	30	24	36	48	12	24	30	24

Table 51.HCO_3 of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	289	291	285	460	285	329	312	339	293	299	302	311	316
Devanapuram	260	265	263	293	260	285	282	292	256	267	275	277	273
P.Thekkampatti	295	295	295	315	302	327	317	333	308	291	311	313	308
C.Thekkampatti	283	285	275	291	287	304	296	314	295	277	285	290	290
C.Kandiyur	295	303	295	222	227	252	243	265	215	224	232	237	251
R.Rajapuram	289	277	281	207	203	239	228	256	228	215	221	223	239
Mean	284	286	282	309	268	296	286	305	272	269	278	282	285
Range	134-525	159-500	159-488	146-1305	171-427	220-462	214-433	227-484	148-415	181-390	196-415	207-429	194-452
SD	76.18	65.47	65.62	191.95	59.69	60.95	60.47	60.95	62.43	52.76	59.11	58.11	54.54
SE	13.06	11.23	11.25	32.92	10.24	10.45	10.37	10.45	10.71	9.05	10.14	9.97	9.35
Control(river water)	134	146	146	146	171	164	160	168	134	134	146	159	151

Range,Mean,SD and SE values represented whole number of water samples

Table 52. Cl^- ***of water samples in and around the factory area (mg*** L^{-1}***)***

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	87.4	91.0	86.3	99.3	83.9	95.7	92.2	96.9	88.6	100.4	89.8	91.0	91.9
Devanapuram	69.9	71.9	69.9	78.0	71.9	86.1	85.1	92.2	77.0	79.0	81.0	82.0	78.7
P.Thekkampatti	86.1	87.1	86.1	93.2	84.1	101.3	100.3	103.3	94.2	97.2	98.2	98.2	94.1
C.Thekkampatti	88.6	88.6	87.4	95.7	94.5	99.3	96.9	101.6	100.4	91.0	92.2	94.5	94.2
C.Kandiyur	93.6	90.8	90.8	103.5	99.3	110.6	109.2	110.6	104.9	106.4	107.8	107.8	102.9
R.Rajapuram	68.5	73.3	70.9	70.9	99.3	106.4	101.6	108.7	78.0	82.7	89.8	92.2	86.9
Mean	83.0	84.2	82.4	91.1	87.0	98.6	96.5	101.1	90.9	93.0	92.8	93.8	91.2
Range	21-121	28-113	28-121	28-163	43-128	71-121	64-113	78-121	35-128	43-156	50-121	57-128	61-116
SD	24.96	19.34	20.87	25.96	20.00	11.63	12.09	10.37	21.62	21.78	16.31	14.61	13.31
SE	4.28	3.32	3.58	4.45	3.43	1.99	2.07	1.78	3.71	3.74	2.80	2.51	2.28
Control(river water)	28.4	42.5	42.5	21.3	28.4	21.3	28.4	28.4	21.3	28.4	21.3	28.4	28.4

Table 53. SO_4 **of water samples in and around the factory area (mg** L^{-1}**)**

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	83.8	84.3	78.8	82.2	81.8	90.0	88.0	90.2	76.2	82.2	83.2	87.7	84.0
Devanapuram	91.6	85.0	74.2	90.1	79.9	97.0	95.9	99.4	70.1	78.8	78.9	92.8	86.2
P.Thekkampatti	108.2	101.8	99.6	106.6	98.1	108.0	106.5	109.7	98.7	103.2	103.3	105.4	104.1
C.Thekkampatti	102.9	102.7	91.8	100.5	98.6	104.5	102.7	106.0	89.9	95.7	100.3	100.6	99.7
C.Kandiyur	77.5	89.1	78.9	76.4	83.6	87.8	86.2	89.9	77.3	79.2	84.2	85.0	82.9
R.Rajapuram	120.3	112.4	103.5	119.4	107.0	117.8	115.4	119.5	102.6	106.0	111.4	113.5	112.4
Mean	96.1	94.5	86.6	94.5	90.2	99.8	98.2	101.4	84.5	89.9	92.1	96.5	93.7
Range	20-227	20-227	33-194	19-226	13-218	35-233	33-232	35-235	30-192	29-198	23-222	32-229	27-216
SD	62.83	60.63	51.33	62.75	59.34	59.68	59.69	59.97	52.15	53.17	58.15	59.57	57.67
SE	10.77	10.40	8.80	10.76	10.18	10.24	10.24	10.28	8.94	9.12	9.97	10.22	9.89
Control(river water)	45.3	36.5	45.3	46.1	31.6	45.8	45.3	46.2	41.3	33.6	39.4	42.1	41.5

Range,Mean,SD and SE values represented whole number of water samples

The sulphate content ranged from 84.5 to 101.4 mg L^{-1} in the well water and 31.6 to 45.8 mg L^{-1} in the river water. The calcium content ranged from 42.4 to 50.9 mg L^{-1} in the well water whereas river water ranged from 11.2 to 19.8 mg L^{-1}. The highest calcium was observed in the summer season (Table 54). The magnesium content ranged from 41.7 to 64.9 mg L^{-1} in well water whereas river water ranged from 5.6 to 23.6. Among the villages C.Thekkampatti recorded the highest magnesium content (Table 55).

The sodium content was more in the well water than that of river water and it increased from 57.3 to 83.1 mg L^{-1} in the well water during different period of analysis (Table 56). The potassium content also more in the well water as compared to river water. The highest value of 6.2 mg L^{-1} was observed in the factory site of Mandaraikadu (Table 57). Two fold increases in the sodium content was observed in the P. Thekkampatti village. Devanapuram and the factory site (Mandaraidadu) recorded very low sodium in the water samples. Among the seasons, summer months recorded higher sodium than the monsoon seasons.

The per cent sodium in the well water samples varied from 25.16 to 29.21 while river water recorded 7.23 to 30.34 per cent (Table 58). The potential salinity of the well water was very high and ranged from 3.2 to 3.9 cmol L^{-1} (Table 59). The highest potential salinity was recorded in C. Kandiyur followed by P. Thekkampatti and C. Thekkampatti. The later two were more or less same. Among the seasons, summer months recorded higher salinity than the monsoon season of September, October and November.

The SAR of the well water sample was high in effluent irrigated soil (1.49 to 1.88) while that of river water recorded very less SAR (0.152 to 0.764) (Table 60). The RSC value of well water samples was negative. It ranged from –1.61 to 0.45 and 0.75

Table 54. Ca of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	44.0	41.1	42.4	74.7	81.5	84.8	78.5	89.9	86.3	77.9	84.2	88.7	72.8
Devanapuram	49.6	49.4	51.0	54.3	62.2	61.8	56.2	64.5	64.4	55.6	60.8	63.9	57.8
P.Thekkampatti	44.0	45.8	47.6	29.4	33.8	34.4	30.3	36.2	35.7	29.4	33.7	35.4	36.3
C.Thekkampatti	45.3	50.2	51.8	31.8	33.7	35.6	33.0	35.3	34.3	31.7	33.8	34.2	37.6
C.Kandiyur	32.3	35.1	36.7	25.6	30.0	31.0	27.6	32.4	30.5	26.4	29.9	30.7	30.7
R.Rajapuram	38.9	44.3	45.2	29.9	34.1	34.1	29.7	37.3	37.7	28.9	33.1	36.3	35.8
Mean	43.2	44.8	46.3	42.4	47.5	48.6	44.2	50.9	49.7	43.3	47.6	49.9	46.5
Range	9.6-78.4	14.4-69	17.6-70	12.6-196	15.4-164	15.4-175	13.8-210	17.9-185	16.3-181	13.0-210	15.2-174	16.6-184	17.1-146
SD	15.97	13.20	13.11	32.63	29.52	30.76	34.61	32.19	31.75	34.67	30.77	32.31	23.80
SE	2.74	2.26	2.25	5.60	5.06	5.28	5.94	5.52	5.45	5.95	5.28	5.54	4.08
Control(river water)	14.4	11.2	12.8	13.8	20.0	18.9	15.7	19.8	19.0	14.9	18.6	18.7	16.5

Table 55. Mg of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	45.7	46.1	47.0	53.0	55.2	56.2	52.5	59.0	57.6	52.4	56.2	59.0	53.3
Devanapuram	38.4	39.1	39.2	49.0	53.4	55.3	51.2	56.9	55.2	51.2	55.2	56.5	50.0
P.Thekkampatti	42.9	43.6	43.8	51.6	63.6	66.0	54.9	67.2	60.9	54.8	65.7	67.0	56.8
C.Thekkampatti	44.1	44.2	44.0	51.6	66.8	67.5	53.4	79.0	75.3	53.7	68.1	79.1	60.6
C.Kandiyur	34.8	35.4	34.8	62.4	69.5	73.2	64.9	64.0	62.3	64.8	73.2	64.3	58.6
R.Rajapuram	45.4	48.0	46.2	60.0	63.1	64.4	61.7	63.6	61.6	61.7	64.4	63.7	58.6
Mean	41.7	42.4	42.3	53.7	61.4	63.2	55.5	64.9	61.9	55.5	63.3	64.9	55.9
Range	14-55	14-56	14-55	18-80	14-108	18-117	21-80	16-136	14-128	21-80	18-118	16-136	21-92
SD	10.31	10.33	10.38	15.19	21.13	21.67	14.71	22.65	21.73	14.87	21.73	22.60	14.56
SE	1.767	1.771	1.781	2.605	3.624	3.716	2.523	3.884	3.727	2.551	3.726	3.875	2.498
Control(river water)	5.6	6.1	7.4	9.2	10.6	12.9	12.2	22.2	23.6	12.2	12.4	22.9	13.1

Range,Mean,SD and SE values represented whole number of water samples

Table 56.Sodium of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	52.3	51.6	51.5	49.7	35.7	48.7	44.9	47.3	36.9	37.2	42.8	43.2	45.1
Devanapuram	37.8	37.6	37.9	31.1	40.0	48.2	40.6	43.5	34.7	32.2	36.1	38.2	38.2
P.Thekkampatti	84.4	81.1	81.3	101.9	190.9	161.8	137.9	144.0	147.0	114.7	121.2	132.5	124.9
C.Thekkampatti	44.1	44.8	44.4	80.3	67.7	86.1	82.2	83.0	76.9	69.7	77.4	79.4	69.7
C.Kandiyur	73.0	74.5	74.1	50.3	62.6	68.4	62.3	67.0	54.6	50.5	55.7	61.7	62.9
R.Rajapuram	55.8	57.4	56.1	56.5	51.2	68.8	63.0	66.5	57.9	53.2	56.5	58.3	58.4
Mean	57.8	57.5	57.3	62.7	79.5	83.1	73.9	77.3	70.6	61.2	66.8	70.9	68.2
Range	26-200	26-177	26-179	12-191	26-756	37-562	29-471	33-456	27-489	20-235	9-452	21-463	28-350
SD	35.53	32.68	32.75	42.07	123.28	89.39	75.32	72.86	79.39	46.05	73.19	75.01	55.61
SE	6.09	5.60	5.62	7.21	21.14	15.33	12.92	12.49	13.62	7.90	12.55	12.86	9.54
Control(river water)	10.0	10.1	10.1	15.0	3.4	17.3	12.2	16.7	6.8	9.7	9.8	8.7	10.8

Table 57.Pottasium of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	5.8	6.0	6.2	10.3	4.9	6.9	6.1	6.4	5.2	5.5	5.5	5.9	6.2
Devanapuram	3.8	4.1	4.3	4.0	3.8	5.3	4.6	5.0	3.9	3.8	4.1	4.3	4.3
P.Thekkampatti	4.1	4.0	4.2	3.9	3.9	4.6	4.3	4.4	3.9	3.8	4.0	4.1	4.1
C.Thekkampatti	4.9	10.7	4.7	2.8	3.4	4.4	4.0	4.2	3.1	3.0	3.1	3.7	4.3
C.Kandiyur	5.5	5.0	4.9	3.1	5.2	5.3	4.7	5.1	4.5	3.8	4.0	4.5	4.6
R.Rajapuram	5.4	16.4	4.4	3.2	4.2	4.4	4.1	4.3	3.9	3.4	3.8	3.8	5.1
Mean	4.8	6.8	4.8	4.7	4.2	5.2	4.7	4.9	4.1	3.9	4.1	4.4	4.7
Range	0.98-12.0	1.25-38.2	1.40-12.0	2.00-36.1	2.30-7.8	3.09-9.4	2.70-8.7	2.85-9.1	2.10-7.9	1.87-8.1	2.03-8.2	2.50-8.5	3.40-9.3
SD	1.75	8.13	1.61	5.68	1.10	1.34	1.15	1.19	1.19	1.11	1.14	1.26	1.31
SE	0.30	1.39	0.28	0.97	0.19	0.23	0.20	0.20	0.20	0.19	0.20	0.22	0.23
Control(river water)	1.0	1.2	1.6	1.6	0.7	1.6	1.4	1.5	1.3	1.5	1.3	1.5	1.3

Range,Mean,SD and SE values represented whole number of water samples

Table 58.Per cent sodium of water samples in and around the factory area

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	26.41	26.55	26.00	20.02	16.27	18.60	19.35	19.17	15.62	17.13	18.18	17.93	20.10
Devanapuram	22.36	22.02	21.88	16.13	18.09	18.71	18.72	19.83	16.22	16.45	17.04	17.00	18.70
P.Thekkampatti	36.24	35.31	34.85	39.94	42.68	40.46	39.39	39.84	40.74	41.30	33.46	36.02	38.35
C.Thekkampatti	23.62	22.50	22.91	37.78	29.69	37.06	32.83	30.96	30.56	34.18	32.48	30.44	30.42
C.Kandiyur	40.04	39.53	39.29	24.68	27.22	27.50	26.65	28.83	26.02	24.56	24.29	27.92	29.71
R.Rajapuram	27.48	26.07	26.72	26.63	23.29	27.64	27.79	28.21	26.13	25.23	25.48	25.92	26.38
Mean	29.21	28.57	28.45	27.72	26.68	28.49	27.54	27.86	26.01	26.78	25.16	25.84	27.36
Range	15.3-69.4	15.2-64.9	15.2-64.4	11.4-63.7	7.5-84.4	11.7-78.4	12.6-75.9	13.6-78.5	10.6-80.1	10.3-65.9	4.8-76.5	9.7-75.9	11.5-73.2
SD	11.54	11.05	10.90	13.93	14.59	14.27	12.98	12.80	13.96	13.82	13.59	13.39	10.75
SE	1.98	1.89	1.87	2.39	2.50	2.45	2.23	2.20	2.39	2.37	2.33	2.30	1.84
Control(river water)	26.36	28.55	25.24	30.34	7.23	20.86	26.05	20.73	9.10	18.93	17.61	11.57	20.22

Table 59.Potential Salinity of water samples in and around the factory area (cmol L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	3.3	3.4	3.3	3.7	3.2	3.5	3.6	3.7	3.3	3.7	3.4	3.5	3.5
Devanapuram	2.9	2.9	2.7	3.1	2.9	3.4	3.4	3.6	2.9	3.0	3.1	3.3	3.1
P.Thekkampatti	3.6	3.5	3.5	3.7	3.4	3.9	4.0	4.1	3.7	3.8	3.8	3.9	3.7
C.Thekkampatti	3.6	3.6	3.4	3.7	3.7	3.8	3.9	4.0	3.8	3.6	3.6	3.7	3.7
C.Kandiyur	3.4	3.5	3.4	3.7	3.7	4.0	4.0	4.1	3.8	3.8	3.9	3.9	3.8
R.Rajapuram	3.2	3.2	3.1	3.2	3.9	4.1	4.2	4.3	3.3	3.4	3.7	3.8	3.6
Mean	3.3	3.4	3.2	3.6	3.4	3.7	3.8	3.9	3.4	3.6	3.6	3.7	3.5
Range	1.6-5.8	1.6-5.6	1.8-5.1	2.0-5.6	1.6-5.3	2.7-5.6	3.0-5.4	3.0-5.5	2.0-5.3	2.1-5.5	2.2-5.7	2.6-5.5	2.6-5.5
SD	1.00	0.85	0.78	0.91	0.86	0.71	0.65	0.68	0.88	0.81	0.80	0.76	0.72
SE	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
Control(river water)	1.3	1.6	1.7	1.1	1.1	1.3	1.1	1.3	1.0	1.2	1.0	1.2	1.2

Range,Mean,SD and SE values represented whole number of water samples

Table 60.SAR of water samples in and around the factory area

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	1.326	1.320	1.300	1.045	0.775	0.785	1.011	0.952	1.002	0.824	0.912	0.913	1.014
Devanapuram	0.986	0.973	0.974	0.730	0.768	0.896	1.031	0.920	0.948	0.749	0.810	0.835	0.885
P.Thekkampatti	2.304	2.155	2.135	2.753	3.719	4.661	3.775	3.550	3.445	3.026	3.000	3.183	3.142
C.Thekkampatti	1.102	1.096	1.084	2.097	1.732	1.597	1.853	2.089	1.899	1.808	1.814	1.757	1.661
C.Kandiyur	2.111	2.106	2.089	1.221	1.307	1.442	1.567	1.455	1.465	1.211	1.255	1.455	1.557
R.Rajapuram	1.402	1.402	1.378	1.377	1.350	1.182	1.563	1.484	1.529	1.256	1.314	1.361	1.383
Mean	1.54	1.50	1.49	1.57	1.68	1.88	1.86	1.80	1.77	1.53	1.57	1.63	1.65
Range	0.70-6.4	0.69-5.4	0.70-5.4	0.38-5.5	0.57-13.2	0.46-19.0	0.72-13.5	0.60-12.3	0.65-11.3	0.56-6.3	0.20-11.4	0.44-11.3	0.63-9.0
SD	1.07	0.94	0.93	1.20	2.16	3.11	2.17	2.01	1.83	1.30	1.88	1.86	1.45
SE	0.18	0.16	0.16	0.21	0.37	0.53	0.37	0.35	0.31	0.22	0.32	0.32	0.25
Control(river water)	0.564	0.602	0.553	0.764	0.245	0.152	0.631	0.533	0.722	0.448	0.430	0.317	0.497

Table 61.RSC of water samples in and around the factory area (mg L^{-1})

Location	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Mean
Mandarikadu	0.32	0.20	-0.03	2.25	-2.91	-2.07	-1.65	-1.68	-1.65	-1.85	-2.21	-2.24	-1.13
Devanapuram	0.01	0.33	0.39	-0.46	-1.73	-1.82	-1.73	-1.28	-1.66	-1.19	-1.62	-1.80	-1.05
P.Thekkampatti	0.94	0.68	0.69	1.29	0.09	0.07	-0.07	0.76	0.01	0.39	-0.31	-0.41	0.34
C.Thekkampatti	-0.04	0.01	-0.16	0.34	-1.55	-0.89	-1.60	0.34	-0.85	0.01	-1.09	-1.83	-0.61
C.Kandiyur	1.17	1.47	1.48	-2.00	-1.91	-2.44	-1.59	-1.91	-2.53	-2.00	-2.70	-1.91	-1.24
R.Rajapuram	0.39	-0.37	-0.20	-1.57	-1.82	-2.05	-1.37	-1.64	-1.76	-1.75	-1.93	-1.79	-1.32
Mean	0.45	0.43	0.39	0.20	-1.57	-1.42	-1.30	-0.77	-1.31	-0.94	-1.55	-1.61	-0.75
Range	-3.09	-2.70	-3.14	-3.24	-8.70	-7.88	-5.79	-4.17	-6.08	-7.99	-7.99	-7.16	-5.66
	5.69	4.78	4.04	16.38	3.60	3.00	2.95	3.34	3.04	2.83	2.48	2.51	4.55
SD	1.67	1.57	1.61	3.44	2.35	2.17	1.88	1.78	1.99	2.04	2.13	2.10	1.45
SE	0.29	0.27	0.28	0.59	0.40	0.37	0.32	0.31	0.34	0.35	0.37	0.36	0.25
Control(river water)	1.01	2.53	2.74	0.94	0.88	0.92	1.13	1.44	1.66	0.84	1.24	0.75	1.34

Range,Mean,SD and SE values represented whole number of water samples

to 2.74 in the well water and river water respectively at different periods of analysis (Table 61). Most of the mean RSC values of well water samples were negative and the positive values were observed in river water. The highest per cent sodium was recorded in P. Thekkampatti and the lowest value was observed in Devanapuram. Among the seasons, summer months recorded higher per cent sodium than the monsoon seasons. The winter season (January and February) also observed higher per cent sodium than the monsoon season.

4.3. Initial analysis of treated effluent, soil, river water and amendments used for the study

4.3.1. Treated effluent analysis

The treated effluent used for the column study had the pH of 6.95 with creamy white colour and EC of 1.22 dSm^{-1}. The total dissolved and suspended solids of the effluent were 781 and 126 mg L^{-1} respectively. The dissolved oxygen content showed was 2.9 mg L^{-1}. The BOD and COD of the effluent were 10.60 and 148 mg L^{-1} respectively. The organic carbon content of the effluent was 0.53 per cent. The calcium and magnesium content of the effluent were 232.8 and 72.3 mg L^{-1} respectively. The chloride, sulphate, ammoniacal nitrogen, phosphorus and potassium content of the effluent were 320, 127, 24.3, 1.2 and 19.4 mg L^{-1}, respectively. The bacterial population was $53x10^6$ ml^{-1}CFU, followed by the fungal population (5 x 10^4 ml^{-1}CFU) and actinomycetes population (3 $x10^3$ ml^{-1}CFU) (Table 62).

4.3.2. River water analysis

The characteristics of river water used for irrigation are presented in Table 62.

The river water had pH of 7.31,EC of 0.10 dS $m^{-1}$and TDS of 57 mg L^{-1}. The dissolved oxygen content of the water was 5.9 mg L^{-1} and it had a BOD and COD of

Table.62.Initial characterstics of treated effluent and river water used for irrigation

Characteristics		Treated Bilt-IPCL effluent	River water
Colour		Creamy white	colourless
pH		6.95	7.31
Electrical Conductivity	(dS m^{-1})	1.22	0.10
Total Dissolved Solids	(mg L^{-1})	781	57
Total Soluble Solids	(mg L^{-1})	126	_
Dissolved oxygen	(mg L^{-1})	2.9	5.9
Biological Oxygen Demand	(mg L^{-1})	10.6	6.2
Chemical Oxygen Demand	(mg L^{-1})	148	59
Organic carbon	(per cent)	0.53	–
Calcium	(mg L^{-1})	232.8	12.80
Magnesium	(mg L^{-1})	72.3	6.36
Sodium	(mg L^{-1})	364.0	10.12
Potassium	(mg L^{-1})	6.6	1.17
Carbonates	(mg L^{-1})	Trace	26.10
Bicarbonates	(mg L^{-1})	117.4	142.13
Chlorides	(mg L^{-1})	320.0	37.93
Sulphates	(mg L^{-1})	127.0	42.37
Ammoniacal Nitrogen	(mg L^{-1})	24.3	_
Phosphorus	(mg L^{-1})	1.2	_
Potassium	(mg L^{-1})	19.4	_
Per cent sodium		56.1	26.7
SAR		15.8	0.57
Bacteria	(x$10^6$$ml^{-1}$CFU)	53	4
Fungi	(x$10^4$$ml^{-1}$CFU)	5	2
Actinomycetes	(x$10^3$$ml^{-1}$CFU)	3	6

Values represented mean of three replications

10.2 and 59 mg L^{-1} respectively. The calcium content of the river water was 12.89 mg L^{-1}, magnesium 6.36 mg L^{-1} and sodium 10.12 mg L^{-1}. The microbial populations viz., bacteria, fungi and actinomycetes varied from 4 x 10^6, 2 x 10^4 and 6 x 10^3 ml^{-1} CFU of water respectively.

4.3.3. Soil analysis

The field soil employed for this study was sandy loam in texture with clay content of 6.10 per cent. The water holding capacity of the soil was 50.42 per cent with a bulk density and particle density of 1.30 and 2.05 Mg dm^{-3} respectively. The soil pH was 6.75 and EC was 0.07 dS m^{-1}. The per cent pore space of the soil was 19.35. The organic carbon content was 0.53 per cent. The available nutrient content of the soil for N, P, K was 136, 28.2, 234 kg ha^{-1} respectively. The exchangeable calcium and magnesium content were 8.93, 4.75 cmol (+) kg^{-1} respectively and it also contain an appreciable amount of micronutrients viz., 1.52 ppm of Cu, 4.74 ppm of Fe, 2.47 ppm of Mn and 4.18 ppm of Zn. The SAR and ESP of the soil were 0.57 and 32.49 respectively.

The total bacterial, fungal and actinomycetes population were 12.1 x 10^6, 5.25 x 10^4 and 11.2 x 10^3 g^{-1} CFU of dry soil respectively. The *Azospirillum, Azotobacter and Rhizobium* population were 8.82 x 10^4, 6.60 x 10^2 and 6.70 x 10^3 g^{-1} of dry soil respectively (Table 63).

4.3.4. Initial amendment analysis

The amendments (Bilt-IPCL solid wastes viz., sludge and fly ash along with FYM and Daincha as green manure) used for the study were analysed and the results are presented in Table 64.

The FYM and Daincha showed a neutral pH with an EC of 1.35 and 0.69 dS m^{-1} respectively. The sludge and fly ash showed a slightly alkaline pH with an EC of 0.86

Table 63. Initial *soil analysis used for the experiment

Parameters		Soil
Mechanical analysis		
Clay	(per cent)	6.10
Silt	(per cent)	7.13
Fine sand	(per cent)	20.44
Coarse sand	(per cent)	49.85
Textural class		sandy loam
Physical properties		
Bulk density	(Mg dm^{-3})	1.30
Particle density	(Mg dm^{-3})	2.05
Per cent Pore space		19.35
Water Holding Capacity	(per cent)	50.42
Chemical properties		
pH		6.75
Electrical Conductivity	(dS m^{-1})	0.07
Organic Carbon	(per cent)	0.53
Available Nitrogen	(kg ha^{-1})	136.06
Available Phosphorus	(kg ha^{-1})	28.22
Available Potassium	(kg ha^{-1})	234.00
Exchangeable Calcium	(cmol (+) kg^{-1})	8.93
Exchangeable Magnesium	(cmol (+) kg^{-1})	4.75
Exchangeable Sodium	(cmol (+) kg^{-1})	6.57
Exchangeable Potassium	(cmol (+) kg^{-1})	0.08
DTPA Copper	(mg kg^{-1})	1.52
DTPA Iron	(mg kg^{-1})	4.74
DTPA Manganese	(mg kg^{-1})	2.47
DTPA Zinc	(mg kg^{-1})	4.18
SAR		0.57
ESP		32.49
Microbiological		
Bacteria	(x 10^6 g^{-1} of dry soil)	12.10
Fungi	(x 10^4 g^{-1} of dry soil)	5.25
Actinomycetes	(x 10^3 g^{-1} of dry soil)	11.20
Azospirillum	(x 10^4 g^{-1} of dry soil)	8.82
Acetobacter	(x 10^2 g^{-1} of dry soil)	6.60
Rhizobium	(x 10^3 g^{-1} of dry soil)	6.70

Values represented mean of three replications

* This soil is used for column,Lab and field experiments

Table 64. Initial amendment analysis used for the experiment

Characteristics		Sludge	Fly ash	FYM	Daincha
Moisture content	(per cent)	34	12	28	32
Colour		Whitish	Black	Brown	Green
pH		7.97	8.01	7.6	7.1
Electrical Conductivity	(dS m^{-1})	0.86	2.38	1.35	0.69
Organic Carbon	(per cent)	28.28	0.27	25.4	26.44
Total Nitrogen	(per cent)	0.34	0.21	0.78	1.5
Total Phosphorus	(per cent)	0.05	0.43	0.26	0.6
Total Potassium	(per cent)	0.42	0.9	0.84	1.2
C:N Ratio		(83:1)	---	(49:1)	(17.6:1)
Total Calcium	(per cent)	1.76	1.36	0.24	0.28
Total Magnesium	(per cent)	0.33	0.91	0.15	0.11
Total Zinc	(mg kg^{-1})	290	281	165	240
Total Copper	(mg kg^{-1})	69	78	55	90
Total Iron	(mg kg^{-1})	752	678	1650	1350
Total Manganese	(mg kg^{-1})	131	118	750	865
Bacteria	($x10^6 g^{-1}$CFU)	32	-	47	51
Fungi	($x10^4 g^{-1}$CFU)	96	-	52	64
Actinomycetes	($x10^3 g^{-1}$CFU)	22	-	26	32

and 2.38 dS m^{-1}. The organic carbon content was more or less same (25.4 to 28.3 per cent) in all amendments except fly ash (0.27 per cent). The sludge had comparatively half of the nutrient status of FYM. The fly ash had comparatively higher nutrient status than FYM except the nitrogen content. Among the amendments, the sludge had a higher concentration of Ca and Mg recording 1.76 and 0.33 per cent respectively followed by fly ash. Among the micronutrient status, copper and zinc were comparatively higher in sludge and fly ash. The microbial populations viz., bacteria, fungi and actinomycetes were observed in the sludge and completely absent in fly ash.

4.4. Impact of effluent on survival of fingerlings (Bio-Assay study)

The effect of treated effluent on survival percentage of *Catla catla, Cyprinus rogu, Mrigal* fingerlings was studied at different effluent concentrations (0, 25, 50, 75 and 100 per cent) under laboratory conditions. The tap water was used as control. The results are presented in Table 65, Fig. 8.

Results obtained from the present work are quite interesting. Marked behavioural changes were observed in effluent treated fingerlings, as they showed restless condition, erratic and jerky movements, loss of balance, jumping, breathing rapidly and keeping the fin stretched laterally. When the period of restlessness subsided in 4 to 6 hours it settled quietly on at the bottom.

4.4.1.*Catla catla*

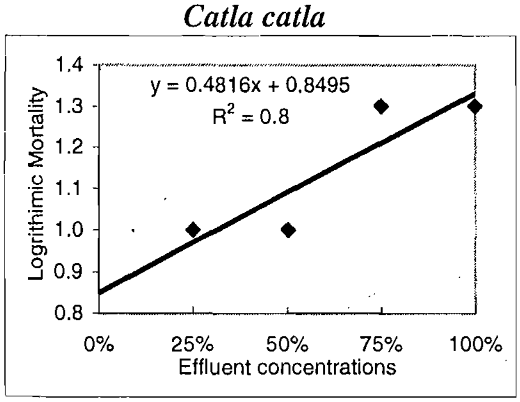
Among the treatments, 0 per cent treated effluent (tap water) was found to be the best recording 100 per cent survival and 75 and 100 per cent treated effluent recorded the poorest survival (80 per cent). As the treated effluent concentration increases, the survival per cent was found to be reduced. (Plate.3).

Table.65.Impact of effluent on survival per cent of fingerlings at different dilutions

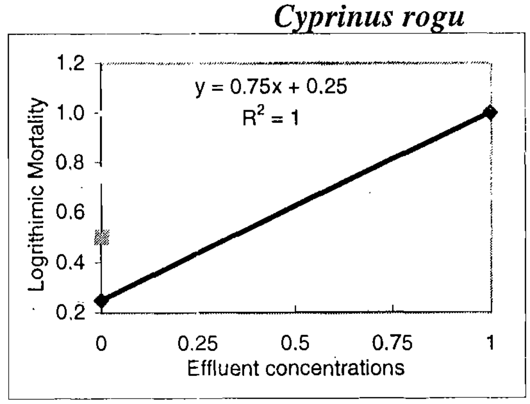
Effluent concentrations	*Catla catla*	*Cyprinus rogu*	*Mrigal*
0 per cent	100	90	0
25 per cent	90	90	60
50 per cent	90	100	40
75 per cent	80	100	50
100 per cent	80	100	20

Fig.8. Logrithimic probability of mortality at different dilutions of effluent

Catla catla



Cyprinus rogu



Mrigal

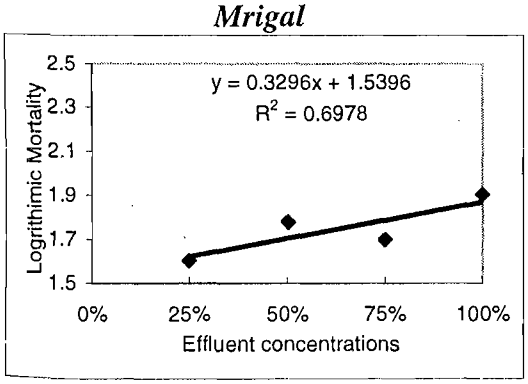
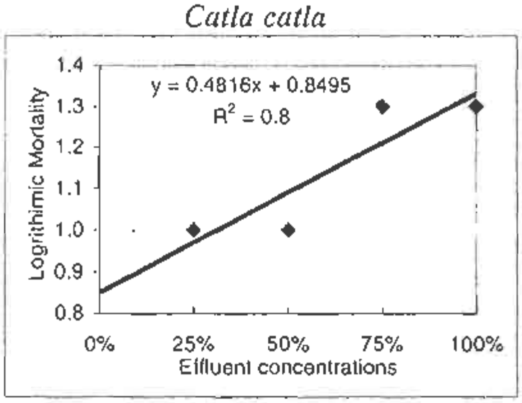


Table.65.Impact of effluent on survival per cent of fingerlings at different dilutions

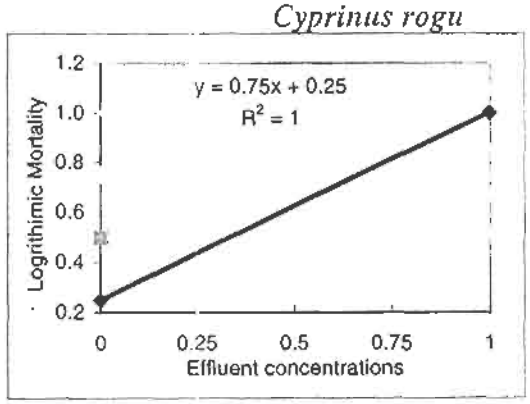
Effluent concentrations	*Catla catla*	*Cyprinus rogu*	*Mrigal*
0 per cent	100	90	0
25 per cent	90	90	60
50 per cent	90	100	40
75 per cent	80	100	50
100 per cent	80	100	20

Fig.8. Logrithimic probability of mortality at different dilutions of effluent

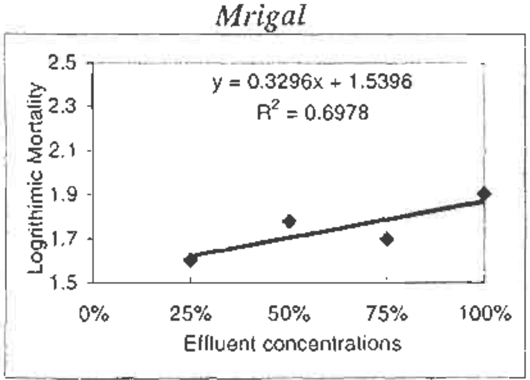
Catla catla



Cyprinus rogu



Mrigal



4.4.2. *Cyprinus rogu*

The survival rate of *Cyprinus rogu* was increased with the increasing concentration of effluent and the maximum survival per cent was recorded in 50,75 and 100 % effluent concentration (Plate.4).

4.4.3. *Mrigal*

In tap water (0 per cent effluent) all the fingerlings died within 96 hours. Fourty per cent survival was observed in the 50 per cent treated effluent. The survival per cent was maximum at 25 per cent effluent concentration, which decreased drastically due to increasing concentration of effluent in case of *Mrigal.*

4.5. Germination studies with effluent

4.5.1. Field crops

The effect of raw and treated effluent on germination, root length, shoot length, VI, and germination of seed were evaluated with rice, maize, sunflower, groundnut, blackgram, greengram, and soybean seedlings and the results are presented hereunder Table 66 to 72.Tap water was used as control.

4.5.1.1. Rice (CO 47)

The data on growth characters of rice seedlings at different dilutions of raw and treated effluents are given in Table 66.

In general the performance of rice was better in treated effluent than in raw effluent. There existed a difference in growth characters at different concentration of raw and treated effluent.

Raw effluent diluted with water in 1:3 ratio recorded 78.50 per cent germination while it was reduced to 61.20 per cent in undiluted raw effluent. Control recorded 90.30 per cent germination.

Root length of 7.1 cm was observed in raw effluent with water in 1:3 ratio. Lowest root length of 5.5 cm was observed in undiluted raw effluent, which was followed by the raw effluent diluted with water in 3:1 ratio. Control recorded the highest root length (8.1 cm), which was followed by the treated effluent with water in 1:3 ratio.

The highest shoot length (4.8 cm) was observed in control. There was no significant difference in shoot length in raw effluent with water 1:3 ratio and 1:1 ratio. In case of treated effluent significant difference was not observed.

The highest Vigour Index (VI) (1165) was observed in control, while the lowest (526) was recorded in undiluted raw effluent.

4.5.1.2. Maize (CO 1)

The data on growth characters of maize at different concentration of raw and treated effluent are given in Table 67.

Better growth of maize seedlings was observed in treated effluent than in raw effluent (Plate.5). The growth parameters like germination per cent, root length, shoot length and VI showed better performance as the concentration of the effluent decreased.

In undiluted raw effluent the seedlings showed only 64.60 per cent germination while 74.20 per cent germination was observed in raw effluent diluted with water 1:3 ratio. In the treated effluent diluted with water 1:3 ratio, 85.50 per cent germination was observed, while the control recorded 81.20 per cent germination.

Root length of 7.8 and 9.5 cm was observed in undiluted raw effluent and raw effluent diluted with water in 1:3 ratio respectively. In control, the root length was 10.8 cm, which was followed by the treated effluent diluted with water in 1:3 ratio.

Table 66. Effect of raw and treated effluent on germination and seedling vigour of rice (CO-47)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**90.30**	**90.30**	**8.1**	**8.1**	**4.8**	**4.8**	**1165**	**1165**
Effluent:water-1:3	78.50	83.60	7.1	7.5	4.3	4.6	895	1012
Effluent:water-1:1	75.30	81.20	6.0	7.1	4.2	4.3	768	926
Effluent:water-3:1	67.30	73.90	5.8	6.5	4.0	4.2	660	791
Undiluted effluent	61.20	65.80	5.5	6.1	3.1	3.2	526	612
SEd	0.84	0.89	0.08	0.07	0.03	0.01	6.07	2.32
CD(0.05)	1.78	1.88	0.16	0.15	0.07	NS	12.86	4.91

Table 67. Effect of raw and treated effluent on germination and seedling vigour of maize (CO-1)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	81.20	81.20	10.8	10.9	7.2	7.2	1462	1470
Effluent:water-1:3	74.20	85.50	9.5	11.5	7.1	8.3	1232	1693
Effluent:water-1:1	72.30	**93.10**	9.1	12.9	6.8	9.7	1150	2104
Effluent:water-3:1	68.50	**93.10**	8.7	**13.7**	6.8	**10.3**	1062	**2234**
Undiluted effluent	64.60	93.10	7.8	13.2	6.2	7.7	**904**	1946
SEd	0.80	1.00	0.11	0.13	0.05	0.10	7.42	4.66
CD(0.05)	1.70	2.13	0.22	0.27	0.10	0.21	15.74	9.88

Values represented mean of five replications

The shoot length of the seedlings grown under control was 7.2 cm, which was on par with raw effluent diluted with water in 1:3 ratio. The shoot length was maximum in treated effluent with water 1:3 ratio (8.3 cm) and 6.2 cm was recorded in undiluted raw effluent.

The highest VI (2234) was observed in treated effluent with water 3:1 ratio. The VI of seedlings decreased with the increasing concentration of raw and treated effluent while the VI was increased with the increasing concentration of treated effluent upto a dilution of 3:1 ratio.

4.5.1.3. Sunflower (K-1)

The data on growth characters of sunflower at different dilutions of raw and treated effluent are presented in Table 68.

Sunflower performed better in treated effluent than in raw effluent. There existed a significant difference in growth characters at different concentration of raw and treated effluent (Plate.5).

Raw effluent diluted with water in 1:3 ratio recorded 65.10 per cent germination, while treated effluent with the same treatment recorded 83.20 per cent germination. Comparatively this treatment performed better than the rests of the treatments.

Raw effluent diluted with water in 1:3 ratio recorded root length of 2.0 cm, which was on par with control. Undiluted raw effluent drastically affected the root length (1.5 cm). Treated effluent diluted with water in 1:3 ratio recorded the highest root length of 3.5 cm followed by treated effluent with water 1:1 ratio and 1:3 ratio and on par with among themselves.

Table 68. Effect of raw and treated effluent on germination and seedling vigour of sunflower (K-1)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	63.50	66.50	2.1	2.1	3.6	3.6	362	379
Effluent:water-1:3	65.10	83.20	2.0	**3.5**	3.5	4.8	358	691
Effluent:water-1:1	62.80	91.50	1.8	3.4	3.4	5.2	327	787
Effluent:water-3:1	61.50	**92.80**	1.7	3.2	3.3	**5.4**	307	**798**
Undiluted effluent	**60.00**	92.70	**1.5**	2.8	**2.8**	4.1	**258**	640
SEd	0.70	0.96	0.04	0.96	0.04	0.49	0.92	4.33
CD(0.05)	1.49	2.04	0.10	2.04	0.10	0.10	1.95	9.17

Table 69. Effect of raw and treated effluent on germination and seedling vigour of groundnut (VRI-2)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	83.80	89.60	9.2	9.2	8.4	8.6	1471	1590
Effluent:water-1:3	94.20	94.60	9.8	9.9	10.3	9.7	1893	1855
Effluent:water-1:1	**95.60**	**95.60**	9.5	**10.6**	9.1	**10.1**	1773	**1977**
Effluent:water-3:1	90.20	90.30	8.0	9.1	7.4	9.2	1387	1652
Undiluted effluent	**80.30**	83.80	**7.8**	8.2	**6.9**	9.1	**1180**	1450
SEd	1.00	1.02	0.08	0.10	0.08	0.10	7.97	7.96
CD(0.05)	2.11	2.15	0.17	0.21	0.18	0.22	16.90	16.87

Values represented mean of five replications

Control recorded a shoot length of 3.6 cm, which was on par with raw effluent diluted with water in 1:3 ratio. The highest shoot length (5.4 cm) was recorded in treated effluent diluted with water in 1:3 ratio followed by 1:1 ratio (5.2).

Treated effluent with water in 3:1 ratio recorded the highest VI (798). The lowest VI (258) was observed in undiluted raw effluent, while raw effluent with water in 1:3 ratio recorded VI of 307.

4.5.1.4. Groundnut (VRI-2)

The data on growth characters of groundnut at various concentration of raw and treated effluent are presented in Table 69. In both raw and treated effluent, the growth characters like germination per cent, root length, shoot length and VI increased significantly as the proportion of water used for dilution increased (Plate.5).

The performance by the seedlings was better in both raw and treated effluent with water 1:1 ratio. The growth parameters of the seedlings were better under treated effluent than under raw effluent. The lowest germination per cent was observed in undiluted raw effluent (80.30) followed by undiluted treated effluent (83.80).

Treated effluent with water in 1:1 ratio recorded root length of 10.6 cm, which was significantly differ from the rests of the treatments. The undiluted raw effluent drastically affected the root length (7.8 cm) whereas the highest root length (10.6 cm) was observed in raw effluent with water in 1:3 ratio.

The highest shoot length (10.3 cm) was observed in raw effluent diluted with water 1:3 ratio followed by effluent with water 1:1 ratio (9.1 cm) and the least (6.9 cm) was observed in undiluted raw effluent. The highest and lowest values of shoot length in treated effluent being 10.1 cm and 8.6 cm in 1:1 and control respectively.

There existed significant differences in the VI of groundnut among the different dilutions of both treated and raw effluent. Very low VI of 1180 was observed in undiluted raw effluent whereas raw effluent diluted with water in 1:3 ratio recorded the highest VI.

4.5.1.5. Blackgram (T-9)

The data on growth characters of blackgram at different dilutions of raw and treated effluent are furnished in Table 70.

Dilution of raw and treated effluent had significant effect on growth characters of seedlings. In general, the growth of blackgram was better in treated effluent than in the raw effluent.

Raw effluent diluted with water in 1:1 ratio recorded 81.20 per cent germination, while the germination of undiluted raw effluent was 74.50 per cent which was followed by the raw effluent with 3:1 ratio.

Root length of 6.1 cm was recorded in treated effluent diluted with water in 3:1 ratio while reduced root length of 3.4 cm was observed in undiluted raw effluent. Similarly in treated effluent growth of root was better in effluent diluted with water. 3:1 ratio when compared to undiluted treated effluent. The lowest root length of 3.7 cm was recorded in control.

The shoot length was reduced with the increasing concentration of raw effluent while an increasing trend due to dilution was observed in treated effluent. Treated effluent diluted with water in 1:1 ratio recorded the highest shoot length of 15.8 cm and the lowest (13.0) was in control.

There existed significant differences in the VI of blackgram among the different dilutions of both treated and raw effluent. Very low VI of 1103 was observed in undiluted raw effluent whereas control recorded the VI of 1378.

Table 70. Effect of raw and treated effluent on germination and seedling vigour of blackgram (T-9)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	82.50	82.50	3.7	3.7	13.0	13.0	1378	1378
Effluent:water-1:3	82.50	82.50	3.6	5.3	12.8	14.7	1353	1650
Effluent:water-1:1	81.20	**92.50**	3.5	5.7	12.3	15.2	1283	1933
Effluent:water-3:1	79.30	**92.50**	3.4	**6.1**	12.0	15.8	1221	**2026**
Undiluted effluent	**74.50**	**92.50**	**3.4**	4.2	**11.4**	14.5	**1103**	1730
SEd	0.89	0.99	3.02	0.11	0.09	0.16	2.59	16.13
CD(0.05)	1.89	2.09	6.39	0.23	0.19	0.33	5.50	34.19

Table 71. Effect of raw and treated effluent on germination and seedling vigour of greengram (Vamban-2)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	66.30	66.30	3.9	3.9	7.2	7.2	738	736
Effluent:water-1:3	65.80	66.50	3.8	**4.2**	7.2	10.5	724	978
Effluent:water-1:1	64.80	82.50	3.6	4.1	6.6	10.7	661	1221
Effluent:water-3:1	60.20	85.40	3.6	4.1	6.4	**10.8**	602	1273
Undiluted effluent	**59.20**	**89.00**	**3.5**	4.1	**6.2**	10.5	**574**	**1299**
SEd	0.66	0.88	0.09	0.10	0.05	0.07	1.98	8.91
CD(0.05)	1.39	1.86	0.19	0.22	0.10	0.15	4.19	18.90

Values represented mean of five replications

4.5.1.6. Greengram (Vamban-2)

The data on growth characters of greengram at different dilutions of raw and treated effluent are presented in Table 71.

Growth of greengram was better in treated effluent than in raw effluent. Treated effluent with water in 3:1 ratio performed comparatively better than the undiluted effluent.

In raw effluent diluted with water at 1:3 ratio, 65.80 per cent germination was observed while undiluted raw effluent recorded the lowest (59.20 per cent) germination. Treated effluent diluted with water in 1:3 ratio recorded 65.50 per cent germination, which was on par with control.

Higher root length of 4.2 cm was recorded in treated effluent diluted with water at 1:3 ratio followed by control. In case of raw effluent control performed better than rests of the treatments.

Raw effluent diluted with water at 1:3 ratio recorded 7.2 cm of shoot length, while the shoot length was drastically reduced to 6.2 cm in undiluted raw effluent.

Treated effluent diluted with water in 3:1 ratio recorded 10.8 cm shoot length followed by 1:1 ratio (10.7 cm) and on par with each other.

The highest VI (1299) was observed in undiluted treated effluent while the same treatment recorded the lowest VI in undiluted raw effluent.

4.5.1.7. Soybean (Vamban-2)

The data on growth characters of soybean at different dilutions of raw and treated effluent are presented in Table 72.

Growth characters of soybean were better in treated effluent than in raw effluent. Control performed better in germination percentage, root length, shoot length and VI than the different dilutions of raw effluent.

Table 72. Effect of raw and treated effluent on germination and seedling vigour of soybeen (Vamban-2)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	66.80	66.80	2.8	2.8	3.6	3.6	428	428
Effluent:water-1:3	66.80	66.80	2.7	2.7	3.5	4.6	414	488
Effluent:water-1:1	65.20	82.50	2.6	2.9	3.3	4.8	385	635
Effluent:water-3:1	60.40	**82.50**	2.5	**3.0**	3.2	**4.9**	344	**652**
Undiluted effluent	**59.20**	82.50	**2.5**	2.8	**3.0**	4.1	**326**	569
SEd	0.71	0.85	0.04	0.04	0.05	0.03	1.47	3.82
CD(0.05)	1.51	1.80	0.08	0.09	0.10	0.07	3.11	8.10

Table 73. Effect of raw and treated effluent on germination and seedling vigour of moringa (PKM-2)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**90.40**	**90.40**	**6.4**	**6.4**	**25.1**	**25.1**	**2847**	**2848**
Effluent:water-1:3	83.80	91.60	6.0	6.3	22.3	24.3	2371	2794
Effluent:water-1:1	80.10	90.20	5.4	6.1	20.8	23.9	2179	2706
Effluent:water-3:1	74.60	86.10	5.0	5.8	19.5	22.6	1828	2445
Undiluted effluent	72.10	83.50	4.7	5.5	16.3	17.1	1514	1887
SEd	0.89	0.98	0.20	0.05	0.15	0.17	6.43	27.63
CD(0.05)	1.89	2.09	0.40	0.11	0.32	0.37	13.63	58.58

Values represented mean of five replications

The highest germination per cent was observed in control which was on par with raw effluent diluted with water in 1:3 ratio and the lowest value recorded in undiluted raw effluent. Treated effluent diluted with water in 1:1 ratio recorded 82.50 per cent which was significantly higher than control and 1:3 ratio and the later two being on par.

Highest root length was recorded in effluent diluted with water in 3:1 ratio (3.0 cm) followed by effluent diluted with water 1:1 ratio.

Raw effluent diluted with water at 1:3 ratio recorded 3.5 cm as shoot length while it was drastically reduced to 3.0 cm in undiluted raw effluent and on par with the following treatment of effluent diluted with water in 3:1 ratio.

The highest VI (652) was observed in treated effluent diluted with water in 3:1 ratio while the lowest value (326) was recorded in undiluted raw effluent. But in treated effluent, the lowest VI was observed in control.

4.5.2. Vegetable crops

The effect of raw as well as treated effluents on germination, root length, shoot length and vigour index were evaluated with bhendi, chilli, tomato, amaranthus, bittergourd, snakegourd and moringa and the results are furnished hereunder, Table 73 to 79.

4.5.2.1. Moringa (PKM-2)

The data on growth characters of moringa seedlings at different dilutions of raw and treated effluents are given in Table 73.

Generally the performance was better in treated effluent than in raw effluent (Plate 6).

Under the raw effluent diluted with water in 1:3 ratio, 83.80 per cent germination was recorded while the germination was reduced to 72.10 per cent in undiluted raw effluent. Control recorded 90.40 per cent germination.

Root length of 6.0 cm was observed in raw effluent with water in 1:3 ratio. Lowest root length of 4.7 cm was observed in undiluted raw effluent, which was on par with the raw effluent diluted with water in 3:1 ratio. Control recorded the highest root length (6.4 cm), which was on par with treated effluent diluted with water in 1:3 ratio.

The highest shoot length (25.1 cm) was observed in control. There was a significant difference in shoot length in the raw effluent with water in 1:3 ratio and also in 1:1 ratio. Significant difference was observed with treated effluent.

The highest VI (2847) was observed in control, while the lowest (1514) was recorded in undiluted raw effluent.

4.5.2.2. Amaranthus (CO-4)

The data on growth characters of amaranthus at different concentration of raw and treated effluents are given in Table 74.

Better growth of amaranthus seedlings was observed in treated effluent than in raw effluent (Plate 9). Generally growth characters like germination per cent, root length, shoot length and VI showed better performance as the concentration of the effluent decreased.

In undiluted raw effluent the seedlings showed only 70.60 per cent germination while 78.60 per cent germination was observed in raw effluent diluted with water in 1:3 ratio. In the treated effluent diluted with water in 1:3 ratio, 82.80 per cent germination was observed, while control recorded the highest germination (86.50 per cent).

Root length of 3.5 and 4.7cm was observed in undiluted raw effluent and raw effluent diluted with water in 1:3 ratio respectively. In control, the root length was 5.3 cm, which was on par with treated effluent diluted with water in 1:3 ratio.

The shoot length of the seedlings grown under control was 4.6 cm, which was on par with the raw effluent diluted with water in 1:3 ratio. But undiluted raw effluent

Table 74. Effect of raw and treated effluent on germination and seedling vigour of amaranthus (CO-4)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**86.50**	**86.50**	**5.3**	**5.3**	**4.6**	**4.6**	**874**	**874**
Effluent:water-1:3	78.60	82.80	4.7	5.2	4.5	4.6	715	811
Effluent:water-1:1	74.10	81.00	4.3	5.0	4.1	4.5	622	769
Effluent:water-3:1	72.80	78.80	3.8	4.3	3.6	4.5	539	678
Undiluted effluent	70.60	76.50	3.5	4.1	3.4	4.4	487	635
SEd	0.86	0.91	0.05	0.06	0.05	0.04	2.77	2.96
CD(0.05)	1.82	1.93	0.10	0.12	0.10	0.08	5.88	6.27

Table 75. Effect of raw and treated effluent on germination and seedling vigour of tomato (CO-3)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**82.00**	**82.00**	**8.1**	**8.1**	7.7	7.7	**1296**	**1296**
Effluent:water-1:3	68.00	71.00	8.0	10.1	7.3	7.7	1040	1264
Effluent:water-1:1	65.00	68.00	7.7	9.5	6.2	7.5	904	1156
Effluent:water-3:1	62.00	65.00	6.1	7.6	5.5	5.9	719	877
Undiluted effluent	57.00	62.00	5.8	6.1	5.1	5.4	621	713
SEd	0.75	0.78	0.09	0.10	0.07	0.08	5.72	4.05
CD(0.05)	1.58	1.65	0.18	0.22	0.16	0.18	12.12	8.59

Values represented mean of five replications

reduced the shoot length to 3.4 cm. The shoot length was higher in treated effluent with water in 1:3 ratio and control (4.6 cm) and the lowest value of 4.4 cm was recorded in undiluted treated effluent.

The highest VI (874) was observed in control. The VI of the seedlings decreased as the concentration of the both raw and treated effluent increased.

4.5.2.3. Tomato (CO-3)

The data on growth characters of tomato at different concentration of raw and treated effluents are presented in Table 75.

Tomato performed better in treated effluent than in raw effluent. There existed a significant difference in growth characters at different concentration of raw and treated effluents.

Very drastic reduction in germination (30.5 per cent) was noticed under undiluted effluent. Raw effluent diluted with water in 1:3 ratio recorded 68.00 per cent germination, while treated effluent with the same treatment recorded 71.00 per cent germination. Comparatively control treatment performed better recording 82.00 per cent germination.

Raw effluent diluted with water in 1:3 ratio recorded root length of 8.0 cm, which was on par with control. Undiluted raw effluent drastically affected the root length (5.8 cm). Treated effluent diluted with water in 1:3 ratio recorded the highest root length of 10.1 cm followed by that treated effluent with water in 1:1 ratio (9.5cm) and the lowest in undiluted treated effluent (6.1cm).

Control recorded a mean shoot length of 7.7 cm, which was on par with treated effluent diluted with water in 1:3 ratio. Control recorded the highest VI (1296). The lowest VI (621) was observed in undiluted raw effluent, while raw effluent with water in 1:3 ratio recorded VI of 1040. Similar trend was observed in treated effluent also.

4.5.2.4. Bhendi (Arka annamica)

The data on growth characters of bhendi at different concentration of raw and treated effluents are given in Table 76.

In both raw and treated effluents, growth characters like germination per cent, root length, shoot length and VI increased significantly as the proportion of water used for diluted increased (Plate.6).

The performance by the seedlings was better in tap water. The growth parameters of the seedlings were better under treated effluent than under raw effluent. Raw effluent recorded 67.80 per cent germination, while raw effluent diluted with water in 1:3 ratio recorded 81.20 per cent germination. In the case of treated effluent 76.50 per cent germination was observed in undiluted treated effluent and 86.30 per cent germination was recorded when the treated effluent was diluted with water in 1:3 ratio which was on par with control (87.20 per cent).

Root length of 5.6 cm was recorded in undiluted raw effluent while 11.3 cm was recorded in raw effluent diluted with water in 1:3 ratio. Treated effluent showed better root growth than the raw effluent. Root length of 7.7 cm was recorded in undiluted treated effluent, while 12.1 cm was observed in treated effluent diluted with water in 1:3 ratio which was on par with control (12.1 cm).

Shoot length also showed similar performance as that of root length. Under control, shoot length was found to be 19.4 cm, while undiluted raw effluent reduced the shoot to 15.5 cm and in case of undiluted treated effluent, the shoot length was 17.0 cm.

4.5.2.5. Chilli (CO-1)

The data on growth characters of chilli at different dilutions of raw and treated effluents are furnished in Table 77.

Table 76. Effect of raw and treated effluent on germination and seedling vigour of bhendi (Arka annamica)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**87.20**	**87.20**	**12.1**	**12.1**	**19.4**	**19.4**	**2747**	**2747**
Effluent:water-1:3	81.20	86.30	11.3	12.1	18.5	19.0	2420	2684
Effluent:water-1:1	75.40	82.00	8.7	12.0	18.3	18.8	2036	2526
Effluent:water-3:1	70.80	78.60	7.3	11.3	17.4	18.2	1749	2319
Undiluted effluent	67.80	76.50	5.6	7.7	15.5	17.0	1431	1890
SEd	0.09	0.91	3.02	0.11	0.18	0.18	6.39	14.06
CD(0.05)	1.82	1.94	6.39	0.23	0.39	0.39	13.55	29.80

Table 77. Effect of raw and treated effluent on germination and seedling vigour of chilli (CO-1)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**85.50**	**85.50**	**12.1**	**12.1**	**9.5**	**9.5**	**1847**	**1847**
Effluent:water-1:3	76.40	83.20	8.3	10.4	6.2	8.2	1108	1547
Effluent:water-1:1	72.60	80.30	7.6	9.0	6.1	7.2	995	1301
Effluent:water-3:1	67.50	75.90	7.3	8.9	5.6	6.4	884	1161
Undiluted effluent	66.20	74.50	6.9	8.5	5.0	6.1	788	1088
SEd	0.83	0.90	0.09	0.10	0.06	0.06	7.09	4.12
CD(0.05)	1.77	1.90	0.19	0.22	0.12	0.13	15.04	8.73

Values represented mean of five replications

Dilution of raw and treated effluents had significant effect on growth characters of the seedlings. In general, growth of chilli was better in treated effluent than in the raw effluent.

Raw effluent diluted with water in 1:3 ratio recorded 76.40 per cent germination, while the germination of undiluted raw effluent was 66.20 per cent which was on par with raw effluent diluted with water in 3:1 ratio. The same trend was observed in treated effluent also.

Root length of 8.3 cm was recorded in raw effluent diluted with water in 1:3 ratio while reduced root length of 6.9 cm was observed in undiluted raw effluent. Similarly in treated effluent growth of root was better in effluent diluted with water in 1:3 ratio when compared to undiluted treated effluent. But control recorded the highest root length of 12.1 cm.

Under control, shoot length of 9.5 cm was recorded. Very low shoot length of 5.0 cm was observed in undiluted raw effluent and shoot length of 6.2 cm was observed in raw effluent diluted with water in 1:3 ratio. Treated effluent diluted with water in 1:3 ratio recorded shoot length of 8.2 cm.

There existed significant differences in the VI of chilli among the different dilutions of both treated and raw effluents. Very low VI of 788 was observed in undiluted raw effluent where as control recorded the highest VI (1847).

4.5.2.6. Bittergourd (CO-1)

The data on growth characters of bittergourd at different dilutions of raw and treated effluents are given in Table 78.

Growth of bittergourd was better in treated effluent than in raw effluent. Control performed comparatively better than the effluents (Plate.6).

Table 78. Effect of raw and treated effluent on germination and seedling vigour of bittergourd **(CO-1)**

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**91.50**	**91.50**	**14.3**	**14.3**	**23.1**	**23.1**	**3422**	**3422**
Effluent:water-1:3	83.30	90.20	12.1	13.5	21.5	23.1	2799	3301
Effluent:water-1:1	81.50	85.80	7.2	10.1	20.3	21.2	2241	2686
Effluent:water-3:1	76.50	84.20	5.4	10.0	18.7	20.1	1844	2534
Undiluted effluent	75.10	81.40	5.1	7.6	12.5	18.3	1322	2108
SEd	0.91	0.96	0.10	0.13	0.13	0.20	7.72	24.22
CD(0.05)	1.93	2.04	0.21	0.28	0.29	0.43	16.36	51.35

Table 79. Effect of raw and treated effluent on germination and seedling vigour of snakegourd (CO-1)

Treatments	Germination per cent		Root Length(cm)		Shoot Length(cm)		Vigour Index	
	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent	Raw effluent	Treated effluent
Control (tap water)	**90.59**	**90.59**	**14.4**	**14.4**	**23.6**	**23.6**	**3354**	**3422**
Effluent:water-1:3	82.47	87.95	12.2	13.6	21.9	23.6	2743	3301
Effluent:water-1:1	80.69	84.66	7.5	10.2	20.5	21.6	2196	2686
Effluent:water-3:1	75.74	82.10	5.5	10.1	19.1	20.4	1807	2534
Undiluted effluent	74.35	78.37	5.3	7.7	12.8	18.3	1295	2108
SEd	0.90	0.94	0.10	0.13	0.14	0.21	7.56	24.22
CD(0.05)	1.91	1.99	0.22	0.28	0.29	0.44	16.03	51.35

Values represented mean of five replications

In raw effluent diluted with water in 1:3 ratio, 83.30 per cent germination was observed and in undiluted raw effluent 75.10 per cent germination was observed. Treated effluent diluted with water in 1:3 ratio recorded 90.20 per cent germination, which was on par with control.

Higher root length of 14.3 cm was recorded in control followed by treated effluent diluted with water in 1:3 ratio. Similar trend was observed in raw effluent also.

Raw effluent diluted with water at 1:3 ratio recorded 21.5 cm as shoot length, while it was drastically reduced to 12.5 cm in undiluted raw effluent. Both control and treated effluent diluted with water in 1:3 ratio recorded 23.1 cm as shoot length. The highest VI (3422) was observed in control, while the lowest (1322) was recorded in undiluted raw effluent. Similar trend was observed in treated effluent also.

4.5.2.7. Snakegourd (CO-1)

The data on growth characters of snakegourd at different dilutions of raw and treated effluent are presented in Table 79.

Growth characters of snakegourd were better in treated effluent than in raw effluent. Control performed better in germination percentage, root length, shoot length and VI than the different dilutions of effluent.

In raw effluent diluted with water in 1:3 ratio, 82.47 per cent germination was observed and in undiluted raw effluent 74.35 per cent was observed. Treated effluent diluted with water in 1:3 ratio recorded 87.95 per cent, which significantly differ with control.

The highest root length was recorded in control (14.4 cm) followed by treated effluent diluted with water in 1:3 ratio. Similar trend was observed in raw effluent also.

Raw effluent diluted with water in 1:3 ratio recorded 21.9 cm as shoot length, while it was drastically reduced to 12.8 cm in undiluted raw effluent. Both control and treated effluent diluted with water 1:3 ratio recorded 23.6 cm as shoot length.

The highest VI (3354) was observed in control, while the lowest (1295) was recorded in undiluted raw effluent. Similar trend was also observed in the treated effluent.

4.6. Impact of effluent and amendments on growth of tree nursery saplings

4.6.1. Biometric characters

4.6.1.1. Root length

The data on root length of the seedlings are presented in Table 80 and plate 7 and 8.

Acacia auriculiformis

Significant differences were observed on root length due to amendments and irrigation. The interaction effect was also significant.

Among the amendments, A_4 (FYM + fly ash) was significantly superior over A_1 (FYM), A_2 (fly ash) and A_5 (FYM + sludge) which were significant with each other. Sludge (A_2) application caused complete drying of seedlings within 20 to 30 days after transplanting (DAT).

Compared to river water, effluent irrigation significantly increased the root length recording 34.2 and 44.3 cm at 60 and120 DAT respectively.

The interaction effect at 60 and 120 DAT showed that A_4 (FYM + fly ash) irrigated with effluent performed better followed by A_4 (FYM+ fly ash) with river water, A_5 (FYM + sludge) and A_2 (fly ash) with effluent. The other treatment combinations were inferior to the above treatment combinations.

Raw effluent diluted with water in 1:3 ratio recorded 21.9 cm as shoot length, while it was drastically reduced to 12.8 cm in undiluted raw effluent. Both control and treated effluent diluted with water 1:3 ratio recorded 23.6 cm as shoot length.

The highest VI (3354) was observed in control, while the lowest (1295) was recorded in undiluted raw effluent. Similar trend was also observed in the treated effluent.

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Compared to river water, effluent irrigation significantly increased the root length recording 34.2 and 44.3 cm at 60 and120 DAT respectively.

The interaction effect at 60 and 120 DAT showed that A_4 (FYM + fly ash) irrigated with effluent performed better followed by A_4 (FYM+ fly ash) with river water, A_5 (FYM + sludge) and A_2 (fly ash) with effluent. The other treatment combinations were inferior to the above treatment combinations.

Table.80.Impact of effluent and amendments on root length(cm) of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	32.2	35.3	33.7	38.5	47.9	43.2	21.2	22.6	21.9	32.0	35.2	33.6	28.3	30.0	29.1	33.5	37.6	35.5
A2	33.0	33.7	33.3	38.3	43.7	41.0	19.5	20.8	20.1	29.6	32.5	31.0	24.5	25.9	25.2	28.3	31.9	30.1
A3	*	*	*	*	*	*	17.7	18.8	18.3	26.3	28.9	27.6	16.6	17.7	17.2	17.6	18.5	18.1
A4	35.9	40.3	38.1	44.4	51.3	47.9	21.9	23.3	22.6	34.3	37.7	36.0	28.4	30.7	29.5	36.2	39.3	37.7
A5	32.5	33.8	33.1	39.8	43.8	41.8	20.4	21.7	21.0	30.4	33.4	31.9	28.3	28.7	28.5	32.9	35.0	33.9
A6	26.6	27.9	27.2	32.4	34.6	33.5	18.8	19.9	19.4	27.5	30.2	28.8	22.3	23.9	23.1	29.3	31.5	30.4
Mean	32.0	34.2	33.1	38.7	44.3	41.5	19.9	21.2	20.5	30.0	33.0	31.5	24.7	26.1	25.4	29.6	32.3	31.0
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.15	0.31		0.20	0.40		0.10	0.20		0.16	0.32		0.13	0.27		0.16	0.33	
A	0.27	0.54		0.34	0.69		0.17	0.35		0.27	0.56		0.23	0.47		0.28	0.57	
IxA	0.37	0.76		0.48	0.97		0.30	NS		0.39	NS		0.32	0.66		0.39	0.80	

Table.81.Impact of effluent and amendments on shoot length(cm) of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	34.6	38.5	36.6	73.4	83.5	78.5	17.9	19.4	18.7	30.9	33.6	32.2	31.5	32.9	32.2	68.6	72.8	70.7
A2	28.2	33.7	31.0	60.4	64.8	62.6	16.9	18.3	17.6	26.9	29.3	28.1	26.9	28.0	27.4	52.3	56.4	54.4
A3	*	*	*	*	*	*	14.9	16.2	15.6	25.5	27.8	26.7	18.6	18.8	18.7	21.0	21.7	21.3
A4	38.2	40.3	39.2	81.5	90.4	85.9	21.4	23.3	22.3	35.5	38.6	37.1	35.3	37.5	36.4	75.4	81.7	78.5
A5	31.1	36.2	33.7	61.9	70.4	66.2	17.2	18.7	18.0	28.9	31.4	30.1	27.3	28.4	27.8	55.6	65.4	60.5
A6	25.4	30.2	27.8	50.2	60.5	55.4	16.1	17.5	16.8	26.3	28.6	27.4	22.5	24.7	23.6	38.7	40.5	39.6
Mean	31.5	35.8	33.6	65.5	73.9	69.7	17.4	18.9	18.2	29.0	31.5	30.3	27.0	28.4	27.7	51.9	56.4	54.2
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.16	0.32		0.33	0.66		0.09	0.20		0.15	0.31		0.14	0.28		0.29	0.59	
A	0.27	0.55		0.56	1.15		0.16	0.33		0.26	0.54		0.24	0.49		0.51	1.03	
IxA	0.38	0.78		0.80	1.62		0.22	NS		0.37	NS		0.34	0.69		0.71	1.45	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S   I-Irrigation; I_1-River water I_2-Effluent

Azadirachta indica

The root length differed significantly due to amendments and irrigation at both the stages of seedling growth. But the interaction effect was not significant at both the stages.

Among the amendments, A_4 (FYM + fly ash) recorded the longest root length of 22.6, 36.0 cm at 60 and 120 DAT respectively, which was significant with rest of the treatments at both the stages of seedling growth. The shortest root length was observed in the A_3 (fly ash+ sludge) and the values were 18.3 and 27.6 cm at 60 and 120 DAT respectively.

Effluent irrigation recorded the longest root length of 21.2 and 33.0 cm at 60 and 120 DAT respectively as compared to river water irrigation. The interaction effect was non significant at both the stages of seedling growth.

Eucalyptus tereticornis

The same trend was noticed in *Eucalyptus tereticornis* as that of *Azadirachta indica.* Root length differed significantly due to amendments and irrigation at both the stages of seedling growth. The interaction effect was significant at 60 and 120 DAT.

Among the amendments, A_4 (FYM + fly) ash recorded the longest root of 29.5 and 37.7 cm at 60 and 120 DAT respectively which was on par with A_1 (FYM) at 60 DAT and significantly differ at 120 DAT. The shortest root was recorded in A_3 (sludge) and the values were 17.2 and 18.1 cm at 60 and 120 DAT respectively.

Effluent irrigation recorded the longest root of 26.1 and 32.3 cm at 60 and 120 DAT respectively as compared to river water irrigation.

The interaction effect at 60 and 120 DAT revealed that A_4 (FYM + fly ash) with effluent irrigation recorded significantly higher root length followed by A_1 (FYM) effluent, A_5 (FYM + sludge) with effluent and the least was found in A_3 (sludge) with river water at both the stages of seedling growth.

4.6.1.2. Shoot length

The data on shoot length of tree seedlings are presented in Table 81.

Acacia auriculiformis

Significant differences were observed on shoot length due to amendments and irrigation in both 60 DAT and 120 DAT. The interaction effect was also significant

Among the amendments, A_4 (FYM+fly ash) was found superior over A_1 (FYM), A_2 (Fly ash) and A_5 (FYM+sludge) rest of the treatments were significantly different from each other. Sludge application caused drying of seedling within 20 to 30 DAT.

Effluent irrigation recorded longer shoot length as compared to river water. The increase being 35.8 to 73.9 cm at 60 to 120 DAT respectively.

The interaction between amendments and irrigation was significant at both 60 DAT and 120 DAT of seedling growth. Effluent with A_4 (FYM+FA) with effluent performed better than rest of the amendment combinations.

Azadirachta indica

Significant differences were observed on shoot length due to amendments and irrigation at both 60 and 120 DAT.

Among the amendments, A_4 (FYM + fly ash) recorded the longest shoot length of 22.3 and 37.1 cm at 60 and 120 DAT respectively followed by A_1(FYM), A_5 (FYM + sludge) and A_2 (fly ash), which were significantly different from each other. The shortest shoot length of 15.6 and 26.7 cm was recorded in sludge at 60 and 120 DAT respectively.

Table.82.Impact of effluent and amendments on collar diameter (mm) of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	1.47	1.60	1.54	3.86	4.24	4.05	2.21	2.41	2.31	3.28	3.61	3.45	1.94	1.94	1.94	4.73	4.96	4.85
A2	1.26	1.38	1.32	3.32	3.73	3.52	2.12	2.31	2.21	3.19	3.51	3.35	1.84	1.88	1.86	3.48	3.86	3.67
A3	*	*	*	*	*	*	2.01	2.11	2.06	3.01	3.21	3.11	1.74	1.77	1.76	2.26	2.53	2.39
A4	1.43	1.72	1.58	4.72	4.89	4.81	2.77	3.01	2.89	3.83	4.21	4.02	2.06	2.26	2.16	4.93	5.24	5.09
A5	1.37	1.49	1.43	2.84	3.96	3.40	2.21	2.31	2.26	3.19	3.51	3.35	1.87	1.94	1.91	2.99	3.97	3.48
A6	1.29	1.33	1.31	1.77	1.90	1.84	2.03	2.21	2.12	3.11	3.31	3.21	1.82	1.83	1.83	2.40	2.57	2.48
Mean	1.37	1.51	1.44	3.30	3.75	3.52	2.22	2.39	2.31	3.27	3.56	3.41	1.88	1.94	1.91	3.46	3.85	3.66
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.01		0.02	0.03		0.01	0.02		0.02	0.03		0.01	0.02		0.02	0.04	
A	0.01	0.02		0.03	0.06		0.02	0.04		0.03	0.06		0.02	0.03		0.03	0.07	
IxA	0.02	0.03		0.04	0.08		0.03	0.06		0.04	0.08		0.02	0.05		0.05	0.10	

Table.83.Impact of effluent and amendments on dry matter production(g plant^{-1}) of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	0.65	0.76	0.71	3.66	6.50	5.08	0.78	0.83	0.81	1.03	1.13	1.08	1.18	1.46	1.32	4.66	5.84	5.25
A2	0.48	0.65	0.57	1.83	3.27	2.55	0.76	0.80	0.78	0.86	0.93	0.90	1.15	1.32	1.24	2.24	3.97	3.10
A3	*	*	*	*	*	*	0.69	0.72	0.71	0.75	0.83	0.79	0.10	0.83	0.47	0.98	1.25	1.12
A4	0.93	1.32	1.13	6.07	7.67	6.87	0.89	0.93	0.91	1.30	1.42	1.36	1.49	1.53	1.51	7.04	8.36	7.70
A5	0.59	0.78	0.69	3.13	4.74	3.93	0.78	0.81	0.80	0.87	0.98	0.93	1.24	1.40	1.32	3.48	4.33	3.90
A6	0.34	0.48	0.41	0.98	1.75	1.37	0.72	0.76	0.74	0.82	0.90	0.86	1.12	1.28	1.20	1.85	2.21	2.03
Mean	0.60	0.80	0.70	3.13	4.79	3.96	0.77	0.81	0.79	0.94	1.03	0.99	1.05	1.31	1.18	3.38	4.33	3.85
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.00	0.01		0.02	0.04		0.01	0.01		0.01	0.01		0.01	0.01		0.02	0.05	
A	0.01	0.01		0.04	0.07		0.01	0.02		0.01	0.02		0.01	0.02		0.04	0.08	
IxA	0.01	0.02		0.05	0.10		0.01	NS		0.01	NS		0.02	0.03		0.06	0.01	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S   I-Irrigation; I_1-River water I_2-Effluent

Effluent irrigation recorded the longest shoot length of 18.9 and 31.5 cm respectively as compared to river water at both the stages of seedling growth. The interaction effect was non significant at both the stages of seedling growth.

Eucalyptus tereticornis

A similar trend as above in *Azadirachta indica* was noticed for this species also. Significant differences were observed on shoot length due to amendments and irrigation at both the stages of tree seedling growth. The interaction effect was significant on 60 and 120 DAT.

Among the amendments, A_4 (FYM+fly ash) recorded the longest shoot of 36.4 and 78.5cm at 60 and 120 DAT respectively followed by FYM (A_1), FYM combination with sludge (A_5), and fly ash (A_2), the later two treatment combinations were on par with each other at 60 DAT and significantly different at 120 DAT. The shortest shoot was recorded in the sludge recording 18.7 and 21.3 cm at 60 and 120 DAT respectively.

Effluent irrigation recorded the longest shoot length of 28.4 and 56.4 cm respectively as compared to river water at both the stages of seedling growth.

The interaction effect at 60 and 120 DAT showed that FYM + Fly ash (A_4) with effluent as well as river water combinations performed better than the rest of amendment combinations and the sludge (A_3) with river water was found to be inferior at both the stages of seedling growth.

4.6.1.3. Collar diameter (CD)

The data on collar diameter of tree seedlings are presented in Table 82.

Acacia auriculiforms

Significant differences were observed in CD due to amendments and effluent irrigation at both the stages of seedling growth. The CD increased with advancement of seedling growth.

Among the amendments, A_4 (FYM + fly ash) was better than rest of the amendments at both the stages of seedling growth recording 1.58 and 4.81 mm respectively which was followed by A_1 (FYM), A_5 (FYM + sludge) and A_2 (fly ash). Under sludge (A_3) application the seedlings were completely dried.

The effluent irrigation performed better than river water irrigation at both the stages of seedling growth.

The interaction between the amendments and effluent was significant at both the stages of seedling growth. The effluent irrigation with A_4 (FYM + fly ash) was found to be superior over the rest of the treatment combination.

Azadirachta indica

Among the amendments, A_4 (FYM + fly ash) performed better CD values of 2.89 and 4.02 mm at 60 and 120 DAT respectively which was followed by A_1 (FYM), A_5 (FYM + sludge), A_2 (fly ash), while sludge recorded the least CD values at both the growth stages.

Effluent irrigation significantly increased the CD as compared to river water. The CD values recorded at 60 and 120 DAT due to effluent irrigation were 2.39 and 3.56 mm respectively.

Eucalyptus tereticornis

Almost similar trend as that of above species was noticed in this species also. Significant differences were noticed for CD due to amendments and effluent irrigation at both the growth stages. The CD increased with advancement of seedling growth.

Among the amendments, A_4 (FYM + fly ash) performed better with CD values of 2.16 and 5.09 mm at 60 and 120 DAT respectively which was followed by A_1 (FYM) and A_5 (FYM+ sludge) while the sludge (A_3) recorded the least CD values at both the growth stages.

Effluent irrigation significantly increased the CD as compared to river water. The CD values recorded at 60 and 120 DAT due to effluent irrigation were 1.94 and 3.85 mm respectively.

The interaction effect due to amendments and irrigation was significant. The treatment combination A_4 (FYM +FA) with effluent irrigation significantly increased CD followed by A_4 (FYM+ FA) with river water, FYM (A_1) and (A_5) FYM + sludge with effluent combinations and the least was in sludge (A_3) with river water irrigation at 60 DAT. However, there was no significant difference between the last three treatment combinations at 120 DAT.

4.6.1.3. Dry matter production (DMP)

The data on dry matter production of tree seedlings are presented in Table 83.

Acacia auriculiformis

Significant differences were noticed for DMP due to amendment, irrigation and interaction at both the stages of seedling growth.

Among the amendments, (A_4) FYM + fly ash performed better than other amendments at both the stages of seedling growth recording 1.13 and 6.87 g seedling^{-1} respectively.

The effluent irrigation recorded significantly higher DMP at both the stages than river water irrigation.

The interaction between the amendments and irrigation was significant at both the stages of seedling growth. The FYM + fly ash (A_4) with effluent combination recorded significantly higher DMP followed by A_4 with river water, FYM (A_1) and FYM + sludge (A_5) with effluent, and the other treatment combinations were inferior to the above treatment combinations.

Azadirachta indica

Significant differences were observed for DMP due to amendment, irrigation at both the stages of seedling growth. The interaction effect was non significant at 60 DAT and 120 DAT.

Among the amendments, A_4 (FYM + fly ash) recorded higher DMP of 0.91and 1.36 g seedling^{-1} at 60 and 120 DAT respectively which was followed by A_1 (FYM) and A_5 (FYM+sludge) and the later two were on par with each other at 60DAT and significantly differ at 120DAT. The DMP was lowest in sludge (A_3) at both the stages of seedling growth.

The effluent irrigation recorded significantly higher DMP at both stages than river water irrigation. The least was found in sludge with river water at all stages of seedling growth.

Eucalyptus tereticornis

This species also showed the same trend as the above species. Significant differences were observed for DMP due to amendment, irrigation and interaction at both the stages of seedling growth.

Among the amendments, A_4 (FYM + fly ash) recorded higher DMP of 1.51 and 7.70 g seedling^{-1} at 60 and 120 DAT respectively which was followed by A_1 and A_5 and the latter two were on par with each other only at 60 DAT and significant difference at 120 DAT. The DMP was the lowest in A_5 at both stages of seedling growth.

Compared to river water, effluent recorded higher DMP of 1.31 and 4.33 g seedling^{-1} at 60 and 120 DAT respectively.

The interaction effect was significant at both the stages. The treatment FYM + fly ash (A_4) with effluent recorded higher DMP followed by FYM+fly ash (A_4) with

Table.84.Impact of effluent and amendments on vigour index of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	4413	5155	4784	5692	6767	6230	2412	2566	2489	2760	2967	2864	2739	2872	2805	4020	4088	4054
A2	3243	3689	3466	5365	5931	5648	1913	2035	1974	2205	2371	2288	2312	2364	2338	3306	3481	3393
A3	*	*	*	*	*	*	1708	1817	1762	1933	2078	2005	1837	1879	1858	2577	2699	2638
A4	4972	6133	5553	8467	10765	9616	2978	3168	3073	3417	3674	3546	3402	3481	3442	6090	6266	6178
A5	3751	4359	4055	5028	6107	5567	2285	2431	2358	2637	2835	2736	1928	1975	1951	3890	3931	3910
A6	2370	2448	2409	3924	4241	4082	1814	1930	1872	2053	2208	2130	1726	1752	1739	3272	3296	3284
Mean	3750	4357	4053	5695	6762	6229	2185	2324	2255	2501	2689	2595	2324	2387	2356	3859	3960	3910
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	19.31	39.29		29.64	60.31		11.40	23.19		13.15	26.76		11.87	24.16		20.41	41.52	
A	33.45	68.05		51.34	104.5		19.75	40.17		22.78	46.35		20.57	41.84		35.35	71.92	
IxA	47.30	96.23		72.61	147.7		27.35	NS		32.50	NS		29.80	NS		49.55	NS	

Table.85.Impact of effluent and amendments on volume of index of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	75.3	99.2	87.2	1094.6	1502.7	1298.6	87.7	112.7	100.2	333.5	437.7	385.6	119.1	124.5	121.8	1537.4	1794.7	1666.0
A2	45.0	64.6	54.8	665.2	902.0	783.6	76.0	97.6	86.8	274.7	360.6	317.7	91.5	99.4	95.4	633.7	841.3	737.5
A3	*	*	*	*	*	*	60.1	72.0	66.1	231.2	286.0	258.6	56.8	59.4	58.1	106.7	138.4	122.5
A4	78.6	119.8	99.2	1818.8	2164.4	1991.6	163.9	210.5	187.2	521.6	684.7	603.2	149.1	191.1	170.1	1835.4	2246.1	2040.8
A5	58.8	80.8	69.8	498.8	1105.0	801.9	83.9	99.7	91.8	294.5	386.6	340.5	95.9	107.4	101.6	496.4	1030.8	763.6
A6	42.5	53.7	48.1	158.3	219.5	188.9	66.5	85.4	75.9	254.0	312.9	283.5	74.8	83.1	78.9	222.3	266.9	244.6
Mean	60.0	83.6	71.8	847.1	1178.7	1012.9	89.7	113.0	101.3	318.3	411.4	364.8	97.9	110.8	104.3	805.3	1053.0	929.2
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	1.03	2.1		16.03	32.6		1.6	3.3		5.7	11.6		1.6	3.3		17.5	35.6	
A	1.78	3.6		27.76	56.5		2.8	5.7		9.8	20.0		2.8	5.8		30.3	61.6	
IxA	2.52	5.1		39.26	79.9		4.0	8.1		13.9	28.3		4.0	8.2		42.8	87.1	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S I-Irrigation; I_1-River water I_2-Effluent

river water and FYM(A_1) with effluent irrigation. The later two were being on par themselves and performed better than the rest of the treatment combinations. The sludge with river water recorded lower values with respect to DMP.

4.6.1.5. Vigour index (VI)

The data on vigour index of tree seedlings are presented in Table 84.

Acacia auriculiformis

Significant differences were noticed for VI due to amendments, effluent irrigation and their interaction at both the stages of seedling growth. The VI was not calculated due to withering of seedlings under sludge.

Among the amendments, A_4 was superior over (A_1), (A_5) and (A_2).

There was a significant difference between VI of well water and effluent irrigated plants. Effluent irrigation performed better than the river water in both the stages.

The interaction was significant at both the stages of the seedling growth and it showed that A_4 (FYM + fly ash) in combination with effluent performed better followed by A_1 (FYM) with effluent. Rest of the treatment combinations were found inferior to them.

Azadirachta indica

The VI significantly differed due to amendments and irrigation at both the stages of crop growth but the interaction effect was not significant.

Among the amendments, A_4 recorded the highest value of 3073 and 3546 at 60 and 120 DAT respectively which was followed by A_1, A_5 and A_2. The effluent irrigation performed better than the river water irrigation. There was no significant interaction observed at both the stages of seedling growth.

Eucalyptus tereticornis

A very similar trend as above was observed for this species also. The VI differed significantly due to amendments and irrigation at both the stages of crop growth, while the interaction effect was not significant.

Among the amendments, A_4 recorded the highest vigour index of 3442 and 6178 at 60 and 120 DAT respectively which was followed by A_1, A_5 and A_2. The least VI was recorded in sludge (A_3). The effluent irrigation performed better than river water invariably at both the stages.

The interaction effect between irrigation sources and amendments was not significant with respect to VI.

4.6.1.6. Volume index (VOI)

The data on volume index of tree seedlings are presented in Table 85.

Acacia auriculiformis

Significant differences were noticed for VOI due to amendments, effluent irrigation and their interaction at both the stages of seedling growth.

Among the amendments, A_4 (FYM + fly ash) performed better with VOI values of 99.2 and 1991.6 at 60 and 120 DAT respectively which was followed by A_1 (FYM), A_5 (FYM + sludge) and A_2 (fly ash). The sludge (A_3)) recorded the lowest VOI values at both the stages of seedling growth.

Effluent performed better than river water with VOI values of 83.6 and 1178 at 60 and 120 DAT respectively.

Significant interaction effect at both the stages of seedling growth revealed that A_4 (FYM + fly ash) with effluent combination significantly increased VOI as compared to rest of the treatment combinations. Among Bilt-IPCL solid wastes, the performance of fly ash with effluent was comparable with that of FYM with river water. This showed that fly ash could possibly be used in place of FYM.

Azadirachta indica

A very similar trend as in *Acacia auriculiformis* was observed for this species also except the withering of seedlings under sludge.

The effluent irrigation performed better with high VOI values as compared to river water irrigation.

Significant interaction observed at 60 and 120 DAT wherein A_4 (FYM + fly ash) with effluent irrigation performed better followed by A_1 (FYM), A_5 (FYM + sludge) with effluent. Rest of the treatment combinations were inferior to them.

Eucalyptus tereticornis

Almost a similar trend as that of *Acacia auriculiformis* and *Azadirachta indica* was noticed for this species also.

The interaction effect was significant at both the stages of 60 and 120 DAT, which showed that A_4 (FYM + fly ash) with effluent irrigation was better than the rest of the treatment combinations.

4.6.2. Effect of effluent and amendments on chemical properties of soil

4.6.2.1. Effect of effluent and amendments on soil reaction

The data on soil reaction at both the stages of tree seedlings growth are given in Table 86.

Acacia auriculiformis

As the duration of both effluent and river water irrigation increased, the soil pH also increased irrespective of amendments. The soils receiving effluent irrigation recorded higher pH values as compared to river water in all the amendments.

Table.86.Impact of effluent and amendments on soil pH of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	7.27	7.54	7.40	7.84	8.16	8.00	7.80	7.94	7.87	7.87	8.12	7.99	7.94	8.18	8.06	8.37	8.48	8.43
A2	8.16	8.42	8.29	8.56	8.80	8.68	8.25	8.44	8.35	8.54	8.72	8.63	8.52	8.72	8.62	8.80	8.98	8.89
A3	8.18	8.34	8.26	8.42	8.54	8.48	8.20	8.42	8.31	8.43	8.62	8.53	8.24	8.36	8.30	8.40	8.74	8.57
A4	7.70	8.07	7.88	8.30	8.22	8.26	7.87	8.07	7.97	8.07	8.25	8.16	8.22	8.30	8.26	8.39	8.56	8.48
A5	7.99	8.08	8.04	8.18	8.38	8.28	8.12	8.30	8.21	8.23	8.50	8.37	8.15	8.32	8.24	8.44	8.57	8.51
A6	9.63	9.97	9.80	9.98	10.35	10.17	9.15	9.42	9.29	9.37	9.74	9.56	9.74	9.87	9.81	10.35	10.43	10.39
Mean	8.16	8.40	8.28	8.55	8.74	8.64	8.23	8.43	8.33	8.42	8.66	8.54	8.47	8.63	8.55	8.79	8.96	8.88
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.04	0.08		0.04	0.09		0.04	0.08		0.04	0.08		0.04	0.09		0.04	0.09	
A	0.07	0.14		0.07	0.02		0.07	0.14		0.07	0.15		0.07	0.15		0.08	0.16	
IxA	0.10	NS		0.10	NS		0.09	NS		0.10	NS		0.10	NS		0.11	NS	

Table.87.Impact of effluent and amendments on soil EC(dS m^{-1}) of tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	0.18	0.23	0.21	0.23	0.29	0.26	0.21	0.29	0.25	0.21	0.31	0.26	0.20	0.27	0.24	0.20	0.32	0.26
A2	0.38	0.55	0.47	0.50	0.61	0.56	0.39	0.55	0.47	0.47	0.68	0.58	0.38	0.56	0.47	0.49	0.70	0.60
A3	0.28	0.30	0.29	0.30	0.38	0.34	0.35	0.40	0.38	0.41	0.49	0.45	0.37	0.39	0.38	0.43	0.48	0.46
A4	0.29	0.31	0.30	0.30	0.35	0.33	0.32	0.34	0.33	0.40	0.45	0.43	0.34	0.38	0.36	0.41	0.46	0.44
A5	0.20	0.27	0.24	0.29	0.34	0.32	0.31	0.33	0.32	0.39	0.44	0.42	0.33	0.37	0.35	0.40	0.45	0.43
A6	0.85	1.15	1.00	1.10	1.32	1.21	0.82	1.12	0.97	0.97	1.28	1.13	0.75	1.08	0.92	0.96	1.36	1.16
Mean	0.36	0.47	0.42	0.45	0.55	0.50	0.40	0.51	0.45	0.48	0.61	0.54	0.40	0.51	0.45	0.48	0.63	0.56
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01	
A	0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01	
IxA	0.01	0.01		0.01	0.02		0.01	0.01		0.01	0.02		0.01	0.01		0.01	0.02	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S   I-Irrigation; I_1-River water I_2-Effluent

The pH of soil increased in amendment applied soils at 60 and 120 DAT. Among the amendments, A_6 (sludge + fly ash) recorded the highest pH values at 60 and 120 DAT followed by A_3 (sludge), A_2 (fly ash) and latter two were also significantly different among themselves. Effluent irrigation significantly increased the soil pH as compared to river water at all stages of seedling growth. The interaction effect was not significant only at 60 and 120 DAT.

Azadirachta indica

Significant differences were noticed for soil pH due to amendments and effluent irrigation. The interaction was not significant at both the stages of the seedling growth. The effluent irrigation out performed with increased pH as compared to river water.

A very similar trend in soil pH due to amendments and irrigation sources was also observed in *Eucalyptus tereticornis*. Among the amendments A_6 recorded high pH values and it was superior to the rest of the amendments. The least soil pH was recorded in A_1 (FYM).

4.6.2.2. Effect of effluent and amendments on electrical conductivity (EC) of soil

The data on soil EC at different stages of seedlings growth *Acacia auriculiformis, Azadirachta indica* and *Eucalyptus tereticornis* are given in Table 87.

Acacia auriculiformis

The soil EC increased due to effluent irrigation as compared to river water irrigation.

The EC of soil increased due to continuous effluent irrigation irrespective of amendment addition. The increase in soil EC between 60 and 120 DAT ranged from 0.47 to 0.55 dS m^{-1} in effluent irrigation and 0.36 to 0.45 dS m^{-1} in river water irrigation.

At 60 DAT, addition of fly ash + sludge (A_6) increased the soil EC as compared to fly ash (A_2), sludge (A_3) except in FYM (A_1). The soil EC was maximum in A_6 (1.00

dS m^{-1}) followed by A_2, A_4. The A_1 (0.21 dS m^{-1}) recorded the lowest EC value. Almost a similar trend was observed at 120 DAT.

The interaction due to amendments and effluent irrigation was significant at both the stages of seedling growth. The build up in soil EC was maximum in A_6 with effluent irrigation, which was followed by A_6 with river water and the least was in A_1 with river water.

Almost a similar trend as in *A. auriculiformis* was noticed in *A. indica* and *E. tereticornis* with respect to amendments, irrigation sources and their interactions.

4.6.2.3. Effect of effluent and amendments on organic carbon (OC) content of soil

The data on OC content of soil at different stages of tree seedlings are given in Table 88.

Acacia auriculiformis

In *Acacia auriculiformis* there was a gradual increase in the OC content of soil irrigated with effluent from 60 DAT to 120 DAT. In contrast with this, the soil OC decreased with river water irrigation irrespective of amendment addition from 60 to 120 DAT.

At 60 DAT, A_5 (FYM + sludge) recorded the highest OC (1.94 per cent), which was followed by (A_3) sludge, (A_4) (FYM + fly ash) and the lowest was in A_2 (fly ash) (0.26 per cent). A similar trend was noticed at 120 DAT with river water irrigation from 60 DAT to 120 DAT.

The interaction effect was significant at all stages of seedling growth. The FYM + sludge(A_5) with effluent irrigation recorded maximum values of 1.95 and 2.13 per cent at 60 and 120 DAT which was closely followed by FYM + sludge(A_5) with river water. The rests of the amendments combinations were inferior to the above two amendments and the minimum was recorded in fly ash (A_2) with river water.

Table.88.Impact of effluent and amendments on organic carbon per cent of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	1.04	1.06	1.05	0.98	1.20	1.09	1.12	1.21	1.17	1.16	1.34	1.25	1.08	1.10	1.09	0.98	1.21	1.10
A2	0.26	0.25	0.26	0.32	0.56	0.44	0.25	0.31	0.28	0.28	0.34	0.31	0.23	0.22	0.23	0.24	0.26	0.25
A3	1.78	1.86	1.82	1.72	1.85	1.79	1.85	1.90	1.88	1.72	1.92	1.82	1.83	1.82	1.83	1.73	1.88	1.81
A4	1.06	1.07	1.07	0.85	1.18	1.02	0.96	0.98	0.97	1.05	1.32	1.19	0.96	0.92	0.94	0.98	1.20	1.09
A5	1.93	1.95	1.94	1.70	2.13	1.91	1.91	2.03	1.97	1.92	2.17	2.05	1.88	1.92	1.90	1.73	2.19	1.96
A6	0.52	0.54	0.53	0.54	0.56	0.55	0.53	0.61	0.57	0.55	0.72	0.64	0.51	0.55	0.53	0.38	0.59	0.49
Mean	1.10	1.12	1.11	1.02	1.25	1.13	1.11	1.17	1.14	1.12	1.30	1.21	1.08	1.09	1.09	1.01	1.22	1.12
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.001	NS		0.01	0.01	
A	0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02	
IxA	0.02	0.03		0.02	0.03		0.16	0.03		0.02	0.03		0.02	0.03		0.02	0.03	

Table.89.Impact of effluent and amendments on available N (kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	99.7	103.9	101.8	88.3	98.6	93.5	103.8	108.9	106.3	79.6	90.8	85.2	102.3	107.6	104.9	78.8	92.7	85.8
A2	61.9	61.4	61.6	63.2	63.5	63.3	68.4	70.7	69.5	55.4	57.3	56.4	62.5	66.4	64.4	57.3	57.6	57.5
A3	81.8	90.4	86.1	74.7	81.8	78.2	87.7	90.4	89.1	75.6	77.8	76.7	87.8	91.4	89.6	77.6	78.7	78.1
A4	120.5	128.7	124.6	107.5	120.6	114.0	120.7	128.8	124.8	84.8	104.6	94.7	127.0	130.5	128.8	83.7	106.6	95.1
A5	130.8	135.5	133.2	107.9	128.8	118.3	131.7	135.7	133.7	95.6	118.5	107.1	133.2	138.8	136.0	92.0	120.8	106.4
A6	98.5	100.8	99.6	84.5	91.4	88.0	99.1	104.9	102.0	70.6	83.7	77.1	102.6	106.7	104.6	69.7	82.4	76.0
Mean	98.9	103.4	101.2	87.7	97.5	92.6	101.9	106.6	104.2	76.9	88.8	82.9	102.6	106.9	104.7	76.5	89.8	83.2
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.52	1.06		0.48	0.97		0.53	1.38		0.42	0.86		0.53	1.09		0.43	0.88	
A	0.90	1.83		0.82	1.68		0.92	1.87		0.73	1.49		0.92	1.88		0.75	1.52	
IxA	1.27	2.59		1.17	2.30		1.30	2.64		1.04	2.11		1.43	NS		1.06	2.15	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S I-Irrigation; I_1-River water I_2-Effluent

The same trend as in *A. auriculiformis* was observed for soils grown with *A. indica* and *E. tereticornis* except the irrigation effect was found to be non significant at 60 DAT and again significant at 120 DAT in *E .tereticornis*

4.6.2.4. Effect of effluent and amendments on soil available nitrogen

The data on available nitrogen status of soil at different stages of tree seedling growth are given in Table 89.

Acacia auriculiformis

The available N status was higher in all amendments irrigated with effluent than in river water at both the stages of crop growth. In general, the available N content decreased at later stage of crop growth. The reduction was gradual in effluent irrigated soils as compared to river water irrigation.

At 60 DAT, the FYM +sludge (A_5) recorded the highest soil available N content (133.2 kg ha^{-1}), which was followed by FYM + fly ash (A_4) and FYM (A_1) and the lowest was under fly ash (A_2) (61.6 kg ha^{-1}). A similar trend was noticed at 120 DAT.

The interaction was significant at 60 and 120 DAT. The FYM + sludge (A_5) with effluent irrigation registered maximum available N content at both the stages of seedling growth followed by A_5 (FYM + sludge) with river water and the least was in A_2 (fly ash) with river water.

In case of *A. indica* and *E. tereticornis* a similar trend at both the stages of crop growth as in *A. auriculiformis* was observed.

4.6.2.5. Effect of effluent and amendments on soil available phosphorus

The data on available phosphorus status of soil at different stages of tree seedling growth are given in Table 90.

Table.90.Impact of effluent and amendments on available P (kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	10.1	10.6	10.4	6.2	7.6	6.9	10.4	11.6	11.0	8.6	9.5	9.1	10.6	11.8	11.2	8.8	9.7	9.3
A2	11.1	11.7	11.4	6.3	8.4	7.4	12.2	11.9	12.0	8.2	9.9	9.0	12.4	12.1	12.3	8.3	10.1	9.2
A3	2.5	3.8	3.2	4.2	4.3	4.3	4.0	4.1	4.1	3.4	3.6	3.5	4.1	4.2	4.2	3.5	3.7	3.6
A4	14.2	15.3	14.8	7.8	9.6	8.7	14.8	15.9	15.4	12.4	14.0	13.2	15.1	16.2	15.7	12.6	14.2	13.4
A5	8.9	9.0	9.0	6.1	7.2	6.7	8.3	8.9	8.6	6.4	7.6	7.0	8.4	9.1	8.8	6.5	7.7	7.1
A6	11.6	12.8	12.2	6.7	8.6	7.7	12.6	14.3	13.5	9.1	13.2	11.2	12.8	14.6	13.7	9.3	13.4	11.4
Mean	9.76	10.56	10.16	6.23	7.64	6.93	10.4	11.1	10.8	8.0	9.6	8.8	10.6	11.4	11.0	8.2	9.8	9.0
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.11		0.04	0.08		0.06	0.01		0.05	0.10		0.06	0.11		0.05	0.11	
A	0.09	0.19		0.07	0.13		0.10	0.20		0.08	0.17		0.10	0.20		0.09	0.18	
IxA	0.13	0.27		0.09	0.19		0.14	0.29		0.12	0.24		0.14	0.28		0.13	0.26	

Table.91.Impact of effluent and amendments on available K (kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	216	221	218	197	211	204	201	231	216	200	209	205	208	239	223	207	216	211
A2	236	226	231	211	223	217	227	234	230	217	229	223	234	241	238	224	236	230
A3	183	185	184	189	189	189	174	177	176	166	178	172	179	182	181	171	183	177
A4	329	337	333	306	311	308	324	333	328	303	319	311	334	343	339	313	329	321
A5	229	247	238	220	234	227	232	236	234	209	222	215	240	244	242	226	236	231
A6	231	239	235	221	239	230	235	244	240	221	228	224	243	252	247	227	236	231
Mean	237	242	240	224	234	229	232	243	238	219	231	225	240	250	245	228	239	233
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	1.2	2.5		1.1	2.3		1.2	2.4		1.1	2.3		1.2	2.5		1.2	2.4	
A	1.1	4.3		2.0	4.1		2.1	4.2		2.0	4.0		2.1	4.4		2.0	4.2	
IxA	3.0	6.0		2.8	5.7		2.9	6.0		2.9	NS		3.0	6.2		2.9	5.9	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S I-Irrigation; I_1-River water I_2-Effluent

Acacia auriculiformis

The available P was higher in all amendments irrigated with effluent than in river water at both the stages of seedling growth. Generally, the available P content decreased as the crop growth advanced. The reduction in available P was gradual in effluent irrigated soils as compared to river water irrigation.

At 60 DAT, A_4 (FYM + fly ash) recorded higher available P (14.8 kg ha^{-1}) followed by A_6 (fly ash + sludge), A_2 (fly ash) and A_1 (FYM) while the lowest was in sludge (A_3) (3.2 kg ha^{-1}). A similar trend was noticed at 120 DAT.

The interaction was significant at both the stages of seedling growth. The FYM + fly ash with effluent irrigation recorded maximum soil available P followed by FYM + fly ash with river water, fly ash + sludge with effluent and the minimum was in sludge with river water.

A. indica and *E. tereticornis* grown soils also exhibited a very similar trend at both the stages of crop growth as in *A. auriculiformis*.

4.6.2.6. Effect of effluent and amendments on soil available potassium

The data on soil available potassium content at different stages of seedling growth are furnished in Table 91.

Acacia auriculiformis

The soil available K status was higher in all amendments irrigated with effluent compared to river water at both the stages of seedlings growth. In general, the soil available K decreased at later stages of seedling growth. The decrease was gradual in both effluent and river water irrigation.

At 60 DAT, the FYM + fly ash (A_4) recorded the maximum available K (332.8 kg ha^{-1}) which was followed by FYM + sludge (A_5) and fly ash + sludge (A_6) and the latter two amendments were on par with each other. The lowest K value was recorded in sludge (A_3) (184.5 kg ha^{-1}). A similar trend was noticed at 120 DAT.

The interaction effect due to amendments and irrigation was significant at both the stages of seedling growth. Among the treatment combinations, FYM + fly ash (A_4) with effluent recorded maximum available K followed by FYM + fly ash (A_4) with river water and FYM + sludge (A_5) with effluent and the minimum recorded in sludge (A_3) with river water irrigation. The available K content was reduced gradually irrespective of treatment combinations.

In case of *A. indica* at 60 DAT, A_4 (FYM + fly ash) recorded the maximum available K (328.4), which was followed by A_6 (fly ash + sludge) and A_5 (FYM + sludge) and significantly differ from themselves. The lowest available K value was observed in A_3 (sludge) (175.5). A similar trend was observed at 120 DAT.

The interaction effect due to amendment and irrigation was significantly differing at 60 DAT. Among the amendment combinations A_4 (FYM + fly ash) with effluent irrigation recorded maximum followed by A_4 (FYM + fly ash) with river water and A_6 (fly ash + sludge) with effluent. The minimum available K was observed in A_3 with river water. The K content was reduced gradually irrespective of amendment combinations.

In case of *E. tereticornis* also exhibited a similar trend at both stages of crop growth in *A. indica.*

4.6.2.7. Effect of effluent and amendments on soil exchangeable calcium

The data on exchangeable Ca content of the soil at different stages of tree seedlings growth are furnished in Table 92.

Table.92.Impact of effluent and amendments on exchangeable calcium (cmol (+) kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	1.35	1.55	1.45	3.41	3.76	3.58	1.84	2.25	2.05	3.78	4.60	4.19	1.80	2.21	2.01	3.71	4.51	4.11
A2	1.75	1.95	1.85	5.11	5.56	5.34	2.94	3.19	3.07	5.22	5.83	5.52	2.89	3.13	3.01	5.11	5.71	5.41
A3	2.56	2.71	2.63	5.51	6.42	5.96	3.19	3.53	3.36	6.29	6.60	6.44	3.13	3.46	3.29	6.17	6.47	6.32
A4	3.01	3.21	3.11	6.17	6.52	6.34	3.37	3.68	3.53	6.39	7.06	6.72	3.31	3.61	3.46	6.27	6.92	6.59
A5	3.01	3.46	3.23	6.62	7.27	6.94	3.94	4.33	4.13	6.65	7.36	7.00	3.86	4.24	4.05	6.52	7.22	6.87
A6	6.52	6.27	6.39	9.27	10.18	9.72	6.42	6.75	6.59	10.12	10.74	10.43	6.30	6.62	6.46	9.92	10.53	10.23
Mean	3.03	3.19	3.11	6.02	6.62	6.32	3.62	3.95	3.79	6.41	7.03	6.72	3.55	3.88	3.71	6.28	6.89	6.59
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.02	0.03		0.03	0.07		0.02	0.04		0.03	0.07		0.19	0.04		0.03	0.07	
A	0.03	0.06		0.06	0.11		0.03	0.07		0.06	0.12		0.03	0.07		0.06	0.12	
IxA	0.04	0.08		0.08	0.16		0.04	NS		0.08	0.17		0.19	NS		0.08	0.17	

Table.93.Impact of effluent and amendments on exchangeable magnesium (cmol (+) kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	1.47	1.60	1.54	3.86	4.24	4.05	2.21	2.35	2.28	3.31	3.53	3.42	1.88	1.89	1.89	4.48	4.86	4.67
A2	1.29	1.33	1.31	1.77	1.90	1.84	2.01	2.11	2.06	3.01	3.21	3.11	1.74	1.77	1.76	2.26	2.53	2.39
A3	1.43	1.72	1.58	4.72	4.89	4.81	2.21	2.41	2.31	3.34	3.58	3.46	1.90	1.92	1.91	4.65	4.96	4.81
A4	1.37	1.49	1.43	2.84	3.96	3.40	2.03	2.21	2.12	3.11	3.31	3.21	1.82	1.83	1.83	2.40	2.57	2.48
A5	1.82	2.05	1.94	4.98	5.36	5.17	2.77	3.01	2.89	3.83	4.21	4.02	2.06	2.26	2.16	4.93	5.24	5.09
A6	1.26	1.38	1.32	3.32	3.73	3.52	2.12	2.31	2.21	3.19	3.51	3.35	1.87	1.94	1.91	2.99	3.97	3.48
Mean	1.44	1.60	1.52	3.58	4.01	3.80	2.22	2.40	2.31	3.30	3.56	3.43	1.88	1.94	1.91	3.62	4.02	3.82
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.02	0.03		0.03	0.07		0.02	0.03		0.03	0.06		0.02	0.03		0.03	0.06	
A	0.03	0.06		0.06	0.12		0.03	0.06		0.05	0.11		0.03	0.06		0.05	0.11	
IxA	0.04	0.08		0.08	0.17		0.04	0.79		0.07	0.15		0.04	0.08		0.07	0.15	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S I-Irrigation; I_1-River water I_2-Effluent

Acacia auriculiformis

The exchangeable Ca content was higher in all amendments irrigated with effluent water than in river water, at both the stages of seedling growth. In general, the exchangeable Ca increased as the seedling growth advanced. The increase was higher in advanced growth stage of effluent irrigated soils than river water.

At 60 DAT, the fly ash + sludge (A_6) recorded the highest exchangeable Ca (6.39 c mol (+) kg^{-1}) followed by sludge (A_3) the latter being significant with each other. FYM (A_1) recorded the lowest values of exchangeable Ca. A similar trend was observed at 120 DAT.

The interaction between amendments and irrigation was significant at all stages of 60, 90 and 120 DAT. Sludge invariably increased the soil exchangeable Ca content either with effluent or river water irrigation. The increase was almost two fold at 120 DAT.

The soils grown with *A. indica* and *E. tereticornis* also exhibited similar trend of two fold increase in exchangeable Ca as observed in *A. auriculiformis* at 120 DAT. The interaction between amendments and irrigation was not significant in *A. indica* and *E. tereticornis* at 60 DAT while it was significant at 120 DAT. Here again the treatment combinations either with effluent or river water irrigation with sludge invariably increased the exchangeable Ca content than rest of the treatment combinations.

4.6.2.8. Effect of effluent and amendments on soil exchangeable magnesium

The data on exchangeable magnesium status of soil at different stages of seedling growth are given in Table 93.

Acacia auriculiformis

There was a significant difference in the exchangeable Mg content of soil under amendments irrigated with effluent and river water. In general, the exchangeable Mg content increased at later stages of crop growth. The increase was comparatively higher in effluent irrigated soils 1.65 to 4.01 C mol (+) kg^{-1}) than river water (1.44 to 3.58 C mol (P^{+}) kg^{-1}).

At 60 DAT, the FYM + sludge (A_5) recorded the highest exchangeable Mg (1.94 c mol (+) kg^{-1}) followed by sludge (A_3) and FYM (A_1) which were on par with each other and significantly higher over A_6 (fly ash + sludge), A_4 (FYM + fly ash) and A_2 (fly ash) while the lowest was recorded in A_2 (fly ash) (1.31 c mol (+) kg^{-1}). A similar trend was observed at 90 and 120 DAT. In general, two fold increases in exchangeable Mg content was noticed at 120 DAT irrespective of amendments and irrigation sources.

The interaction was significant at both 60 and 120 DAT. Irrigation either with effluent or river water in A_5 (FYM + sludge) amended soils invariably increased the exchangeable Mg which was closely followed by irrigation with effluent in A_3 (sludge) and rest of the treatment combinations were found to be inferior.

The same trend as in *A. auriculiformis* was observed in soils grown with *C. equisetifolia, A. indica* and *E. tereticornis* at both the stages of crop growth except that the two fold increase was observed only in the *E. tereticornis.*

4.6.2.9. Effect of effluent and amendments on soil exchangeable sodium

The data on exchangeable Na content of the soil at different stages of tree seedling growth are given in Table 94.

Acacia auriculiformis

Effluent irrigation performed better than river water irrigation on all the amendments. In general, the exchangeable Na increased as the crop growth advanced. The increase was higher in effluent irrigated soils than in river water irrigation.

Table.94.Impact of effluent and amendments on exchangeable sodium (cmol (+) kg ha^{-1}) of soil on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	0.64	0.68	0.66	0.96	1.20	1.08	0.75	1.12	0.93	1.17	1.40	1.28	0.80	1.20	1.00	1.25	1.50	1.38
A2	2.19	2.56	2.37	2.71	3.51	3.11	2.24	2.61	2.42	2.05	2.56	2.31	2.41	2.81	2.61	2.21	2.76	2.48
A3	3.16	3.61	3.38	3.76	4.41	4.09	2.33	3.50	2.91	2.66	3.36	3.01	2.51	3.76	3.13	2.86	3.61	3.23
A4	0.98	1.25	1.12	0.92	1.28	1.10	0.70	1.12	0.91	1.07	1.45	1.26	0.75	1.20	0.98	1.15	1.55	1.35
A5	0.75	0.98	0.87	1.20	1.48	1.34	0.84	1.26	1.05	0.98	1.31	1.14	0.90	1.35	1.13	1.05	1.40	1.23
A6	4.16	4.71	4.44	5.86	7.62	6.74	4.43	4.96	4.69	5.59	5.78	5.69	4.76	5.33	5.05	6.02	6.22	6.12
Mean	1.98	2.30	2.14	2.57	3.25	2.91	1.88	2.43	2.15	2.25	2.64	2.45	2.02	2.61	2.32	2.42	2.84	2.63
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.02		0.02	0.03		0.01	0.03		0.01	0.03		0.01	0.03		0.01	0.04	
A	0.02	0.04		0.03	0.06		0.02	0.04		0.02	0.05		0.02	0.05		0.03	0.05	
IxA	0.03	0.06		0.04	0.08		0.03	0.06		0.04	0.07		0.03	0.07		0.04	0.07	

Table.95.Impact of effluent and amendments on bacterial population (10^{6} g^{-1}of dry soil) on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	68.5	74.0	71.2	124.0	156.6	140.3	18.5	20.7	19.6	22.8	28.8	25.8	19.6	21.9	20.7	24.2	30.5	27.3
A2	6.4	7.6	7.0	28.5	39.6	34.0	5.9	6.9	6.4	9.6	10.9	10.2	6.2	7.3	6.8	10.1	11.5	10.8
A3	86.4	95.9	91.2	160.7	196.1	178.4	23.0	26.7	24.9	32.0	34.3	33.2	24.4	28.3	26.3	33.9	36.3	35.1
A4	18.3	22.7	20.5	52.6	84.5	68.6	9.7	12.6	11.2	13.5	17.1	15.3	10.3	13.4	11.8	14.3	18.1	16.2
A5	75.8	84.7	80.3	145.8	173.8	159.8	20.4	22.9	21.6	28.0	31.5	29.8	21.6	24.2	22.9	29.7	33.4	31.5
A6	37.3	44.4	40.9	74.4	98.8	86.6	13.5	15.9	14.7	18.2	21.5	19.8	14.3	16.8	15.6	19.2	22.8	21.0
Mean	48.8	54.9	51.8	97.7	124.9	111.3	15.2	17.6	16.4	20.7	24.0	22.4	16.1	18.6	17.3	21.9	25.4	23.7
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.28	0.57		0.59	1.20		0.08	0.17		0.12	0.23		0.09	0.18		0.13	0.26	
A	0.49	0.99		1.02	2.07		0.14	0.29		0.20	0.41		0.15	0.30		0.22	0.45	
IxA	0.69	1.40		1.44	2.93		0.20	0.41		0.28	0.57		0.21	0.43		0.31	0.63	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S I-Irrigation; I_1-River water I_2-Effluent

At 60 DAT, A_6 (fly ash + sludge) recorded significantly higher exchangeable Na content (4.44 c mol (+) kg^{-1}) followed by A_3 (sludge), A_2 (fly ash) and A_4 (FYM + fly ash), which were significant with each other. A similar trend was observed at 90 and 120 DAT. In general exchangeable Na content increased invariably in all amendments except that the increase was significantly higher in A_6 (fly ash + sludge) at both the stages of seedling growth.

The interaction effect was significant at 60, 90 and 120 DAT. Fly ash + sludge (A_6) with effluent irrigation recorded the highest value of exchangeable Na followed by fly ash + sludge (A_6) with river water. The other amendment combinations were inferior to them. This showed that addition of fly ash + sludge (A_6) increased the exchangeable Na content irrespective of irrigation source and the increase was around 20 to 25 per cent.

The same trend as that of *A. auriculiformis* was observed in *A. indica* and *E. tereticornis* also.

The interesting observation here was that the *A. indica* and *E. tereticornis* could able to withstand higher Na levels in soils whereas the *A. auriculiformis,* could not.

4.6.3. Effect of effluent and amendments on soil microflora

4.6.3.1. Effect of effluent and amendments on bacterial population

The data on bacterial population of the soil at different stages of seedling growth are presented in Table 95.

Acacia auriculiformis

The bacterial population showed a significant difference among the various amendments irrigated with effluent and river water at different stages of seedling growth. In general, the bacterial population was higher at later stages of seedling growth both in effluent and river water irrigated soils except in fly ash.

At 60 DAT, the sludge recorded the highest bacterial population (91.2×10^6 g^{-1} of dry soil) followed by FYM + sludge and FYM and very low bacterial population were observed in fly ash (7.0×10^6 g^{-1} of dry soil).

The interaction effect was significant between the amendment and irrigation combinations. The sludge either with effluent irrigation or river water recorded more population followed by A_5 (FYM+sludge) and the least was in river water with A_2 (fly ash) at both the stages of seedling growth.

A. indica and *E. tereticornis* soils also exhibited a similar trend as above at both stages of seedling growth. The bacterial population was very high in rhizosphere soils of *A. auriculiformis*.

4.6.3.2. Effect of effluent and amendments on actinomycetes population

The data on actinomycetes population of soil at different stages of tree seedlings are given in Table 96.

Acacia auriculiformis

There was a significant difference between actinomycetes population of effluent and river water irrigated plants. The actinomycetes population increased as the seedling growth advanced under effluent and river water irrigations.

At 60 DAT, the sludge (A_3) scored the highest actinomycetes population (62.6×10^3 g^{-1} of dry soil) followed by FYM + sludge (A_5) and FYM (A_1). A_2 (fly ash) had an adverse effect on soil rhizosphere actinomycetes population at both the stages of seedling growth.

The interaction effect was found to be significant among the treatment combinations. The sludge both with effluent or river water irrigation had a significantly higher load of actinomycetes and it was closely followed by FYM + sludge (A_5) either

Table.96.Impact of effluent and amendments on actinomycetes population ($10^{3} g^{-1}$ of dry soil) on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	40.1	44.7	42.4	50.6	58.8	54.7	25.3	26.2	25.8	28.7	30.2	29.4	27.0	27.9	27.4	30.6	32.1	31.3
A2	8.1	9.6	8.9	11.2	75.8	43.5	5.0	5.8	5.4	6.5	6.8	6.6	5.3	6.2	5.8	6.9	7.2	7.1
A3	58.4	66.8	62.6	74.9	88.0	81.5	33.8	37.9	35.9	38.8	42.5	40.7	36.0	40.3	38.1	41.3	45.2	43.3
A4	11.4	14.1	12.8	14.9	25.6	20.3	6.3	7.4	6.8	9.8	10.6	10.2	6.7	7.8	7.3	10.4	11.2	10.8
A5	49.3	55.3	52.3	63.3	73.4	68.3	28.4	30.6	29.5	33.3	35.4	34.3	30.2	32.6	31.4	35.4	37.7	36.5
A6	24.2	27.5	25.8	30.2	38.4	34.3	14.2	15.5	14.8	16.8	18.0	17.4	15.1	16.4	15.8	17.8	19.1	18.5
Mean	31.9	36.3	34.1	40.9	60.0	50.4	18.8	20.6	19.7	22.3	23.9	23.1	20.1	21.9	21.0	23.7	25.4	24.6
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.19	0.38		0.28	0.56		0.11	0.22		0.12	0.25		0.11	0.23		0.14	0.28	
A	0.32	0.66		0.48	0.97		0.19	0.38		0.21	0.44		0.19	0.32		0.24	0.48	
IxA	0.46	0.93		0.67	1.38		0.27	0.54		0.30	0.62		0.27	0.55		0.33	0.68	

Table.97.Impact of effluent and amendments on fungal population ($10^{4} g^{-1}$ of dry soil) on tree nursery seedlings

Amendments	*Acacia auriculiformis.*						*Azadirachta indica*						*Eucalyptus tereticornis*					
	60DAT			120DAT			60DAT			120DAT			60DAT			120DAT		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
A1	10.4	11.6	11.0	18.3	26.2	22.3	5.2	5.9	5.6	6.8	7.0	6.9	5.5	6.2	5.9	7.1	7.4	7.3
A2	3.1	4.5	3.8	4.2	7.1	5.7	1.5	1.9	1.7	1.7	2.5	2.1	1.6	2.0	1.8	1.8	2.6	2.2
A3	30.6	36.3	33.4	40.2	52.4	46.3	18.7	20.5	19.6	23.8	26.5	25.1	19.6	21.6	20.6	25.1	27.9	26.5
A4	11.5	13.2	12.4	16.1	21.8	18.9	8.2	8.7	8.4	6.2	7.4	6.8	8.6	9.1	8.9	6.5	7.8	7.2
A5	21.8	25.5	23.6	29.7	38.8	34.2	9.3	10.7	10.0	12.9	14.8	13.8	9.8	11.2	10.5	13.5	15.5	14.5
A6	12.7	13.2	13.0	19.5	24.1	21.8	6.8	7.3	7.0	9.0	10.1	9.6	7.1	7.7	7.4	9.5	10.6	10.1
Mean	15.0	17.4	16.2	21.4	28.4	24.9	8.3	9.2	8.7	10.1	11.4	10.7	8.7	9.6	9.2	10.6	12.0	11.3
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.09	0.18		0.13	0.27		0.05	0.01		0.06	0.12		0.05	0.11		0.07	0.14	
A	0.16	0.37		0.23	0.47		0.09	0.18		0.11	0.21		0.09	0.18		0.12	0.24	
IxA	0.22	0.45		0.33	0.66		0.12	0.25		0.15	0.30		0.13	0.26		0.17	0.34	

A-Amendments; A1-FYM; A2-FA(Fly ash); A3-S(Sludge); A4-FYM+FA; A5-FYM+S; A6-FA+S   I-Irrigation; I_1-River water I_2-Effluent

with effluent or river water irrigation. A_2 (fly ash) either with effluent or with river water had an adverse effect on actinomycetes population.

The soils grown with the *Azadirachta indica* and *E. tereticornis* also exhibited similar trend at both the stages of crop growth as that of *A. auriculiformis*.

4.6.3.3. Effect of effluent and amendments on fungal population

The data on fungal population of the soil at different stages of tree seedlings growth are furnished in Table 97.

Acacia auriculiformis

Effluent irrigation performed better than river water irrigation. The fungal population showed a significant increase due to various amendments irrigated with effluent and river water at all stages of seedling growth. In general, the fungal population was higher at later stages of seedling growth under both irrigation sources.

At 60 DAT, sludge recorded higher fungal load (33.4 x 10^4 g^{-1} of dry foil) followed by FYM + sludge and Fly ash +Sludge. Fly ash drastically reduced the fungal growth. The trend was similar at 60, and 120 DAT except that the fungal population got increased along with duration of seedling growth.

Interaction effect observed between the amendments and irrigation sources was significant registering more fungal population in sludge (A_3) either with effluent or river water irrigation. The fungal population was eliminated completely under fly ash irrespective of the sources of irrigation.

The soils grown with *A. indica* and *E. tereticornis* also exhibited a same trend at both the stages of seedling growth as that of soils of *Acacia auriculiformis*.

4.7. Impact of effluent and amendments on field crops of maize and sunflower

4.7.1. Effect of effluent and amendments on physico-chemical characteristics of the field soil

The results on the physico-chemical characteristics of the soil as influenced by treated effluent irrigation and amendments on maize and sunflower are presented in Table 98 to 110 and Plates 9 to 11.

4.7.1.1. Effect of effluent and amendments on soil bulk density (Table 98)

The bulk density varied from 1.12-1.47 Mg dm^{-3} at vegetative stage of maize crop. In general the bulk density increased with the advancement of crop growth. Among the irrigation sources, soils irrigated with effluent recorded higher bulk density than river water. Among the amendments, T_4 (sludge) recorded the maximum bulk density of 1.44 Mg dm^{-3} which was significantly different from rest of the treatments. The minimum bulk density was observed in fly ash with green manure application treatment (1.15 Mg dm^{-3}). In general effluent irrigation enhanced the bulk density of the soil samples.

The interaction effect was non signifigant at all stages of crop growth. In general the bulk density gradually decreased upto flowering stage and again increased marginally at harvest stage. Similar trends were observed in sunflower grown soil except marginal increase in bulk density at harvest stage.

4.7.1.2. Effect of effluent and amendments on soil reaction (pH)

In maize, the soil pH varied from 6.99 to 8.32 at vegetative stage (Table 99). In case of effluent irrigation, soil pH increased with advancement of crop growth. Among the amendments, T_5 (fly ash+sludge) recorded higher pH values (7.94 to 8.13) followed by T_4 (sludge) and T_3 (fly ash) and the later two being on par with each other and

Table.98.Effect of effluent and amendments on soil bulk density (Mg dm^{-3}) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	1.29	1.35	1.32	1.25	1.33	1.29	1.31	1.33	1.32	1.46	1.49	1.47	1.34	1.40	1.37	1.30	1.34	1.32
T_2	1.26	1.33	1.30	1.23	1.30	1.27	1.28	1.31	1.30	1.43	1.46	1.44	1.31	1.37	1.34	1.27	1.31	1.29
T_3	1.17	1.22	1.19	1.13	1.20	1.17	1.17	1.19	1.18	1.28	1.30	1.29	1.17	1.23	1.20	1.16	1.20	1.18
T_4	1.40	1.47	1.44	1.36	1.44	1.40	1.42	1.45	1.43	1.58	1.61	1.60	1.45	1.52	1.49	1.41	1.45	1.43
T_5	1.20	1.26	1.23	1.17	1.24	1.20	1.22	1.24	1.23	1.36	1.38	1.37	1.24	1.31	1.28	1.21	1.25	1.23
T_6	1.12	1.17	1.15	1.10	1.16	1.13	1.11	1.13	1.12	1.21	1.24	1.22	1.11	1.17	1.14	1.10	1.14	1.12
T_7	1.36	1.43	1.39	1.32	1.40	1.36	1.38	1.40	1.39	1.53	1.56	1.55	1.41	1.48	1.44	1.37	1.41	1.39
T_8	1.18	1.24	1.21	1.14	1.21	1.18	1.19	1.22	1.21	1.31	1.34	1.33	1.21	1.27	1.24	1.19	1.22	1.20
Mean	1.25	1.31	1.28	1.21	1.29	1.25	1.26	1.29	1.27	1.39	1.42	1.41	1.28	1.34	1.31	1.25	1.29	1.27
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02	
T	0.02	0.03		0.02	0.03		0.02	0.03		0.02	0.03		0.02	0.03		0.02	0.03	
IXT	0.02	NS		0.02	NS		0.02	NS		0.02	NS		0.02	NS		0.02	NS	

Table.99.Effect of effluent and amendments on soil reaction under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	7.00	7.70	7.35	7.15	7.86	7.50	7.14	7.92	7.53	7.30	7.66	7.48	7.15	7.86	7.50	7.22	7.87	7.55
T_2	6.99	7.69	7.34	7.14	7.85	7.50	7.13	7.91	7.52	7.28	7.65	7.47	7.14	7.85	7.50	7.21	7.86	7.54
T_3	7.48	8.22	7.85	7.57	8.32	7.94	7.63	8.46	8.04	7.81	8.20	8.01	7.64	8.40	8.02	7.71	8.41	8.06
T_4	7.52	8.27	7.90	7.61	8.37	7.99	7.67	8.52	8.09	7.86	8.25	8.06	7.68	8.45	8.07	7.76	8.46	8.11
T_5	7.56	8.32	7.94	7.65	8.42	8.03	7.71	8.56	8.13	7.90	8.30	8.10	7.72	8.34	8.03	7.80	8.50	8.15
T_6	7.01	7.71	7.36	7.15	7.87	7.51	7.14	7.93	7.54	7.31	7.68	7.50	7.15	7.87	7.51	7.23	7.88	7.55
T_7	7.05	7.76	7.41	7.20	7.92	7.56	7.19	7.99	7.59	7.36	7.73	7.55	7.20	7.92	7.56	7.28	7.93	7.61
T_8	7.39	8.13	7.76	7.54	8.30	7.92	7.53	8.36	7.95	7.71	8.10	7.90	7.54	8.30	7.92	7.62	8.31	7.96
Mean	7.25	7.97	7.61	7.38	8.11	7.75	7.39	8.21	7.80	7.57	7.95	7.76	7.40	8.12	7.76	7.48	8.15	7.82
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.09		0.05	0.09		0.05	0.09		0.05	0.09		0.46	0.09		0.05	0.10	
T	0.09	0.19		0.09	0.19		0.09	0.19		0.09	0.19		0.09	0.19		0.09	0.19	
IXT	0.13	NS		0.13	NS		0.13	NS		0.13	NS		0.13	NS		0.13	NS	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

significantly different from rest of the treatments. Effluent irrigation increased the soil pH values than that of river water.

At vegetative stage of sunflower, the pH values varied from 7.65 to 8.30 and 7.28 to 7.90 in effluent and river water irrigated plots respectively. The soil pH increased along with duration of effluent irrigation irrespective of the treatments. The same trend as that of flowering stage was recorded at harvest stage also.

4.7.1.3. Effect of effluent and amendments on soil electrical conductivity (EC)

The details on soil EC at different stages of maize and sunflower are presented in Table 100. In general, the EC increased along with duration of effluent irrigation.

At vegetative stage, the effluent irrigation recorded higher EC values than river water irrigation. Among the amendments, fly ash recorded higher EC values of 0.38, 0.41 and 0.43 dS m^{-1} at different stages of crop growth respectively. Fly ash continues to maintain higher EC values at flowering and harvest stages. The fly ash was on par with T_2 (FYM) and significantly different from rest of the treatments irrespective of stages of crop growth.

A similar trend as above was observed in sunflower grown soils also. The interaction effect was found to be significant at harvest stage.

4.7.1.4.Effect of effluent and amendments on soil organic carbon (OC)

The details on soil OC at different stages of maize and sunflower are presented in Table 101. In general, the OC increased due to continuous effluent irrigation at all stages of crop growth and decreased with increasing duration.

The OC content of the maize grown soils varied from 0.59 to 0.86 and 0.54 to 0.71 per cent in the effluent and river water irrigated plots respectively at vegetative stage. The corresponding values at flowering stage varied from 0.58 to 0.83 and 0.50 to 0.66 and for harvest stage it varied from 0.53 to 0.76 and 0.48 to 0.63 respectively.

Table.100.Effect of effluent and amendments on soil EC (dS m^{-1}) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.30	0.43	0.37	0.33	0.45	0.39	0.36	0.47	0.41	0.34	0.46	0.40	0.36	0.48	0.42	0.38	0.59	0.48
T_2	0.30	0.44	0.37	0.34	0.46	0.40	0.36	0.48	0.42	0.34	0.47	0.41	0.36	0.49	0.43	0.38	0.60	0.49
T_3	0.31	0.45	0.38	0.35	0.47	0.41	0.37	0.48	0.43	0.35	0.48	0.41	0.37	0.50	0.43	0.39	0.61	0.50
T_4	0.28	0.41	0.35	0.31	0.42	0.37	0.34	0.48	0.41	0.32	0.44	0.38	0.34	0.46	0.40	0.36	0.56	0.46
T_5	0.28	0.40	0.34	0.30	0.41	0.35	0.33	0.46	0.40	0.31	0.43	0.37	0.33	0.44	0.39	0.35	0.54	0.44
T_6	0.24	0.35	0.30	0.25	0.34	0.30	0.29	0.41	0.35	0.27	0.38	0.33	0.29	0.39	0.34	0.30	0.47	0.39
T_7	0.26	0.38	0.32	0.29	0.39	0.34	0.31	0.44	0.38	0.30	0.41	0.35	0.31	0.42	0.37	0.33	0.51	0.42
T_8	0.25	0.36	0.31	0.27	0.36	0.32	0.30	0.42	0.36	0.28	0.39	0.34	0.30	0.41	0.35	0.32	0.49	0.40
Mean	0.28	0.40	0.34	0.31	0.41	0.36	0.33	0.46	0.39	0.31	0.43	0.37	0.33	0.45	0.39	0.35	0.55	0.45
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01	
T	0.01	0.01		0.01	0.01		0.01	0.02		0.01	0.01		0.01	0.01		0.01	0.02	
IXT	0.01	NS		0.01	NS		0.01	NS		0.01	NS		0.01	NS		0.01	0.02	

Table.101.Effect of effluent and amendments on soil organic carbon per cent under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.55	0.60	0.58	0.51	0.59	0.55	0.49	0.54	0.51	0.56	0.67	0.62	0.54	0.56	0.55	0.49	0.50	0.50
T_2	0.60	0.66	0.63	0.56	0.65	0.61	0.53	0.59	0.56	0.58	0.70	0.64	0.56	0.59	0.57	0.52	0.53	0.53
T_3	0.54	0.59	0.57	0.50	0.58	0.54	0.48	0.53	0.50	0.56	0.67	0.61	0.53	0.56	0.54	0.49	0.49	0.49
T_4	0.69	0.83	0.76	0.64	0.80	0.72	0.61	0.74	0.68	0.65	0.84	0.74	0.62	0.71	0.66	0.57	0.59	0.58
T_5	0.57	0.62	0.59	0.53	0.61	0.57	0.50	0.55	0.53	0.57	0.68	0.62	0.54	0.57	0.55	0.50	0.51	0.51
T_6	0.63	0.77	0.70	0.59	0.74	0.66	0.56	0.68	0.62	0.61	0.76	0.68	0.58	0.67	0.62	0.54	0.56	0.55
T_7	0.71	0.86	0.78	0.66	0.83	0.74	0.63	0.76	0.70	0.66	0.86	0.76	0.63	0.72	0.68	0.58	0.60	0.59
T_8	0.65	0.78	0.72	0.60	0.75	0.68	0.57	0.70	0.63	0.61	0.80	0.71	0.59	0.67	0.63	0.55	0.57	0.56
Mean	0.62	0.72	0.67	0.57	0.69	0.63	0.55	0.64	0.59	0.60	0.75	0.67	0.57	0.63	0.60	0.53	0.54	0.54
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01	
T	0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.21	
IXT	0.02	0.04		0.02	0.03		0.02	0.03		0.02	0.03		0.02	0.03		0.01	NS	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

Higher organic carbon content was recorded in T_7 which was on par with T_4 and significantly different from rest of the amendments.

The interaction was significant at all stages of both the crops except at harvest stage of sunflower. The treatments T_7 which was on par with T_4 in effluent irrigation continue to maintain higher OC content irrespective of different stages and crops followed by T_8 and T_6 with effluent and the later two being on par with each other. The lowest value was found in control with river water (I_1T_1) at all stages of crop growth. Maize grown soils recorded higher organic carbon content than the sunflower grown soil.

4.7.1.5. Effect of effluent and amendments on soil available nitrogen

The details on soil available N at different stages of maize and sunflower are presented in Table 102. In general, the available N decreased during later stages of crop growth irrespective of source of irrigation. The available N status was higher in effluent irrigated plots than river water irrigated plots in maize and sunflower.

In maize, among the amendments, T_6 recorded the highest available N followed by T_7, T_8 and significantly superior over FYM (T_2) and the lowest available N was recorded in T_1 (control). The interaction was significant at all stages of crop growth. At vegetative stage, T_6 recorded the highest available N (255 kg ha^{-1}) followed by T_7 and T_8 in effluent irrigated plots, and the least was observed in T_1 in river water irrigation. At flowering stage, the available N content varied from 182 to 246 and 158 to 186 kg ha^{-1} in effluent and river water irrigated soils respectively. At harvest stage, the available N content varied from 173 to 195 kg ha^{-1} in the effluent irrigated plot; whereas in river water plots it was from 153 to 180 kg ha^{-1}.

As far as sunflower grown soils were concerned, effluent irrigation enhanced the available N status of the soil than river water. The interaction effects at all stages were found to be significant. At vegetative stages, T_8 with effluent irrigation recorded higher available N content followed by T_6 with effluent and the lowest was recorded in T_1 with river water. The similar trend was observed at later stages of crop growth.

4.7.1.6. Effect of effluent and amendments on soil available phosphorus

The data on soil available P at different stages of maize and sunflower are presented in Table 103. In general, the available P decreased along with duration of effluent irrigation. The available P status was higher in the effluent irrigation than river water irrigation in both the crops. The soil available P status was marginally increased in maize than sunflower.

In maize, effluent irrigation enhanced the available P content of the soil. While comparing the effluent alone receiving treatment, treatment receiving both effluent and amendments (T_2 to T_8) recorded higher available P content than control (T_1) irrespective of the duration of irrigation. Among the amendments in the maize grown soil, T_8 (fly ash+ sludge + green manure) and T_6 (fly ash + green manure) recorded high available P and significantly different from each other. At flowering stage also these treatments recorded higher available P content. The interaction effect was significant in all the stages of both maize and sunflower.

In case of sunflower grown soil, generally effluent irrigation increased the available P content of the soil. In sunflower grown soil at vegetative stage, the available P content varied from 10.60 to 15.72 and 9.64 to 13.10 kg ha^{-1} in effluent and river water irrigated plots respectively. At flowering stage, the available P status was lesser than vegetative stage samples and it varied from 13.35 to 12.44 and 11.47 to 10.18 kg ha^{-1} in effluent and river water irrigated plots respectively.

Table.102.Effect of effluent and amendments on soil available N (kg ha^{-1}) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	159	183	171	160	184	172	155	175	165	141	157	149	133	148	140	132	148	140
T_2	176	220	198	171	214	193	166	180	173	151	181	166	142	174	158	138	165	151
T_3	165	190	178	163	188	175	158	178	168	143	161	152	135	151	143	133	149	141
T_4	156	179	167	158	182	170	153	173	163	138	154	146	131	147	139	131	146	139
T_5	170	204	187	168	201	185	163	184	173	148	166	157	139	156	148	136	152	144
T_6	189	255	222	182	246	214	177	191	184	162	194	178	151	191	171	146	175	161
T_7	183	247	215	177	238	207	171	185	178	157	189	173	147	185	166	142	170	156
T_8	193	223	208	186	215	201	180	195	188	165	198	182	154	194	174	149	179	164
Mean	174	213	193	170	209	189	166	183	174	151	175	163	142	168	155	138	161	150
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	1.16	2.38		1.14	2.33		1.04	2.12		0.98	1.99		0.93	1.90		0.90	1.83	
T	2.32	4.75		2.28	4.66		2.08	4.25		1.95	3.99		1.86	3.80		1.79	3.66	
IXT	3.29	6.72		3.22	6.58		2.94	NS		2.76	5.64		2.63	5.38		2.53	5.17	

Table.103.Effect of effluent and amendments on soil available P (kg ha^{-1}) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	10.84	11.16	11.00	9.77	11.04	10.41	8.66	9.09	8.87	10.25	11.28	10.76	9.00	10.17	9.58	8.17	9.56	8.87
T_2	12.12	15.76	13.94	10.93	14.21	12.57	9.68	12.10	10.89	11.83	13.96	12.90	10.50	13.64	12.07	9.14	11.43	10.28
T_3	11.29	11.63	11.46	10.18	11.50	10.84	9.02	9.47	9.24	10.79	12.41	11.60	9.57	10.82	10.19	8.51	9.96	9.24
T_4	10.62	10.94	10.78	9.58	10.82	10.20	8.48	8.91	8.70	9.64	10.60	10.12	8.55	9.66	9.10	8.01	9.37	8.69
T_5	11.76	12.93	12.35	10.60	11.98	11.29	9.39	10.52	9.96	11.24	12.93	12.08	9.97	11.27	10.62	8.87	10.37	9.62
T_6	13.02	16.92	14.97	11.74	15.26	13.50	10.40	13.83	12.11	12.71	15.25	13.98	11.27	14.65	12.96	9.82	13.06	11.44
T_7	12.63	16.41	14.52	11.38	14.80	13.09	10.09	13.11	11.60	12.20	14.64	13.42	10.93	14.21	12.57	9.52	12.38	10.95
T_8	13.42	17.45	15.43	12.10	15.73	13.92	10.72	14.26	12.49	13.10	15.72	14.41	11.62	15.11	13.36	10.12	13.46	11.79
Mean	11.96	14.15	13.06	10.78	13.17	11.98	9.55	11.41	10.48	11.47	13.35	12.41	10.18	12.44	11.31	9.02	11.20	10.11
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.08	0.16		0.07	0.15		0.06	0.13		0.07	0.15		0.07	0.14		0.06	0.12	
T	0.16	0.32		0.14	0.30		0.13	0.26		0.15	0.30		0.14	0.28		0.12	0.25	
IXT	0.22	0.45		0.20	0.42		0.18	0.37		0.21	0.43		0.19	0.40		0.17	0.35	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

4.7.1.7.Effect of effluent and amendments in soil available potassium

The data on soil available K at different stages of maize and sunflower are presented in Table 104. In general, the available K decreased with the advancement of crop growth irrespective of source of irrigation. The available K status was higher in the effluent irrigated plots than the river water irrigated plots in both maize and sunflower crops.

In maize effluent irrigated soil recorded higher available potassium than river water receiving soil. In general amendments added plots recorded higher K status. In maize grown soil at vegetative stage, T_2 (FYM) and T_8 (fly ash + sludge + green manure) recorded maximum potassium content than rest of the treatments in case of effluent as well as river water irrigated plots.

At flowering stage, T_2 (FYM) recorded the highest available K content (257 kg ha^{-1}) in effluent irrigated plots which was significantly different from other treatments. The similar trend of available K was observed in the river water irrigated plots. The interaction effect was non-significant at all the three stages in maize crop.

In sunflower grown soil, the effluent irrigated plots recorded higher soil available K content than the river water irrigated plots and among the amendments, FYM (T_2) added plots recorded higher values followed by (T_8). The interaction effect was found to be significant only at harvest stage. The treatment combination I_2T_2 recorded higher available K content that is on par with I_2T_3, I_2T_6 and the lowest value was found in I_1T_5.

4.7.1.8.Effect of effluent and amendments on soil exchangeable calcium

As in the case of major nutrients, the exchangeable calcium content was higher under effluent irrigation than under river water irrigation. There was no significant

Table.104.Effect of effluent and amendments on soil available K (kg ha^{-1}) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	215	221	218	214	217	216	207	203	205	206	216	211	196	212	204	197	205	201
T_2	253	265	259	252	257	255	243	234	238	224	235	229	217	235	226	213	227	220
T_3	228	240	234	228	230	229	222	213	218	213	223	218	207	223	215	201	227	214
T_4	210	215	213	210	212	211	199	199	199	204	210	207	191	206	198	193	197	195
T_5	206	210	208	206	207	207	195	197	196	202	208	205	189	204	196	191	195	193
T_6	238	250	244	237	242	240	231	222	227	217	228	222	211	228	219	206	220	213
T_7	224	228	226	223	226	225	215	213	214	210	221	216	200	217	209	199	208	204
T_8	245	257	251	245	250	247	238	229	234	221	232	227	215	233	224	211	224	218
Mean	227	236	232	227	230	229	219	214	216	212	222	217	203	220	212	201	213	207
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	1.38	2.82		1.37	2.79		1.29	2.64		1.29	2.64		1.26	2.58		1.24	2.53	
T	2.77	5.65		2.73	5.58		2.58	5.28		2.59	5.29		2.53	5.16		2.48	5.06	
IXT	3.91	NS		3.86	NS		3.66	NS		3.66	NS		3.57	NS		3.50	7.15	

Table.105.Effect of effluent and amendments on soil exchangeable calcium per cent under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.12	0.14	0.13	0.12	0.13	0.13	0.13	0.13	0.13	0.11	0.13	0.12	0.11	0.13	0.12	0.11	0.13	0.12
T_2	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.12	0.14	0.13	0.11	0.14	0.13	0.12	0.13	0.13
T_3	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.17	0.16	0.15	0.16	0.15	0.14	0.16	0.15
T_4	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.16	0.15	0.14	0.16	0.15	0.13	0.16	0.15	0.13	0.15	0.14
T_5	0.15	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.15	0.14	0.12	0.15	0.14	0.12	0.14	0.13
T_6	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.18	0.18	0.16	0.18	0.17	0.15	0.17	0.16	0.15	0.16	0.16
T_7	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.18	0.20	0.19	0.17	0.19	0.18	0.16	0.18	0.17
T_8	0.20	0.21	0.21	0.20	0.21	0.20	0.20	0.20	0.20	0.19	0.21	0.20	0.18	0.20	0.19	0.17	0.18	0.17
Mean	0.17	0.18	0.17	0.16	0.17	0.16	0.16	0.16	0.16	0.15	0.17	0.16	0.14	0.16	0.15	0.14	0.15	0.15
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.002	NS		0.002	NS		0.002	NS		0.002	0.004		0.002	0.003		0.002	0.003	
T	0.004	0.008		0.004	0.007		0.003	0.007		0.004	0.007		0.003	0.007		0.003	0:007	
IXT	0.006	NS		0.005	NS		0.005	NS		0.005	NS		0.005	NS		0.005	NS	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

difference between the irrigation sources. The details on soil exchangeable Ca at different stages of maize and sunflower are presented in Table 105.

Both amendment and effluent received plots recorded higher Ca content than the treatment received effluent irrigation alone. At vegetative stage, the available Ca content varied from 0.14 to 0.21 and 0.12 to 0.20 per cent in the effluent and river water irrigated plots respectively. At flowering stage, the available Ca content varied from 0.13 to 0.21 and 0.12 to 0.20 per cent in the effluent and river water irrigated plots respectively. The same trend was observed at harvest stage also.

In case of sunflower grown soil, effluent irrigated plots recorded higher Ca content than the river water irrigated plots and amendment with effluent treatments recorded higher Ca content than unamended plots (T_1). Among the amendments, T_8 (FA+S+GM) recorded the highest exchangeable Ca than the rest of the amendments. The significant difference was not observed between the irrigation sources and amendments in all the stages.

4.7.1.9.Effect of effluent and amendments on soil exchangeable magnesium

The details on soil exchangeable Mg at different stages of maize and sunflower are presented in Table 106. In general, the exchangeable Mg decreased with the advancement of crop growth irrespective of irrigation sources.

Amendments with effluent irrigation recorded higher values than the river water irrigated maize plots. Among the amendments, T_3 (sludge) recorded the highest Mg content than the rest of the amendments. The interaction effect was found to be significant at vegetative and harvest stages. At vegetative stage, the exchangeable Mg content varied from 0.06 to 0.11 and 0.05 to 0.09 per cent in the effluent and river water irrigated plots respectively. At flowering stage, the exchangeable Mg content varied from 0.07 to 0.11 and 0.05 to 0.08 per cent in the effluent and river water

Table.106.Effect of effluent and amendments on soil exchangeable magnesium per cent under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.05	0.06	0.06	0.05	0.07	0.06	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.03	0.04	0.04
T_2	0.06	0.07	0.06	0.05	0.07	0.06	0.04	0.05	0.05	0.04	0.06	0.05	0.04	0.06	0.05	0.03	0.05	0.04
T_3	0.09	0.12	0.10	0.08	0.11	0.09	0.08	0.09	0.09	0.07	0.10	0.08	0.07	0.10	0.08	0.06	0.09	0.07
T_4	0.08	0.10	0.09	0.07	0.09	0.08	0.07	0.08	0.07	0.06	0.08	0.07	0.06	0.08	0.07	0.05	0.07	0.06
T_5	0.06	0.07	0.07	0.05	0.08	0.07	0.05	0.06	0.05	0.04	0.06	0.05	0.04	0.06	0.05	0.04	0.05	0.04
T_6	0.08	0.11	0.10	0.08	0.10	0.09	0.07	0.09	0.08	0.07	0.09	0.08	0.07	0.09	0.08	0.06	0.08	0.07
T_7	0.07	0.09	0.08	0.06	0.08	0.07	0.06	0.07	0.07	0.05	0.08	0.07	0.05	0.08	0.07	0.05	0.07	0.06
T_8	0.07	0.08	0.07	0.06	0.09	0.07	0.05	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.06	0.04	0.06	0.05
Mean	0.07	0.09	0.08	0.06	0.09	0.07	0.06	0.07	0.06	0.05	0.07	0.06	0.05	0.07	0.06	0.04	0.06	0.05
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00	
T	0.00	0.00		0.02	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00	
IXT	0.00	0.01		0.00	NS		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.00	

Table.107.Effect of effluent and amendments on DTPA copper (ppm) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	1.45	1.59	1.52	1.49	1.61	1.55	1.48	1.53	1.50	1.56	1.65	1.60	1.51	1.57	1.54	1.48	1.54	1.51
T_2	1.51	1.66	1.58	1.54	1.66	1.60	1.56	1.61	1.58	1.62	1.72	1.67	1.57	1.63	1.60	1.55	1.61	1.58
T_3	1.71	1.88	1.79	1.70	1.84	1.77	1.75	1.80	1.77	1.80	1.91	1.85	1.74	1.81	1.77	1.71	1.78	1.75
T_4	1.59	1.75	1.67	1.60	1.73	1.67	1.64	1.69	1.67	1.69	1.79	1.74	1.63	1.70	1.67	1.61	1.68	1.64
T_5	1.86	2.04	1.95	1.83	1.98	1.91	1.84	1.89	1.87	1.93	2.13	2.03	1.87	2.06	1.96	1.84	2.03	1.93
T_6	2.06	2.26	2.16	2.01	2.17	2.09	2.02	2.08	2.05	2.10	2.31	2.20	2.03	2.23	2.13	2.00	2.20	2.10
T_7	1.98	2.17	2.07	1.93	2.08	2.01	1.94	1.99	1.96	2.04	2.24	2.14	1.97	2.17	2.07	1.94	2.13	2.04
T_8	2.10	2.31	2.21	2.05	2.21	2.13	2.10	2.16	2.13	2.12	2.27	2.19	2.05	2.19	2.12	2.02	2.16	2.09
Mean	1.78	1.96	1.87	1.77	1.91	1.84	1.79	1.84	1.82	1.86	2.00	1.93	1.80	1.92	1.86	1.77	1.89	1.83
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.01	0.23		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02		0.01	0.02	
T	0.02	0.46		0.02	0.04		0.02	0.04		0.02	0.05		0.02	0.05		0.02	0.04	
IXT	0.03	NS		0.03	NS		0.03	NS		0.03	0.06		0.03	0.06		0.03	0.06	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

irrigated plots respectively. At harvest stage, the exchangeable Mg content varied from 0.05 to 0.09 and 0.04 to 0.08 per cent in the effluent and river water irrigated plots respectively.

In case of sunflower grown soil, the amendment T_3 (sludge) recorded the highest Mg content than the rest of the amendments. The interaction effect was found to be significant at all the three stages. In sunflower grown soil, at vegetative stage, the Mg content varied from 0.05 to 0.10 and 0.04 to 0.07 per cent in the effluent and river water irrigated plots respectively. At flowering and harvest stage also the same trend as that of vegetative stage were followed.

4.7.1.10. Effect of effluent and amendments on soil DTPA copper

In maize grown soil at vegetative stage, the Cu content varied from 1.59 to 2.31 ppm in the effluent irrigated plots and 1.45 to 2.10 ppm in the river water irrigated plots. As far as amendments were concerned, T_8 (FA + S + GM) recorded the highest DTPA Cu content and on par with T_6 (FA + GM). Control (T_1) recorded low values followed by T_2 (FYM) and it was significantly different from others. The DTPA Cu content varied from 1.61 to 2.21 ppm at flowering stage in the effluent irrigated plots and 1.49 to 2.05 ppm was recorded in river water irrigated plots. All the treatments showed significant variations in the main effect. At harvest stage, the Cu content varied from 1.53 to 2.16 ppm in the effluent irrigated plots and 1.48 to 2.10 ppm in the river water irrigated plots.

The Cu content varied from 1.65 to 2.31 ppm in the effluent irrigated plots and 1.56 to 2.12 ppm in the river water irrigated plots in sunflower grown soil. The interaction effect due to irrigation and amendments was significant. Fly ash + GM (T_6) and T_8 were on par with each other and significantly different from T_7 and T_5 . With reference to irrigation all the treatments showed significant variations. At flowering and harvest stage, in the effluent irrigated plots, the DTPA Cu content varied from 1.57 to 2.23 and 1.54 to 2.20 ppm respectively; whereas in river water irrigated plots, the DTPA Cu content varied from 1.51 to 2.05 and 1.48 to 2.02 ppm for flowering and harvest stage respectively.

4.7.1.11. Effect of effluent and amendments on soil DTPA iron

The Fe content differed significantly due to treatments at flowering and harvest stages (table 108). At vegetative stage, in maize grown soil, the Fe content was higher in effluent irrigation followed by river water irrigation. At flowering and harvest stage, the Fe content varied from 4.73 to 4.93 and 4.69 to 4.89 ppm respectively in the effluent irrigated plots and in the river water irrigated plots, it varied from 4.63 to 4.79 and 4.60 and 4.76 ppm for flowering and harvest stage respectively (Table 108).

In sunflower grown soil, T_8 recorded highest DTPA Fe content and on par with rest of the other amendments. At vegetative stage it was not significant with treatments but significant differences with irrigation was observed. The DTPA Fe content showed decreasing trend at flowering stage. In the effluent irrigated plots, T_8, T_7, T_6, T_5 were significantly different from each other and T_1 (control), which recorded the lowest Fe content. At harvest stage also decreasing trend was observed and the DTPA Fe content showed a range from 4.63 to 4.94 ppm in the effluent irrigated plots and 4.55 to 4.80 ppm in the river water irrigated plots .

4.7.1.12. Effect of effluent and amendments on DTPA manganese

The data on soil DTPA Mn at different stages of maize and sunflower are presented in Table 109. In general, the DTPA Mn decreased in later stages of crop growth. Effluent irrigation increased the exchangeable Mn.

In maize grown soil at vegetative stage, the available Mn varied from 2.60 to 2.90 and 2.35 to 2.63 ppm in the effluent and river water irrigated plots respectively.

Table.108.Effect of effluent and amendments on DTPA iron (ppm) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	4.68	4.81	4.74	4.63	4.73	4.68	4.60	4.69	4.64	4.68	4.77	4.72	4.57	4.66	4.61	4.55	4.63	4.59
T_2	4.70	4.82	4.76	4.65	4.75	4.70	4.62	4.71	4.66	4.70	4.79	4.74	4.60	4.70	4.65	4.58	4.67	4.63
T_3	4.73	4.86	4.79	4.69	4.79	4.74	4.67	4.76	4.71	4.74	4.83	4.78	4.68	4.78	4.73	4.66	4.75	4.70
T_4	4.71	4.83	4.77	4.67	4.77	4.72	4.64	4.73	4.68	4.71	4.81	4.76	4.64	4.73	4.69	4.62	4.70	4.66
T_5	4.76	4.89	4.82	4.72	4.86	4.79	4.69	4.81	4.75	4.75	4.87	4.81	4.72	4.88	4.80	4.70	4.80	4.75
T_6	4.81	4.93	4.87	4.77	4.91	4.84	4.74	4.87	4.80	4.80	4.92	4.86	4.78	4.94	4.86	4.76	4.90	4.83
T_7	4.78	4.91	4.84	4.74	4.88	4.81	4.71	4.83	4.77	4.77	4.89	4.83	4.75	4.91	4.83	4.73	4.87	4.80
T_8	4.82	4.95	4.88	4.79	4.93	4.86	4.76	4.89	4.82	4.82	4.98	4.90	4.82	4.98	4.90	4.80	4.94	4.87
Mean	4.75	4.87	4.81	4.71	4.83	4.77	4.68	4.78	4.73	4.75	4.86	4.80	4.69	4.82	4.76	4.68	4.78	4.73
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.03	0.06		0.03	0.06		0.03	0.06		0.03	0.06		0.03	0.06		0.03	0.06	
T	0.06	NS		0.06	0.12		0.06	0.12		0.06	NS		0.06	0.01		0.06	0.12	
IXT	0.08	NS		0.08	NS		0.08	NS		0.08	NS		0.08	NS		0.08	NS	

Table.109.Effect of effluent and amendments on DTPA manganese (ppm) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	2.35	2.60	2.47	2.36	2.52	2.44	2.33	2.52	2.43	2.42	2.59	2.51	2.41	2.58	2.49	2.33	2.57	2.45
T_2	2.63	2.90	2.77	2.64	2.82	2.73	2.51	2.72	2.61	2.73	2.90	2.82	2.68	2.87	2.77	2.59	2.85	2.72
T_3	2.38	2.62	2.50	2.39	2.55	2.47	2.35	2.55	2.45	2.44	2.62	2.53	2.43	2.60	2.52	2.35	2.59	2.47
T_4	2.43	2.67	2.55	2.44	2.60	2.52	2.38	2.58	2.48	2.49	2.67	2.58	2.48	2.66	2.57	2.40	2.64	2.52
T_5	2.45	2.70	2.58	2.46	2.63	2.54	2.41	2.61	2.51	2.54	2.73	2.64	2.53	2.70	2.61	2.44	2.69	2.57
T_6	2.53	2.79	2.66	2.54	2.71	2.62	2.44	2.65	2.55	2.62	2.79	2.70	2.59	2.77	2.68	2.50	2.76	2.63
T_7	2.58	2.84	2.71	2.59	2.76	2.68	2.47	2.67	2.57	2.68	2.84	2.76	2.64	2.83	2.73	2.55	2.81	2.68
T_8	2.60	2.87	2.74	2.61	2.79	2.70	2.49	2.70	2.59	2.70	2.87	2.79	2.66	2.85	2.76	2.57	2.83	2.70
Mean	2.49	2.75	2.62	2.50	2.67	2.59	2.42	2.62	2.52	2.58	2.75	2.67	2.55	2.73	2.64	2.47	2.72	2.59
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.02	0.32		0.02	0.03		0.01	0.03		0.02	0.03		0.02	0.32		0.02	0.03	
T	0.03	0.64		0.03	0.06		0.03	0.06		0.03	0.07		0.03	0.06		0.03	0.06	
IXT	0.04	NS		0.04	NS		0.04	NS		0.05	NS		0.04	NS		0.04	NS	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

Treatment received FYM (T_2) showed higher values of DTPA Mn content than the other treatments. At flowering stage, the DTPA Mn content showed a range of 2.52 to 2.82 ppm in the effluent irrigated soil; whereas in river water it was 2.36 to 2.64 ppm. At harvest stage, the range observed in DTPA Mn content was 2.52 to 2.72 ppm in effluent irrigation and 2.33 to 2.51 ppm in the river water.

In sunflower, at vegetative stage, the DTPA Mn content varied from 2.59 to 2.90 and 2.42 to 2.73 ppm in effluent and river water irrigation respectively. The DTPA Mn content showed a decreasing trend at flowering and harvest stage. Treatment received FYM (T_2) along with effluent irrigation showed higher values than the other treatments. The interaction due to amendments and irrigation source was non significant.

4.7.1.13. Effect of effluent and amendment on soil DTPA zinc

The details on soil DTPA Zn at different stages of maize and sunflower are presented in Table 110. In general, the DTPA Zn gradually decreased with advancement of crop growth. The DTPA Zn content was higher in effluent than river water.

In the maize grown soil, among the amendments, T8, T_7, T_4, and T_6 showed higher DTPA Zn content than the other amendments. The DTPA Zn content at vegetative stage ranged from 4.23 to 4.41 ppm in effluent irrigated plots and 4.27 to 4.40 ppm in river water irrigated plots. Treatments T_4, T_6, T_7 and T_8 were on par among themselves.

4.7.2. Effect of effluent on biological properties of soil

The results obtained in the enumeration of microbial load from the field trial are presented in Table 111.

Table.110.Effect of effluent and amendments on DTPA zinc (ppm) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	4.22	4.23	4.23	4.19	4.20	4.20	4.17	4.20	4.18	4.23	4.37	4.30	4.20	4.33	4.26	4.17	4.30	4.23
T_2	4.24	4.25	4.25	4.22	4.22	4.22	4.19	4.23	4.21	4.25	4.38	4.32	4.21	4.34	4.28	4.18	4.31	4.25
T_3	4.27	4.28	4.27	4.24	4.25	4.24	4.21	4.25	4.23	4.27	4.40	4.33	4.23	4.36	4.30	4.20	4.33	4.27
T_4	4.38	4.40	4.39	4.35	4.37	4.36	4.36	4.38	4.37	4.36	4.54	4.45	4.32	4.50	4.41	4.29	4.47	4.38
T_5	4.29	4.30	4.29	4.26	4.27	4.26	4.24	4.28	4.26	4.30	4.43	4.37	4.26	4.39	4.33	4.23	4.36	4.30
T_6	4.34	4.35	4.35	4.31	4.32	4.32	4.31	4.34	4.32	4.33	4.51	4.42	4.29	4.47	4.38	4.26	4.43	4.35
T_7	4.40	4.42	4.41	4.37	4.39	4.38	4.38	4.41	4.40	4.37	4.55	4.46	4.33	4.51	4.42	4.30	4.48	4.39
T_8	4.41	4.41	4.41	4.38	4.38	4.38	4.40	4.43	4.41	4.39	4.57	4.48	4.35	4.53	4.44	4.32	4.50	4.41
Mean	4.32	4.33	4.32	4.29	4.30	4.30	4.28	4.31	4.30	4.31	4.47	4.39	4.27	4.43	4.35	4.24	4.40	4.32
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.03	NS		0.03	NS		0.03	NS		0.03	0.05		0.03	0.05		0.03	0.53	
T	0.05	0.11		0.05	0.11		0.05	0.11		0.05	0.11		0.05	0.11		0.05	0.11	
IXT	0.07	NS		0.07	NS		0.07	NS		0.07	NS		0.07	NS		0.07	NS	

Table.111.Effect of effluent and amendments on soil amylase (mg reducing sugars g^{-1} soil 24 $hours^{-1}$) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.27	0.35	0.31	0.30	0.36	0.33	0.21	0.32	0.26	0.22	0.27	0.24	0.23	0.26	0.25	0.18	0.21	0.20
T_2	0.34	0.44	0.39	0.37	0.45	0.41	0.24	0.37	0.31	0.26	0.33	0.30	0.28	0.32	0.30	0.22	0.26	0.24
T_3	0.36	0.50	0.43	0.40	0.51	0.46	0.26	0.41	0.33	0.28	0.40	0.34	0.29	0.34	0.32	0.24	0.27	0.25
T_4	0.29	0.38	0.33	0.32	0.39	0.35	0.22	0.33	0.27	0.23	0.29	0.26	0.24	0.28	0.26	0.20	0.22	0.21
T_5	0.38	0.54	0.46	0.43	0.55	0.49	0.27	0.54	0.40	0.29	0.43	0.36	0.31	0.45	0.38	0.25	0.29	0.27
T_6	0.41	0.58	0.50	0.46	0.59	0.53	0.29	0.57	0.43	0.31	0.46	0.38	0.33	0.48	0.41	0.27	0.30	0.28
T_7	0.31	0.41	0.36	0.35	0.42	0.38	0.23	0.35	0.29	0.25	0.31	0.28	0.26	0.30	0.28	0.21	0.24	0.22
T_8	0.44	0.62	0.53	0.49	0.63	0.56	0.30	0.60	0.45	0.33	0.48	0.40	0.35	0.51	0.43	0.28	0.32	0.30
Mean	0.35	0.48	0.41	0.39	0.49	0.44	0.25	0.43	0.34	0.27	0.37	0.32	0.29	0.37	0.33	0.23	0.26	0.25
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.002	0.005		0.003	0.006		0.002	0.005		0.002	0.005		0.003	0.006		0.002	0.005	
T	0.005	0.010		0.006	0.011		0.005	0.010		0.005	0.009		0.005	0.001		0.004	0.008	
IXT	0.007	0.014		0.008	0.016		0.007	0.014		0.070	NS		0.007	0.001		0.006	0.001	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

4.7.2.1. Effect of effluent of amendments on soil amylase activity

The activity of soil amylase increased in plots received effluent irrigation than river water irrigation at all stages of crop growth. Among the amendments T8 recorded highest amylase activity (0.53 mg) followed by T6 (0.50 mg). The least was observed in control (T1). In the maize crop at vegetative stage, the amylase activity varied from 0.35 to 0.62 mg in the effluent irrigated plots and 0.27 to 0.44 mg in the river water irrigated plots. All the treatments showed significant variations in the main as well as interaction effects. At flowering stage also the treatments showed significant variations in the main as well as interaction effects. The amendments repeated the same trend almost at all stages of maize and sunflower growth. The amylase activity varied from 0.36 to 0.63 and 0.30 to 0.49 mg in the effluent and river water irrigated plots respectively. At harvest stage, it varied from 0.32 to 0.60 mg in the effluent irrigated plots and 0.21 to 0.30 mg in the river water irrigated plots. In sunflower grown soil, also observed the same trend, effluent irrigated plots recorded more amylase activity than the river water irrigated plots. It was comparatively lesser than the maize grown soil. At vegetative stage, interaction effect was not observed (Table 111).

4.7.2.2. Effect of effluent on soil invertase activity

In general, effluent irrigated plots recorded more invertase activity than the river water irrigated plots. The activity of invertase was higher in amendment-received plots than the unamended plots. In maize at vegetative stage the invertase activity varied from 0.26 to 0.50 mg in effluent irrigated plots and 0.22 to 0.37 mg in the river water irrigated plots. All the treatments showed significant variations in main and interaction effects. At flowering stage and harvest stage in the effluent irrigated plots, the invertase activity varied from 0.27 to 0.53 and 0.20 to 0.30 mg respectively. Whereas in river water irrigated plots the invertase activity varied from 0.24 to 0.39 and 0.19 to 0.27 mg at flowering and harvest stage respectively. All the treatments were significantly different from each other both in the main and interaction effects except at harvest stage. In case of sunflower grown soil, observed the same trend as the effluent irrigated plots recorded more invertase activity during the vegetative stage there was no significant difference between irrigation and amendments. But in flowering and harvest stage all the treatments showed significant variations in main and interaction effect (Table 112).

4.7.2.3. Effect of effluent on cellulase activity (Table 113)

The cellulase activity recorded was higher in effluent irrigated plots. Among the amendments, T_8 (FA + S + GM) recorded the increased cellulase activity invariably at all stages of crop growth.. In maize grown soil at vegetative stage, the cellulase activity variety from 11.19 to 16.37 µg in the effluent irrigated plots and 10.34 to 15.12 µg in the river water irrigated plots. Significant interactions were not observed between different treatments and irrigation sources. At flowering and harvest stage the enzyme activity of the effluent irrigated plots varied from 12.57 to 17.45 and 8.26 to 11.34 µg respectively but it varied from 10.61 to 14.72 and 7.96 to 10.93 µg for flowering and harvest stage respectively in river water irrigated plots. All the treatments recorded significant main and interaction effects. In sunflower, the effluent irrigation increased the cellulase activity. The interaction between irrigation and amendments was found to be significant at all the stages.

4.7.2.10. Effect of effluent and amendments on bacterial population

The bacterial population was significantly influenced by treatments and sources of irrigation. Effluent irrigated plots recorded more bacterial population than river water irrigated plots. Among the amendments, T_7 recorded the highest population of

Table.112.Effect of effluent and amendments on soil invertase (mg reducing sugars g^{-1} soil 24 $hours^{-1}$) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	0.22	0.26	0.24	0.24	0.27	0.26	0.19	0.20	0.20	0.19	0.24	0.22	0.21	0.26	0.24	0.14	0.17	0.16
T_2	0.24	0.28	0.26	0.26	0.29	0.27	0.20	0.21	0.20	0.20	0.25	0.23	0.23	0.27	0.25	0.15	0.18	0.17
T_3	0.28	0.33	0.30	0.30	0.34	0.32	0.22	0.24	0.23	0.23	0.29	0.26	0.26	0.31	0.28	0.18	0.22	0.20
T_4	0.26	0.30	0.28	0.28	0.32	0.30	0.21	0.22	0.22	0.22	0.27	0.24	0.24	0.29	0.26	0.17	0.20	0.18
T_5	0.30	0.41	0.35	0.32	0.43	0.37	0.23	0.25	0.24	0.25	0.31	0.28	0.27	0.37	0.32	0.19	0.26	0.23
T_6	0.32	0.28	0.30	0.34	0.28	0.31	0.24	0.27	0.26	0.27	0.33	0.30	0.29	0.40	0.34	0.21	0.28	0.24
T_7	0.35	0.47	0.41	0.37	0.50	0.43	0.26	0.29	0.27	0.29	0.35	0.32	0.31	0.43	0.37	0.22	0.30	0.26
T_8	0.37	0.50	0.43	0.39	0.53	0.46	0.27	0.30	0.28	0.30	0.37	0.33	0.33	0.45	0.39	0.24	0.33	0.29
Mean	0.29	0.35	0.32	0.31	0.37	0.34	0.23	0.25	0.24	0.24	0.30	0.27	0.27	0.35	0.31	0.19	0.24	0.22
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00	
T	0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01		0.00	0.01	
IXT	0.01	0.01		0.01	0.01		0.01	NS		0.01	NS		0.01	0.01		0.00	0.01	

Table.113.Effect of effluent and amendments on soil cellulase (ug reducing sugars g^{-1} soil 24 $hours^{-1}$) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	10.34	11.19	10.76	10.61	12.57	11.59	7.96	8.26	8.11	9.32	11.04	10.18	9.87	10.91	10.39	7.55	8.34	7.94
T_2	12.96	14.03	13.50	13.02	15.44	14.23	9.77	10.14	9.95	10.53	13.52	12.03	11.16	14.33	12.74	9.18	11.79	10.48
T_3	11.00	11.91	11.45	11.16	13.23	12.20	8.38	8.69	8.53	9.51	11.26	10.39	10.07	11.13	10.60	7.78	8.60	8.19
T_4	11.58	12.53	12.05	11.63	13.79	12.71	8.73	9.05	8.89	9.80	11.61	10.71	10.39	11.47	10.93	8.11	8.95	8.53
T_5	12.31	13.33	12.82	12.37	14.67	13.52	9.28	9.63	9.46	10.00	11.85	10.93	10.60	11.71	11.15	8.53	9.43	8.98
T_6	13.64	14.77	14.21	13.56	16.08	14.82	10.18	10.56	10.37	10.74	13.80	12.27	11.38	14.62	13.00	9.56	12.28	10.92
T_7	14.52	15.72	15.12	14.28	16.93	15.60	10.60	11.00	10.80	11.19	14.38	12.78	11.86	15.23	13.54	10.06	12.92	11.49
T_8	15.12	16.37	15.75	14.72	17.45	16.09	10.93	11.34	11.13	11.42	14.67	13.04	12.10	15.54	13.82	10.48	12.95	11.72
Mean	12.68	13.73	13.21	12.67	15.02	13.84	9.48	9.83	9.66	10.31	12.77	11.54	10.93	13.12	12.02	8.91	10.66	9.78
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.08	0.16		0.08	0.17		0.06	0.12		0.01	0.11		0.72	0.15		0.06	0.12	
T	0.16	0.32		0.17	0.34		0.12	0.24		0.10	0.28		0.14	0.30		0.12	0.24	
IXT	0.22	NS		0.24	NS		0.16	NS		0.20	0.40		0.20	0.42		0.17	0.34	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

22.73, 25.89 and 26.06 x 10^6 g^{-1} of dry soil in all the three stages respectively. The lowest population was observed in control.

The interaction effect was found to be significant. At vegetative stage, the non-rhizosphere bacterial population varied from 13.50 to 25.25 and 12.14 to 20.20 x 10^6 g^{-1} of dry soil in the effluent and river water irrigated plots respectively in the maize grown soil. At flowering and harvest stage, the bacterial population varied from 13.82 to 27.40 x 10^6 and 13.94 to 32.81 x 10^6 g^{-1} of dry soil respectively in the effluent irrigated plots and 12.30 to 24.39 and 9.96 to 19.30 x 10^6 of dry soil respectively in the river water irrigated plot (Table 114).

As far as sunflower was concerned, as the duration of effluent irrigation increased, the population also increased. But it was lesser than the maize grown soils. The amendment T_7 was found to be the best account of bacterial population followed by T_4 at all stages.

The interaction effect was found to be significant at all the three stages. At vegetative stage, it varied from 7.70 to 15.84 and 8.11 to 13.20 x 10^6 g^{-1} of dry soil in the effluent and river water irrigated plots respectively in sunflower grown soil. The similar trend was observed at flowering and harvest stage also.

4.7.2.11. Effect of effluent and amendments on actinomycetes population

The actinomycetes population showed a significant difference among the various amendments irrigated with effluent and river water at different stages of crop growth. In general effluent irrigated plots showed higher population than the river water irrigated plots. The treatment T_8 recorded the maximum actinomycetes population at all stages of crop growth.

The interaction effect was found to be significant. In maize at vegetative stage, the actinomycetes population varied from 14.15 to 25.73 and 8.09 to 14.70 x 10^3 g^{-1} of

Table.114.Effect of effluent and amendment on soil bacterial population (x 10^{6} g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	12.14	13.50	12.82	12.30	13.82	13.06	9.96	13.94	11.95	8.11	7.70	7.90	8.47	9.23	8.85	8.62	10.52	9.57
T_2	13.20	14.67	13.94	13.98	15.71	14.85	11.19	15.67	13.43	8.81	8.37	8.59	9.11	9.93	9.52	9.58	11.69	10.63
T_3	14.50	16.13	15.31	15.71	17.65	16.68	12.43	17.41	14.92	9.68	9.20	9.44	10.01	10.91	10.46	10.30	12.57	11.43
T_4	19.39	24.24	21.82	22.92	25.76	24.34	18.14	30.84	24.49	12.67	15.84	14.26	13.82	14.22	14.02	13.77	16.80	15.29
T_5	16.59	20.74	18.67	19.61	22.04	20.82	14.69	24.98	19.84	11.08	11.96	11.52	11.95	12.30	12.13	12.04	14.69	13.37
T_6	15.76	17.53	16.64	17.65	19.83	18.74	13.37	18.72	16.04	10.52	10.00	10.26	11.12	12.12	11.62	11.32	13.81	12.56
T_7	20.20	25.25	22.73	24.39	27.40	25.89	19.30	32.81	26.06	13.20	15.18	14.19	14.40	14.82	14.61	14.20	17.32	15.76
T_8	18.03	22.54	20.29	21.32	23.95	22.64	16.51	28.07	22.29	11.78	14.73	13.26	12.99	14.33	13.66	12.95	15.80	14.37
Mean	16.23	19.33	17.78	18.49	20.77	19.63	14.45	22.80	18.63	10.73	11.62	11.18	11.48	12.23	11.86	11.60	14.15	12.87
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.11	0.22		0.12	0.24		0.12	0.24		0.07	0.14		0.07	0.15		0.08	0.16	
T	0.22	0.44		0.24	0.49		0.24	0.48		0.14	0.28		0.14	0.29		0.16	0.32	
IXT	0.31	0.63		0.34	0.69		0.34	0.68		0.19	0.39		0.20	0.41		0.22	0.45	

Table.115.Effect of effluent and amendment on soil actinomycetes population (x 10^{3} g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	11.47	20.08	15.78	11.08	19.40	15.24	15.36	22.27	18.81	11.86	21.95	16.91	12.25	21.45	16.85	17.27	19.86	18.56
T_2	14.70	25.73	20.21	14.20	24.85	19.53	20.10	29.15	24.62	15.20	30.54	22.87	15.70	27.48	21.59	22.60	32.77	27.69
T_3	9.09	15.90	12.50	8.78	15.36	12.07	12.16	17.64	14.90	9.40	17.38	13.39	9.71	16.99	13.35	13.68	15.73	14.70
T_4	10.33	18.07	14.20	9.98	17.46	13.72	13.82	20.04	16.93	10.68	19.75	15.22	11.03	19.30	15.17	15.54	17.87	16.71
T_5	8.09	14.15	11.12	7.81	13.67	10.74	10.83	15.70	13.26	8.36	15.47	11.92	8.64	15.12	11.88	12.17	14.00	13.08
T_6	12.34	21.59	16.96	11.92	20.86	16.39	16.69	24.20	20.45	12.76	23.60	18.18	13.18	23.06	18.12	18.77	27.22	22.99
T_7	12.99	22.73	17.86	12.55	21.95	17.25	17.76	25.75	21.75	13.43	26.98	20.20	13.87	24.27	19.07	19.97	28.95	24.46
T_8	13.97	24.44	19.20	13.49	23.61	18.55	19.10	27.69	23.39	14.44	29.01	21.72	14.92	26.10	20.51	21.47	31.13	26.30
Mean	11.62	20.34	15.98	11.23	19.64	15.44	15.73	22.80	19.27	12.02	23.09	17.55	12.41	21.72	17.07	17.68	23.44	20.56
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.10	0.20		0.10	0.20		0.12	0.24		0.11	0.23		0.11	0.22		0.13	0.26	
T	0.20	0.41		0.19	0.39		0.24	0.48		0.23	0.46		0.21	0.44		0.25	0.52	
IXT	0.28	0.58		0.27	0.56		0.34	0.68		0.32	0.64		0.30	0.62		0.36	0.73	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

dry soil in the effluent and river water irrigated plots respectively. At flowering and harvest stage, it varied from 13.67 to 24.85 and 15.70 to 29.15 x 10^4 g^{-1} of dry soil respectively in the effluent irrigated plots; whereas in river water irrigated plots, it varied from 7.81 to 14.20 and 10.83 to 20.10 x 10^3 g^{-1} of dry soil respectively at flowering and harvest stage (Table 115).

In sunflower, effluent irrigation enhanced the actinomycetes population slightly and FYM (T_2) received plots showed more population than other amendments. In sunflower at vegetative, flowering and harvest stage in the effluent irrigated plots, it varied from 15.47 to 30.54,15.12 to 27.48 and 14.00 to 32.77 x 10^3 g^{-1} of dry soil respectively. Whereas in river water irrigated plots it varied from 8.36 to 15.20, 8.64 to 15.70 and 12.17 to 22.60 x 10^3 g^{-1} of dry soil at vegetative, flowering and harvest stage respectively (Table 115).

4.7.2.12. Effect of effluent and amendments on fungal population

The fungal population showed a marked difference among the various amendments and amendment combinations either with effluent or river water. The gradual increase was noticed upto flowering stage and after that it reduced gradually. In general effluent irrigation enhanced the fungal population. In maize among the amendments T_4 recorded the maximum population followed by T_7 .The maximum population was 9.00, 8.93 and 9.25 x 10^4 g^{-1} of dry soil at vegetative, flowering and harvest stages respectively. The interaction effect was found to be significant at all the three stages. In maize at vegetative, flowering and harvest stage, it varied from 7.41 to 10.50, 7.51 to 10.26 and 7.07 to 11.40 x 10^4 g^{-1} of dry soil respectively in the effluent irrigated plots, while in river water irrigated plots it varied from 5.29 to 7.50, 5.36 to 7.60 and 4.40 to 7.10 x 10^4 g^{-1} of dry soil at vegetative flowering and harvest stage respectively (Table 116).

Table.116.Effect of effluent and amendment on soil fungal population (x 10^4 g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	5.29	7.41	6.35	5.36	7.51	6.43	4.40	7.07	5.74	4.37	7.44	5.91	4.59	7.57	6.08	3.71	6.87	5.29
T_2	6.17	8.64	7.41	6.25	8.76	7.51	5.78	9.28	7.53	5.10	8.67	6.89	5.35	8.83	7.09	4.29	7.93	6.11
T_3	5.57	7.80	6.68	5.64	7.90	6.77	4.79	7.68	6.24	4.60	7.83	6.22	4.83	7.97	6.40	3.87	7.16	5.51
T_4	7.50	10.50	9.00	7.60	10.26	8.93	7.10	11.40	9.25	6.20	10.54	8.37	6.50	10.73	8.61	5.10	8.42	6.76
T_5	5.80	8.12	6.96	5.88	8.23	7.06	5.32	8.54	6.93	4.80	8.15	6.48	5.03	8.30	6.66	4.07	7.53	5.80
T_6	6.50	9.10	7.80	6.58	9.22	7.90	6.15	9.87	8.01	5.37	9.13	7.25	5.63	9.29	7.46	4.42	7.29	5.85
T_7	7.20	10.08	8.64	7.30	10.21	8.76	6.75	10.83	8.79	5.95	10.12	8.04	6.24	10.30	8.27	4.85	7.99	6.42
T_8	6.77	9.48	8.12	6.86	9.60	8.23	6.41	10.28	8.35	5.59	9.51	7.55	5.87	9.68	7.77	4.60	7.59	6.10
Mean	6.35	8.89	7.62	6.43	8.96	7.70	5.84	9.37	7.60	5.25	8.92	7.09	5.50	9.08	7.29	4.36	7.60	5.98
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.09		0.05	0.10		0.05	0.10		0.04	0.09		0.04	0.09		0.04	0.08	
T	0.09	0.19		0.09	0.19		0.09	0.19		0.09	0.18		0.09	0.18		0.07	0.15	
IXT	0.13	0.27		0.13	0.27		0.13	0.27		0.12	0.25		0.13	0.26		0.11	0.21	

Table.117.Effect of effluent and amendment on soil azotobacter population (x 10^4 g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	6.76	7.10	6.93	6.31	7.07	6.69	5.16	6.81	5.98	6.16	6.48	6.32	6.24	5.93	6.08	5.77	6.61	6.19
T_2	7.88	8.29	8.08	7.36	8.25	7.81	6.41	8.46	7.44	7.27	7.64	7.45	7.28	7.34	7.31	7.18	8.51	7.84
T_3	7.49	7.87	7.68	7.00	7.83	7.42	6.03	7.96	6.99	6.97	7.33	7.15	6.91	6.57	6.74	6.75	7.73	7.24
T_4	7.04	7.40	7.22	6.58	7.36	6.97	5.54	7.32	6.43	6.56	6.89	6.72	6.50	6.17	6.34	6.21	7.11	6.66
T_5	6.42	6.75	6.58	6.00	6.72	6.36	4.74	6.26	5.50	5.73	6.02	5.88	5.93	5.63	5.78	5.31	6.08	5.70
T_6	8.74	9.18	8.96	8.16	9.14	8.65	7.03	9.28	8.15	8.05	8.46	8.26	8.06	8.14	8.10	7.87	9.33	8.60
T_7	8.21	8.63	8.42	7.67	8.59	8.13	6.68	8.82	7.75	7.73	8.12	7.93	7.58	7.65	7.61	7.48	8.86	8.17
T_8	9.10	9.56	9.33	8.50	9.52	9.01	7.40	9.77	8.58	8.30	8.72	8.51	8.40	8.48	8.44	8.20	9.72	8.96
Mean	7.70	8.10	7.90	7.20	8.06	7.63	6.12	8.08	7.10	7.10	7.46	7.28	7.11	6.99	7.05	6.85	7.99	7.42
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.10		0.05	0.09		0.04	0.09		0.04	0.09		0.04	0.09		0.04	0.09	
T	0.95	0.19		0.09	0.19		0.09	0.18		0.09	0.18		0.08	0.17		0.09	0.18	
IXT	0.13	NS		0.13	NS		0.12	0.25		0.12	NS		0.12	0.24		0.13	0.26	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

In sunflower effluent irrigated plots showed higher population than the river water irrigated plots. The same trend as in maize grown soil was noticed in sunflower. At vegetative, flowering and harvest stage, it varied from 7.44 to 10.54, 7.57 to 10.73 and 6.87 to 8.42 x 10^4 g^{-1} of dry soil respectively in the effluent irrigated plots, whereas in river water irrigated plots it varied from 4.37 to 6.20, 4.59 to 6.50 and 3.71 to 5.10 x 10^4 g^{-1} of dry soil respectively at vegetative, flowering and harvest stage (Table 116).

4.7.2.13. Effect of effluent and amendments on *Azotobacter* population

The *Azotobacter* population showed a significant difference due to various amendments irrigated with effluent as well as river water at all stages of crop growth. In general, it showed a decreasing trend till the end of harvest stage irrespective of irrigation sources. The performance of T_8 was better than rest of the amendments at all stages of crop growth. Effluent irrigation resulted in significantly higher population load than river water.

In maize grown soil, at vegetative, flowering and harvest stage the *Azotobacter* population varied from 6.75 to 9.56, 6.72 to 9.52 and 6.26 to 9.77 x 10^2 g^{-1} of dry soil respectively in the effluent irrigated plots, while in river water irrigated plots it varied from 6.42 to 9.10, 6.00 to 8.50 and 4.74 to 7.40 x 10^2 g^{-1} of dry soil at vegetative, flowering and harvest stage respectively. All the treatments were significantly differ with each other and the interaction effect was found to be significant only at harvest stage (Table 117).

In sunflower grown soil, the effluent irrigated plots showed higher *Azotobacter* population. Treatment received FA + S + GM (T_8) showed higher population than other treatments. The effluent irrigated plots at vegetative, flowering and harvest stage, the *Azotobacter* population varied from 6.02 to 8.72, 5.63 to 8.48 and 6.08 to 9.72 x 10^2 g^{-1} of dry soil respectively, while in the river water irrigated plots it varied from 5.73 to

8.30, 5.93 to 8.40 and 5.31 to 8.20 x 10^2 g^{-1} of dry soil at vegetative flowering and harvest stage respectively (Table 117).

4.7.2.14. Effect of effluent and amendments on *Azospirillum* population

The details regarding *Azospirillum* population as influenced by irrigation sources and amendments on maize and sunflower are furnished in Table 118.Effluent performed better than river water. Among the amendments, T_8 recorded the maximum population at all the three stages.

In maize, the interaction effect was seen at all the stages except the harvest stage. The gradual decrease in population was observed invariably at the harvest stage. At vegetative, flowering and harvest stage, the population varied from 14.56 to 18.73, 13.55 to 21.28 and 8.61 to 15.62 x 10^4 g^{-1} of dry soil, respectively in the effluent irrigated plots. Whereas in river water irrigated plots it varied from 8.82 to 10.70, 9.68 to 13.30 and 7.83 to 14.20 x 10^4 g^{-1} of dry soil at vegetative, flowering and harvest stage, respectively.

In sunflower also the amendment T_8 recorded the maximum population at all the three stages. The *Azospirillum* population varied from 9.31 to 14.36, 10.29 to 15.14 and 9.98 to 15.05 x 10^4 g^{-1} of dry soil at vegetative, flowering and harvest stage respectively in the effluent irrigated plots; whereas in river water irrigated plots it varied from 8.62 to 13.30, 9.53 to 14.70 and 8.25 to 17.70 x 10^4 g^{-1} of dry soil at vegetative, flowering and harvest stage respectively. The interaction effect was seen only at the harvest stage.

4.7.2.15. Effect of effluent and amendments on *Rhizobium* population

The data on *Rhizobium* population of the soil at different stages of maize and sunflower are presented in Table 119. The population showed a significant difference among the various amendments with effluent and river water at different stages of crop

Table.118.Effect of effluent and amendment on soil azospirillum population (x 10^4 g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	8.82	14.56	11.69	9.68	13.55	11.62	7.83	8.61	8.22	8.62	9.31	8.96	9.53	10.29	9.91	8.25	9.98	9.11
T_2	9.87	16.28	13.08	11.17	15.64	13.41	10.62	11.68	11.15	10.72	11.57	11.15	11.84	12.79	12.32	12.39	14.99	13.69
T_3	9.47	15.63	12.55	10.50	14.71	12.61	9.56	10.51	10.03	10.07	10.88	10.48	11.13	12.02	11.58	10.78	13.04	11.91
T_4	9.19	15.16	12.18	10.19	14.27	12.23	8.70	9.57	9.13	9.37	10.12	9.74	10.35	11.18	10.77	9.59	11.60	10.60
T_5	10.49	18.35	14.42	12.90	20.64	16.77	13.49	14.84	14.16	12.64	13.65	13.14	13.97	14.38	14.17	16.82	14.29	15.55
T_6	9.97	17.44	13.71	11.76	18.82	15.29	11.67	12.83	12.25	11.16	12.06	11.61	12.34	12.71	12.52	14.07	11.96	13.02
T_7	10.17	17.29	13.73	12.13	19.40	15.77	12.55	13.80	13.17	12.00	12.96	12.48	13.27	13.66	13.47	15.64	13.29	14.47
T_8	10.70	18.73	14.71	13.30	21.28	17.29	14.20	15.62	14.91	13.30	14.36	13.83	14.70	15.14	14.92	17.70	15.05	16.37
Mean	9.83	16.68	13.26	11.45	17.29	14.37	11.07	12.18	11.63	10.98	11.86	11.42	12.14	12.77	12.46	13.15	13.03	13.09
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.08	0.17		0.09	0.18		0.07	0.14		0.07	0.14		0.07	0.15		0.08	NS	
T	0.16	0.33		0.18	0.36		0.14	0.29		0.14	0.28		0.15	0.30		0.16	0.32	
IXT	0.23	0.47		0.25	0.51		0.20	NS		0.20	NS		0.21	NS		0.22	0.46	

Table.119.Effect of effluent and amendment on soil rhizobium population (x 10^3 g^{-1} of dry soil) under maize and sunflower

Amendments	Maize									Sunflower								
	Vegetative stage			Flowering stage			Harvest stage			Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	6.70	9.04	7.87	7.24	10.13	8.68	5.73	7.28	6.51	3.98	6.16	5.07	4.68	6.31	5.49	4.43	5.36	4.90
T_2	8.06	10.88	9.47	8.71	12.20	10.46	7.78	9.88	8.83	5.58	8.64	7.11	6.14	7.67	6.91	5.82	7.04	6.43
T_3	7.50	10.12	8.81	8.10	11.35	9.73	7.00	8.89	7.94	4.96	7.69	6.33	5.71	7.14	6.42	5.41	6.55	5.98
T_4	7.12	9.62	8.37	7.70	10.78	9.24	6.37	8.09	7.23	4.42	6.85	5.63	5.20	7.01	6.11	4.93	5.96	5.44
T_5	9.50	12.83	11.17	10.27	16.44	13.35	9.88	9.98	9.93	6.94	7.70	7.32	7.32	7.68	7.50	6.94	7.29	7.11
T_6	8.58	11.58	10.08	9.27	14.83	12.05	8.55	8.63	8.59	6.13	6.80	6.46	6.46	6.79	6.62	6.13	6.44	6.28
T_7	9.03	12.19	10.61	9.76	15.61	12.69	9.19	9.28	9.23	6.52	7.24	6.88	6.95	7.30	7.12	6.59	6.92	6.76
T_8	9.90	13.37	11.63	10.70	17.12	13.91	10.40	10.50	10.45	7.30	8.10	7.70	7.70	8.09	7.89	7.30	7.67	7.49
Mean	8.30	11.20	9.75	8.97	13.56	11.26	8.11	9.07	8.59	5.73	7.40	6.56	6.27	7.25	6.76	5.94	6.66	6.30
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.06	0.12		0.07	0.14		0.05	0.11		0.04	0.08		0.04	0.08		0.04	0.08	
T	0.12	0.24		0.14	0.28		0.10	0.21		0.08	0.16		0.08	0.17		0.08	0.15	
IXT	0.17	0.34		0.20	0.40		0.15	0.30		0.11	0.23		0.11	0.23		0.11	0.22	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

growth. Generally gradual increase of population upto flowering stage, after that reduced gradually in the harvest stage. The treatment T_8 recorded the maximum population in all the stages of both maize and sunflower. The interaction effect was found to be significant at all the stages.

In maize at vegetative, flowering and harvest stage, the *Rhizobium* population varied from 9.04 to 13.37, 10.13 to 17.12 and 7.28 to 10.50 x 10^3 g^{-1} of dry soil respectively in the effluent irrigated plots; whereas in the river water irrigated plots it varied from 6.70 to 9.90, 7.24 to 10.70 and 5.73 to 10.40 x 10^3 g^{-1} of dry soil at vegetative, flowering and harvest stage, respectively.

In case of sunflower also the interaction effect was significant at all stages of crop growth. At vegetative, flowering and harvest stage at varied from 6.16 to 8.64, 6.31 to 8.09 and 5.36 to 7.67 x 10^3 g^{-1} of dry soil, respectively in the effluent irrigated plots; whereas in river water irrigated plots it varied from 3.98 to 7.30, 4.68 to 7.70 and 4.43 to 7.30 x 10^3 g^{-1} of dry soil at vegetative, flowering and harvest stage, respectively.

4.7.3. Effect of effluent and amendments on plants

4.7.3.1. Effect of effluent on vigour index

Effluent irrigation along with amendment application enhanced the germination per cent and VI of maize and sunflower.

In maize crop the germination percentage varied from 80.28 to 94.45 by effluent irrigation and 78.27 to 90.20 by the river water irrigation. Treatment T_8 (FA + S + GM) showed higher germination percentage while T_4 (S) recorded the least. The root length showed a variation of 12.08 to 14.21 cm in the effluent irrigated plots while in river water irrigated plots it was from 11.78 to 13.57 cm. The shoot length of the seedlings varied from 14.17 to 16.67 cm in the effluent irrigated plots; whereas in river water irrigated plots, it was from 13.81 to 15.92 cm. All the treatments showed significant variations in the shoot length. Highest shoot length was observed in treatment received FA + S + GM (T_8) and lowest shoot length was recorded in the sludge received plots (T_4). The VI of the seedlings varied from 2107 to 2917 in the effluent irrigated plots, and 2003 to 2660 in the river water plots (Table 120).

In sunflower, the germination percentage varied from 80.13 to 95.32 in the effluent irrigated plots and 78.12 to 91.03 per cent in the river water irrigated plots. The root length showed a variation of 12.06 to 14.22 cm by the effluent irrigation and 11.76 to 13.56 cm by the river water irrigation. Shoot length varied from 14.16 to 16.66 cm in the effluent irrigated plots and 13.80 to 15.90 cm in the river water irrigated plots. The VI of the sunflower seedlings varied from 2103 to 2943 in the effluent irrigated plots and it was from 1997 to 2682 in the river water irrigated plots (Table 120).

4.7.3.2. Effect of effluent and amendments on plant height (cm)

Details on plant height of maize and sunflower recorded at different stages of crop growth are furnished in Table 121.

Effluent irrigation performed better than river water irrigation.

In maize at vegetative stage, T_8 recorded the highest plant height (67.3 cm) followed by T_6 (65.2 cm). Similar trend was observed during the later stages. The plant height varied from 54.7 to 68.4 cm in the effluent irrigated plots and 53.3 to 66.1 cm in the river water irrigated plots. At flowering stage, the plant height varied from 115.1 to 145.2 cm in the effluent irrigated plots and 112.3 to 139.6 cm by river water irrigated plots. Similar trend was exhibited at harvest stage also.

In sunflower, the amendment T_8 (FA + S + GM) recorded the increased plant height than the other amendments. At vegetative stage, the plant height varied from

Table 120.Effect of effluent and amendments on germination per cent and vigour indices under maize and sunflower

Amendments	Maize											
	Germination per cent			Root Length (cm)			Shoot Length (cm)			Vigour Index		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	78.49	80.50	79.50	11.81	12.11	11.96	13.85	14.21	14.03	2014	2119	2067
T_2	89.50	92.74	91.12	13.46	13.95	13.71	15.80	16.37	16.08	2619	2812	2715
T_3	85.36	87.73	86.55	12.84	13.20	13.02	15.07	15.48	15.28	2382	2517	2450
T_4	78.27	80.28	79.27	11.78	12.08	11.93	13.81	14.17	13.99	2003	2107	2055
T_5	86.79	89.11	87.95	13.06	13.41	13.23	15.32	15.73	15.52	2463	2596	2529
T_6	89.43	92.67	91.05	13.45	13.94	13.70	15.78	16.36	16.07	2615	2808	2711
T_7	81.97	84.33	83.15	12.33	12.69	12.51	14.47	14.88	14.68	2197	2325	2261
T_8	90.20	94.45	92.33	13.57	14.21	13.89	15.92	16.67	16.30	2660	2917	2788
Mean	85.00	87.73	86.36	12.79	13.20	12.99	15.00	15.48	15.24	2369	2525	2447
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.02	0.03		0.00	0.01		0.01	0.01		1.70	3.48	
T	0.03	0.06		0.01	0.02		0.01	0.02		3.40	6.95	
I X T	0.04	0.09		0.01	0.03		0.02	0.03		4.81	9.83	

Amendments	Sunflower											
	Germination (%)			Root Length (cm)			Shoot Length (cm)			Vigour Index		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	78.20	80.20	79.20	11.77	12.07	11.92	13.80	14.18	13.99	2000	2107	2053
T_2	89.44	92.68	91.06	13.41	13.90	13.66	15.77	16.34	16.05	2610	2803	2706
T_3	85.20	87.86	86.53	12.83	13.18	13.01	15.06	15.48	15.27	2375	2518	2447
T_4	78.12	80.13	79.12	11.76	12.06	11.91	13.81	14.16	13.98	1997	2103	2050
T_5	86.63	88.94	87.79	13.05	13.39	13.22	15.31	15.72	15.52	2457	2590	2523
T_6	89.28	92.52	90.90	13.44	13.93	13.69	15.78	16.35	16.06	2609	2802	2706
T_7	82.73	85.12	83.93	12.34	12.70	12.52	14.46	14.88	14.67	2217	2346	2281
T_8	91.03	95.32	93.18	13.56	14.22	13.89	15.90	16.66	16.28	2682	2943	2813
Mean	85.08	87.85	86.46	12.77	13.18	12.98	14.99	15.47	15.23	2368	2526	2447
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.26	0.53		0.00	0.01		0.05	0.09		7.34	14.99	
T	0.52	1.05		0.01	0.02		0.09	0.19		14.68	29.97	
I X T	0.73	1.49		0.01	0.03		0.13	NS		20.76	42.39	

Amendments : T_1-control; T_2-FYM; T_3-Fly ash(FA); T_4-Sludge(S);
T_5-FA+S; T_6-FA+Green manure(GM); T_7-S+GM; T_8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

Table 121.Effect of effluent and amendments on plant height (cm) under maize and sunflower

Amendments	Maize								
	Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	54.4	55.8	55.1	114.6	117.6	116.1	132.7	136.1	134.4
T_2	63.6	65.9	64.7	133.9	138.7	136.3	155.6	161.3	158.4
T_3	51.1	59.7	58.9	122.4	125.8	124.1	141.7	145.6	143.7
T_4	53.3	54.7	54.0	112.3	115.1	113.1	129.9	133.3	131.6
T_5	60.4	62.0	61.2	127.2	130.6	128.9	147.2	151.1	149.1
T_6	64.0	66.4	65.2	135.2	138.8	137.0	156.3	161.0	158.6
T_7	55.1	56.7	55.9	116.1	119.4	117.8	134.4	138.2	136.3
T_8	66.1	68.4	67.3	139.6	145.2	142.4	161.6	169.2	165.4
Mean	59.4	61.2	60.3	125.2	128.9	127.0	144.9	149.5	147.2
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.18	0.37		0.38	0.78		0.44	0.90	
T	0.36	0.74		0.76	1.55		0.88	1.80	
I X T	0.51	NS		1.07	NS		1.24	NS	

Amendments	Sunflower								
	Vegetative stage			Flowering stage			Harvest stage		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	40.2	41.2	40.7	76.2	78.1	77.2	114.5	117.5	116.0
T_2	48.7	50.6	49.6	92.4	95.8	94.1	139.0	145.1	142.1
T_3	43.8	45.0	44.4	83.0	85.3	84.1	124.7	128.2	126.4
T_4	39.6	40.4	40.0	74.6	76.2	75.4	111.3	115.2	113.2
T_5	45.8	47.1	46.4	86.8	89.2	88.0	130.6	134.0	132.3
T_6	51.0	52.8	51.9	96.6	100.1	98.4	145.3	150.5	147.9
T_7	41.0	42.2	41.6	77.7	79.9	78.8	116.8	120.1	118.4
T_8	52.8	55.3	54.1	100.1	104.8	102.5	150.5	157.6	154.1
Mean	45.4	46.8	46.1	85.9	88.7	87.3	129.1	133.5	131.3
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.14	0.28		0.26	0.53		0.39	0.80	
T	0.28	0.56		0.52	1.07		0.79	1.61	
I X T	0.39	NS		0.74	NS		1.11	NS	

Amendments : T_1-control; T_2-FYM; T_3-Fly ash(FA); T_4-Sludge(S); T_5-FA+S; T_6-FA+Green manure(GM); T_7-S+GM; T_8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

40.4 to 55.3 cm in the effluent irrigated plots and 39.6 to 52.8 cm in the river water irrigated plots. At flowering and harvest stage also the similar trend as that of vegetative stage was observed .

4.7.3.7. Effect of effluent on yield parameters

The data regarding yield parameters of maize are furnished in Table 122. All the treatments showed significant variation in cob length, cob weight, grain weight and yield. Effluent irrigated crop recorded higher yield than river water irrigation. Among the amendments, T_8 recorded the highest yield parameters followed by T_6. The least was observed in T_4. As far as cob length was concerned, the length varied from 14.6 to 18.5 cm in the effluent irrigated plots and 14.2 to 17.7 cm in the river water irrigated plots. Effluent had significant influence on the yield of the crop and the yield ranged from 3088 to 3920 kg ha^{-1} in the effluent irrigated plots whereas in river water it ranged from 3011 to 3748 kg ha^{-1}.

As far as sunflower was concerned, the number of grains and 1000 grains weight were higher in T_8 which received FA + S + GM as amendment. The yield of the crop varied from 1085 to 1478 kg ha^{-1} in the effluent irrigated plots and 1056 to 1410 kg ha^{-1} in the river water irrigated plots. The interaction effect was not significant.

4.7.3.9. Effect of effluent and amendments on carbohydrate and protein content of maize

The data on protein content and carbohydrate content of maize are furnished in Table 123.

The effluent irrigated maize recorded higher protein and carbohydrate content than the river water irrigation.

Among the various amendments the highest protein and carbohydrate content was observed under T_8 (FA+S+FYM). The interaction effect between amendments and

***Table 122.* Effect of effluent and amendments on yield parameters under maize and sunflower**

Amendments	Maize														
	Cob Length(cm)			Cob weight(g)			Grain weight(g)			1000 grainweight(g)			Yield (kg ha^{-1})		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	14.4	14.8	14.6	67.6	69.3	68.5	45.90	47.00	46.50	194.5	199.4	196.9	3074	3153	3114
T_2	16.9	17.6	17.3	79.1	81.8	80.5	53.60	55.80	54.70	228.1	235.3	231.7	3592	3721	3656
T_3	15.5	15.9	15.7	72.2	74.3	73.2	49.00	50.40	49.70	207.7	213.5	210.6	3284	3375	3329
T_4	14.2	14.6	14.4	63.3	68.0	67.1	45.00	46.10	45.50	190.4	195.3	192.9	3011	3088	3041
T_5	16.1	16.5	16.3	75.1	77.1	76.1	50.90	52.20	51.60	215.7	221.5	218.6	3411	3502	3456
T_6	17.1	17.7	17.4	79.6	82.5	81.1	53.90	56.10	55.00	228.7	238.6	233.6	3618	3745	3682
T_7	14.7	15.1	14.9	68.5	70.5	69.5	46.50	47.80	47.10	196.9	202.6	199.8	3114	3203	3159
T_8	17.7	18.5	18.1	82.5	86.3	84.4	55.90	58.50	57.20	237.8	248.0	242.9	3748	3920	3834
Mean	15.8	16.3	16.1	73.9	76.2	75.0	50.10	51.70	50.90	212.5	219.3	215.9	3357	3463	3410
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.04		0.22	0.46		0.15	0.31		0.65	1.32		10.16	20.75	
T	0.10	0.20		0.45	0.92		0.30	0.62		1.29	2.63		20.32	41.51	
I X T	0.14	NS		0.63	NS		0.43	NS		1.83	NS		28.74	NS	

Amendments	Sunflower								
	No.Grains Head^{-1}			1000 grain wt(g)			Yield(kg ha^{-1})		
	I_1	I_2	M	I_1	I_2	M	I_1	I_2	M
T_1	272.7	279.7	276.2	62.72	64.33	63.52	1074	1102	1088
T_2	330.9	344.8	337.9	76.30	79.20	77.75	1318	1362	1340
T_3	296.9	305.2	301.0	68.29	70.19	69.24	1170	1202	1186
T_4	270.3	276.2	273.2	61.80	63.30	62.55	1056	1085	1071
T_5	310.8	319.1	315.0	71.49	73.40	72.45	1224	1257	1241
T_6	345.8	358.4	352.1	79.54	82.43	80.99	1362	1412	1387
T_7	277.8	287.0	282.4	63.94	65.78	64.86	1095	1127	1111
T_8	358.3	375.2	366.8	82.42	86.30	84.36	1410	1478	1444
Mean	307.9	318.2	313.1	70.81	73.12	71.96	1214	1253	1233
	SEd	CD(0.05)		SEd	CD(0.05)		SEd	CD(0.05)	
I	0.94	1.91		0.22	0.44		3.72	7.60	
T	1.87	3.83		0.43	0.88		7.45	15.21	
I X T	2.65	NS		0.61	NS		10.53	NS	

Amendments : T1-control; T2-FYM; T3-Fly ash(FA); T4-Sludge(S); T5-FA+S; T6-FA+Green manure(GM); T7-S+GM; T8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

Table 123.Effect of effluent and amendments on carbohydrate per cent and protein per cent of maize and protein per cent and oil per cent under sunflower

Amendments	Maize					
	Carbohydrate per cent			Protein per cent		
	I_1	I_2	M	I_1	I_2	M
T_1	43.22	44.33	43.77	9.88	10.13	10.01
T_2	50.47	52.30	51.39	11.54	11.96	11.75
T_3	46.16	47.44	46.80	10.55	10.84	10.70
T_4	42.32	43.41	42.87	9.67	9.92	9.80
T_5	47.94	49.22	48.58	10.96	11.25	11.11
T_6	50.83	52.67	51.75	11.62	12.04	11.83
T_7	43.77	45.03	44.40	10.01	10.29	10.15
T_8	52.64	55.12	53.88	12.03	12.60	12.32
Mean	47.17	48.69	47.93	10.78	11.13	10.96
	SEd	CD(0.05)		SEd	CD(0.05)	
I	0.02	0.05		0.01	0.01	
T	0.05	0.10		0.01	0.02	
I X T	0.07	0.14		0.02	0.03	

Amendments	Sunflower					
	Protein per cent			Oil per cent		
	I_1	I_2	M	I_1	I_2	M
T_1	13.85	14.21	14.03	34.31	35.21	34.76
T_2	15.77	16.34	16.05	39.11	40.53	39.82
T_3	14.45	14.82	14.64	35.76	36.76	36.26
T_4	13.24	13.58	13.41	32.80	33.65	33.23
T_5	14.96	15.35	15.16	37.02	38.02	37.52
T_6	15.84	16.42	16.13	39.23	40.65	39.94
T_7	13.72	14.12	13.92	33.80	34.76	34.28
T_8	17.55	18.38	17.97	40.66	42.58	41.62
Mean	14.92	15.40	15.16	36.59	37.77	37.18
	SEd	CD(0.05)		SEd	CD(0.05)	
I	0.05	0.09		0.11	0.23	
T	0.09	0.18		0.22	0.45	
I X T	0.13	0.26		0.31	NS	

Amendments : T_1-control; T_2-FYM; T_3-Fly ash(FA); T_4-Sludge(S);
T_5-FA+S; T_6-FA+Green manure(GM); T_7-S+GM; T_8-FA+S+GM
T-Amendments; I-Irrigation; I_1-river water; I_2-effluent; M-Mean

irrigation was not significant. The carbohydrate content of the grains varied from 43.41 to 55.12 per cent in the effluent and 42.32 to 52.64 per cent in the river water irrigated plots. The protein content ranged from 9.92 to 12.60 and 9.67 to 12.03 per cent in the effluent and river water irrigated plots respectively.

4.7.3.10. Effect of effluent and amendments on protein and oil content of sunflower crops

The details on protein and oil content of sunflower are presented in Table 123. Incorporation of FA+S+FYM (T_8) recorded the highest protein and oil content of sunflower followed by T_6. The oil per cent varied from 33.65 to 42.58 the effluent irrigation plots and 32.80 to 40.66 per cent in the river water irrigated plots. The protein per cent varied from 13.58 to 18.38 in the effluent irrigated plots of sunflower and 13.24 to 17.55 per cent in the river water irrigated plots. There was no adverse effect on the quality parameters of sunflower due to effluent irrigation and in fact it was improved due to effluent irrigation.

4.8. Column lysimeter experiment for nutrient movement

4.8.1. Physico-chemical properties of the soil of column lysimeter

The results on the post analysis of surface and sub-surface soil are presented in Tables 124 to140.

The pH of the column samples ranged from 7.85 to 8.53 in surface soil. In sub surface soil it varied from 7.85 to 8.38. In general the pH of the amended soil was higher than the control (T_0 –well water) in both surface and sub-surface soil. Among the amendments, sludge (T_4) and fly ash + sludge (T_5) received columns showed higher pH than the other amendments. The pH of T_6 (Fly ash+GM) was on par with T_7 (Sludge+GM) and T_2 (FYM) in both the depths. The pH was increased due to effluent irrigation compared to river water in surface soil while a reverse trend was observed in sub-surface soils. The pH decreased invariably in all treatments in sub-surface soil except T_0 (without amendment) (Table 124).

The EC of the surface soil ranged from 0.42 to 0.55 dSm^{-1} whereas in sub-surface soil it ranged from 0.37 to 0.49 dSm^{-1}. The EC of the (To) river water received column was lower than that of amendments received columns in both the soils. Marked difference of EC value was observed between surface and sub-surface soil. The highest EC value was recorded in T_3 of surface soil and similar trend was observed in sub-surface soil also (Table 124).

The organic carbon content of the soil from lysimeter increased along with effluent irrigation. Accumulation of OC was found more in surface soil (0.66%) than sub-surface soil (0.59%). Sludge + GM applied treatment (T_7) showed higher OC content followed by $T_{4,}$ while the lowest OC content was observed in fly ash (T_3) (Table124).

The exchangeable calcium content in amended soils ranged from 5.29 to 7.95 c mol(+) kg^{-1} in surface soils and 5.16 to 7.64 c mol(+) kg^{-1} in sub-surface soil. The exchangeable calcium was observed to be more in the effluent irrigated treatments than the well water irrigated control (T_0) in both surface and sub-surface column soils. Among the amendments, T_8 (FA + S + GM) recorded the highest exchangeable calcium content and significantly different from other amendments. In sub-surface, the exchangeable calcium content of the soil reduced invariably in all the treatments except T_0 (Table 125).

The exchangeable magnesium was increased under effluent irrigation. Surface soil accumulated more of exchangeable magnesium than sub-surface soil except in river water (To). Among the amendments, fly ash (T_3) recorded the highest value than

Table.124.Effect of effluent and amendments on reaction,EC(dS m^{-1}) and organic carbon per cent of soil collected from column lysimeter

Treatments	pH		EC		Organic Carbon	
	surface	subsurface	surface	subsurface	surface	subsurface
T_0	7.85	7.92	0.42	0.45	0.60	0.63
T_1	7.90	7.86	0.53	0.47	0.58	0.52
T_2	7.89	7.85	0.54	0.47	0.62	0.56
T_3	8.44	8.36	0.55	0.49	0.57	0.51
T_4	8.49	8.41	0.52	0.44	0.76	0.66
T_5	8.53	8.38	0.50	0.42	0.59	0.53
T_6	7.90	7.87	0.44	0.37	0.70	0.62
T_7	7.96	7.92	0.48	0.40	0.77	0.68
T_8	8.34	8.30	0.46	0.38	0.71	0.63
Mean	8.18	8.12	0.50	0.43	0.66	0.59
SEd	0.12	0.13	0.01	0.01	0.01	0.01
CD(0.05)	0.28	0.27	0.02	0.01	0.02	0.02

Table.125.Effect of effluent and amendments on exchangeable cations (cmol (+) kg^{-1}) of soil collected from column lysimeter

Treatments	Ca		Mg		Na		K	
	surface	subsurface	surface	subsurface	surface	subsurface	surface	subsurface
T_0	4.72	5.00	1.05	1.25	0.53	0.50	0.51	0.49
T_1	5.29	5.16	1.50	1.15	0.75	0.80	0.49	0.51
T_2	5.60	5.40	1.63	1.26	0.56	0.60	0.54	0.53
T_3	6.71	6.55	2.57	2.25	0.66	0.67	0.55	0.53
T_4	6.40	6.05	2.21	1.90	0.67	0.67	0.57	0.59
T_5	5.92	5.66	1.77	1.38	0.69	0.78	0.58	0.60
T_6	7.02	6.82	2.41	2.09	0.60	0.62	0.62	0.64
T_7	7.59	7.34	2.02	1.75	0.65	0.66	0.64	0.68
T_8	7.95	7.64	1.96	1.55	0.63	0.63	0.66	0.70
Mean	6.56	6.33	2.01	1.67	0.64	0.66	0.57	0.59
SEd	0.11	0.10	0.03	0.03	0.01	0.01	0.01	0.01
CD(0.05)	0.23	0.22	0.07	0.06	0.02	0.02	0.02	0.02

wellwater; T_1-effluent alone; T_2-FYM; T_3-FA(Fly ash); T_4-S(Sludge); T_5-FA
T_6-FA+ Greenmanure (GM); T_7-S+GM; T_8-FA+S+GM

rest of the amendments and the lowest was observed in T_5 in both the depths (Table 125).

The exchangeable sodium content of surface and sub-surface column soils ranged from 0.53 to 0.75 and 0.50 to 0.80 c mol (p+) kg^{-1} respectively. The exchangeable sodium content increased with effluent irrigation as compared to river water irrigation in both surface and sub-surface column soils. Accumulation of sodium was comparatively higher in sub-surface soil. Addition of different amendments reduced the exchangeable sodium content in both the surfaces. Among the amendments, T_5 recorded higher exchangeable sodium (0.69 c mol (+) kg^{-1}) followed by T_4 (0.67 c mol (+) kg^{-1}) in surface soil and the lowest exchangeable sodium content was observed in T_2 (FYM). Very similar trend was observed in sub-surface column soils (Table 125).

The Exchangeable potassium also exhibited a similar trend as that of sodium but at lesser extent. As the effluent irrigation increased the exchangeable potassium content also increased in both the surfaces. In general, the exchangeable potassium accumulation was comparatively more in sub-surface soils except T_1, T_2 and T_3. Among the amendments, the exchangeable potassium content ranged from 0.54 to 0.66 and 0.53 to 0.70 c mol (p+) kg^{-1} in surface and sub-surface soils respectively. Treatment T_8 (FA+S+GM) recorded the highest exchangeable potassium in both surface and sub-surface soils. The least was observed in T_3 (FYM) (Table 125).

The data on soil available nutrients are presented in Table 136.The available nitrogen content was increased due to effluent irrigation (T_1) in surface and sub-surface soils and showed a decreasing trend from surface soil to sub-surface soil. Addition of different amendments invariably increased the available nitrogen content in both the surfaces. Among the amendments, the available nitrogen ranged from 164 to

218 and 164 to 187 kg ha^{-1} in surface and sub-surface soil respectively. Treatment T_6 (FA+GM) recorded the highest available nitrogen followed by T_7 in both the surfaces of soil. The least available nitrogen was observed in T_4 in both the surfaces (Table 126).

Effluent irrigation improved the soil available phosphorus status in both the surfaces and available phosphorus accumulation was more in surface soil. Addition of different amendments invariably increased the available phosphorus content in both the surfaces. Among the amendments, the available phosphorus varied from 10.24 to 15.42 and 9.14 to 13.86 kg ha^{-1} in both the surfaces of soil. Treatment T_8 (FA+S+GM) recorded the highest available phosphorus followed by T_6 in both the surfaces while T_4 recorded the lowest available phosphorus.

The same trend as the above was observed in available potassium also. Effluent irrigation increased the available potassium compared to river water. It showed decreasing trend from surface soil to sub-surface soil. Addition of different amendments invariably increased the available potassium content in both the surfaces. Among the amendments,T_3 (FA) recorded the highest available potassium (246 kg ha^{-1}) followed by T_6 (235 kg ha^{-1}) in both the surfaces and the lowest available potassium was observed in T_5 .

4.8.2. Biological properties of the soil of column lysimeter

In general, effluent irrigation performed better than river water with respect to bacterial population in both depths. The total bacterial population was more in surface soil than in sub-surface soil. Addition of different amendments invariably increased the bacterial population in both the surfaces. The variation in bacterial population due to addition of amendments ranged from 10.10 to 25.07 x 10^6 $g^{-1}$and 10.60 to 19.60 x 10^6 g^{-1} in surface and sub surface soil respectively. Among the amendments, T_7 (S + GM)

Table.126.Effect of effluent and amendment on available nutrient status (kg ha^{-1}) of soil collected from column lysimeter

Treatments	Available N		Available P		Available K	
	surface	subsurface	surface	subsurface	surface	subsurface
T_0	161	160	10.12	9.45	202	200
T_1	166	161	10.60	9.50	215	204
T_2	194	172	13.93	11.77	246	230
T_3	169	164	11.16	9.71	227	220
T_4	164	160	10.24	9.14	209	198
T_5	179	168	11.62	10.45	206	196
T_6	218	183	14.96	13.44	235	221
T_7	212	178	14.51	12.75	221	211
T_8	205	187	15.42	13.86	241	227
Mean	188	170	12.80	11.12	225	212
SEd	2.96	2.74	0.20	0.18	0.01	0.01
CD(0.05)	6.28	5.81	0.43	0.39	0.02	0.03

Table.127.Effect of effluent and amendment on biological properties of soil collected from column lysimeter

Treatments	Bacteria ($x10^6 g^{-1}$)		Actinomycetes ($X10^4 g^{-1}$)		Fungi ($x10^3 g^{-1}$)	
	surface	subsurface	surface	subsurface	surface	subsurface
T_0	10.10	10.60	13.30	16.20	7.40	7.60
T_1	12.23	10.77	21.06	20.42	7.54	7.85
T_2	13.68	11.95	30.96	26.16	8.79	8.60
T_3	14.99	13.31	16.68	16.17	7.93	7.42
T_4	23.82	18.57	18.96	18.38	10.49	9.91
T_5	19.83	15.96	14.85	14.39	8.26	8.04
T_6	16.26	14.89	25.71	21.96	9.25	8.58
T_7	25.07	19.60	27.35	23.11	10.26	9.41
T_8	21.93	17.82	29.41	24.85	9.64	8.94
Mean	17.55	14.83	22.03	20.18	8.84	8.48
SEd	0.34	0.30	0.38	0.33	0.15	0.14
CD(0.05)	0.71	0.68	0.81	0.70	0.32	0.29

T_0-wellwater; T_1-effluent alone; T_2-FYM; T_3-FA(Fly ash); T_4-S(Sludge); T_5-FA+S
T_6-FA+ Greenmanure (GM); T_7-S+GM; T_8-FA+S+GM

showed higher numerical value in bacterial population followed by T_4 (sludge alone) and significantly superior to FYM (T_2) (Table 127).

The same trend was observed in the fungal and actinomycetes population also. Among the amendments actinomycetes varied from 14.85 to 30.96 x 10^3 and 14.39 to 26.16 x 10^3 g^{-1} of soil in surface and sub surface soil respectively. Fungal population showed a variation of 7.93 to 10.49 x 10^4 g^{-1} and 7.42 to 9.41 x 10^4 g^{-1} in surface and sub surface soil respectively (Table 127).

4.8.3. Physico-chemical properties of the leachates collected from column lysimeter.

The total dissolved solid content of the leachate was comparatively reduced at 60 days after incubation (DAI) irrespective of the treatments. Effluent alone received treatment showed more of solids in leachates. Among the amendments T_3 recorded higher solids (15.80 mg L^{-1}) followed by T4 (15.50 mg L^{-1}) in 30 DAI (Table 128).

The pH of the leachate was marginally increased along with duration of effluent addition. Effluent alone received column (T_1) recorded higher pH than the amendment and river water received columns in both 30 and 60 DAI. Among the amendments, T_8 (FA + S + GM) showed higher pH (6.85, 6.96) than rest of the treatments in 30 and 60 DAI (Table 128).

Effluent alone received treatment showed more EC (0.38 dSm^{-1}) than the treatment received both effluent and amendments. The similar trend was observed in the 60 DAI. The EC of the leachate was comparatively higher at 60 DAI than 30 DAI. Among the amendments, sludge (T_4) and sludge + GM (T_7) showed more EC and on par with each other. The lowest EC was observed in T_6 (Fly ash) in both 30 DAI and 60 DAI (Table 128).

Table.128.Effect of effluent and amendments on total solids(mg L^{-1}), pH and EC(dS m-1) of leachates collected from of column lysimeter

Treatments	Total solids		pH		EC	
	30DAI	60DAI	30DAI	60DAI	30DAI	60DAI
T_0	5.00	4.90	6.65	6.70	0.13	0.15
T_1	16.20	10.20	7.15	7.20	0.38	0.38
T_2	14.60	9.30	6.60	6.78	0.34	0.35
T_3	15.80	7.50	6.70	6.80	0.32	0.34
T_4	15.50	7.10	6.75	6.85	0.37	0.40
T_5	15.20	6.80	6.75	6.86	0.35	0.39
T_6	14.80	8.60	6.78	6.89	0.30	0.33
T_7	13.60	8.00	6.82	6.93	0.36	0.38
T_8	14.20	8.20	6.85	6.96	0.34	0.38
Mean	13.88	7.84	6.78	6.89	0.32	0.34
SEd	0.24	0.14	0.11	0.11	0.01	0.01
CD(0.05)	0.50	0.29	0.23	0.23	0.01	0.01

Table.129.Effect of effluent and amendments on organic carbon (per cent) ,BOD and COD (mg L-1) of leachates collected from of column lysimeter

Treatments	OC		BOD		COD	
	30DAI	60DAI	30DAI	60DAI	30DAI	60DAI
T_0	0.02	0.02	2.90	2.60	15.40	12.10
T_1	0.09	0.06	6.60	1.30	82.50	20.20
T_2	0.06	0.05	5.50	1.00	60.00	18.30
T_3	0.07	0.05	5.80	1.00	58.30	18.20
T_4	0.06	0.05	6.20	1.50	60.50	22.60
T_5	0.06	0.04	5.60	0.90	62.10	20.60
T_6	0.05	0.03	5.50	0.80	55.30	16.50
T_7	0.04	0.02	6.00	1.00	56.20	19.30
T_8	0.05	0.03	5.30	0.70	52.00	17.20
Mean	0.06	0.04	5.49	1.20	55.81	18.33
SEd	0.001	0.001	0.090	0.190	0.910	0.310
CD(0.05)	0.002	0.002	0.190	0.040	1.940	0.650

T_0-wellwater; T_1-effluent alone; T_2-FYM; T_3-FA(Fly ash); T_4-S(Sludge); T_5.FA+S
T_6-FA+ Greenmanure (GM); T_7-S+GM; T_8-FA+S+GM

Very low per cent of organic carbon was observed in the leachates. Leachate collected from T_1 (effluent alone) had more of organic carbon content than river water. As the duration of the effluent irrigation increased, the organic carbon percentage of the leachates decreased (Table 129).

The BOD of the leachate was higher in effluent alone received treatment (T_1) than the river water. The amendment received treatments showed lesser BOD compared to effluent alone. The BOD varied from 5.30 to 6.20 and 0.70 to 1.00 mg L^{-1} at 30 and 60 DAI respectively. Among the amendments, T_4 (sludge) and T_7 (sludge + GM) showed more BOD and on par with each other, which was lesser than the T_1 (effluent alone). As the duration of the effluent irrigation increased, the BOD of the leachate got reduced (Table 129).

As far as COD was concerned, better reduction was observed. Effluent irrigation increased COD as compared to river water. Addition of amendments reduced the COD invariably in all the treatments. Among the amendments, COD varied from 52.00 to 62.10 and 16.50 to 22.60 mg L^{-1} at 30 and 60 DAI respectively. Treatment T_8 (FA + S + GM) recorded the lowest COD followed by T_6 (FA + GM). Treatment T_6 showed the highest reduction from 30 DAI to 60 DAI than rest of the treatments. At 60 DAI, in all the treatments the COD was very much reduced (Table 129).

Among the treatments, amendments received treatments showed lesser cations than the effluent alone received treatment (T_1). Effluent performed better than river water with respect to exchangeable cations. Among the amendment received columns, T_8 (FA + S + GM) showed lesser exchangeable calcium than the rest of the treatments (Table 130).

The leachate had negligible quantity of exchangeable magnesium compared to the effluent. As the duration of effluent irrigation increased, the exchangeable

Table.130.Effect of effluent and amendments on exchangeable Calcium, Magnesium Sodium (cmol L^{-1}) and SAR of soil leachates collected from column lysimeter

Treatments	Ca		Mg		Na		SAR	
	30DAI	60DAI	30DAI	60DAI	30DAI	60DAI	30DAI	60DAI
T_0	0.09	0.07	0.035	0.019	0.02	0.01	0.08	0.06
T_1	1.85	1.23	0.080	0.058	2.25	1.92	2.29	2.39
T_2	1.42	0.96	0.072	0.045	2.21	1.89	2.56	2.67
T_3	1.38	0.88	0.070	0.048	2.20	1.76	2.58	2.58
T_4	1.35	0.85	0.062	0.053	2.14	1.73	2.55	2.57
T_5	1.30	0.82	0.060	0.050	2.12	1.70	2.57	2.58
T_6	1.20	0.78	0.052	0.040	2.10	1.68	2.65	2.62
T_7	1.18	0.76	0.050	0.040	2.08	1.65	2.65	2.61
T_8	1.08	0.72	0.049	0.039	2.05	1.63	2.73	2.65
Mean	1.21	0.79	0.06	0.04	1.91	1.55	2.30	2.30
SEd	0.019	0.014	0.002	0.002	0.032	0.027	0.040	0.039
CD(0.05)	0.042	0.028	0.005	0.005	0.068	0.058	0.085	0.084

wellwater; T_1-effluent alone; T_2-FYM; T_3-FA(Fly ash); T_4-S(Sludge); T_5-FA
T_6-FA+ Greenmanure (GM); T_7-S+GM; T_8-FA+S+GM

magnesium decreased. Amendment received treatments showed lesser exchangeable magnesium than the unamended column (T_1). Among the amendments T_2 and T_3 recorded the highest magnesium content (0.072, 0.070 c mol L^{-1}) respectively and on par with each other (Table 130).

The leachate from the column showed the exchangeable sodium in the range of 0.02 to 2.25 and 0.01 to 1.92 cmol L^{-1} at 30 and 60 DAI respectively. Effluent alone received treatment (T_1) showed more sodium (2.25 cmol L^{-1}) than the amendment received treatments. The lowest sodium content was observed in the T_8 (FA + S + GM) treatment. A better reduction of sodium was noticed on the 60 DAI (Table 130).

The sodium adsorption ratio (SAR) was higher in leachates than the effluent because of reduced calcium and magnesium cations and increased sodium. The SAR ranged from 0.08 to 2.73 and 0.06 to 2.67 at 30 and 60 DAI respectively (Table 130).

Discussion

CHAPTER V

DISCUSSION

Indiscriminate discharge of industrial effluent into natural water is posing a serious problem in India. Water requirement to meet agricultural, domestic and other demand indicate the need for recycling of waste water. Since much industrial waste water fall in the border line as saline water, these can be considered as potential sources for irrigation. Paper and board mill is one of the major industries in India that contributes water pollution. The paper industry pollution to the recipient water is so high that every effort to reduce the pollution is clearly beneficial (Lounsi *et al.*, 1986).

Industrial effluents are being used for irrigation in dry land areas. These effluent not only contain nutrients that enhance the growth of crop plants but also have toxic materials that might interfere with the soil ecosystem. Hence it is essential that implications of the use of industrial effluents in the agricultural fields should be assessed properly. In order to develop ameliorative approach to nullify the possible illeffects of this waste water and to restore the ecosystem, an attempt has been made to assess the impact of effluent and solid wastes on the soil–water– plant ecosystem. The results obtained are discussed hereunder.

5.1. Effluent characteristics

The colour of the effluent released from Ballarpur Industrial Packaging Company Limited (Bilt–IPCL) after treatment processes was light yellow to creamy white which could be ascribed to the presence of lignin and its derivatives formed during pulping and bleaching process. The presence of colouring matter had a very serious impact on the aesthetic value of consumer (Upathyaya and Singh, 1991). Mittal and Mehrotra (1981) reported that the colouring matter present in the waste water was organic in nature. Similar observations have been reported for pulp and paper industry waste water by many early workers (Paice and Jurasek, 1984; Subrahmanyam *et al.*, 1984; Sharma and Bandhyopadhyay, 1991; Mittar *et al.*, 1992; Alfred *et al.*, 1998; Malathi, 2001).

The phenolic odour of the effluent might be due to the presence of hydrogen sulphide, methyl marcaptan and dimethyl sulphide, thus producing phenolic odour (Srinivasachari, 1999).

The treated effluent contained appreciable amounts of suspended and total solids. Higher amount of suspended solids present in untreated effluent might be due to the presence of considerable amounts of fibers and fillers used in waste water from pulping and bleaching section, which is in confirmation with the reports of Sastry *et al.* (1974) and Chaudhuri (1982). The suspended and dissolved solids contents were higher during summer season of March 2001 (Fig.9). This is similar to the observations of earlier reports (Oblisami and Palaniswami, 1991; Palaniswami and Sree Ramulu, 1994; Alfred, (1998).

The pH of the treated effluent varied from 6.95 to 7.21 and the increase in pH is due the addition of caustic soda, talc and lime for the cooking of waste papers for converting into paper board. The pH of the inlet was acidic in nature, after aerobic treatment it was brought to neutral condition by adding lime. The highest pH was observed in March 2001, which could be due to the hot summer season (Fig.10). This is in confirmation with earlier reports of Subrahmanyam and Sundaresan (1982), Subrahmanyam *et al.* (1984), Verma *et al.* (1988), Oblisami and Palaniswami (1991) and Hameed (1997).

The electrical conductivity (EC) of the effluent ranged from 1.18 to 1.23 dS m^{-1} (Fig.11). The higher EC could be attributed to the use of inorganic chemicals (caustic

Fig.9. TS of Bilt-IPCL effluent at periodical intervals

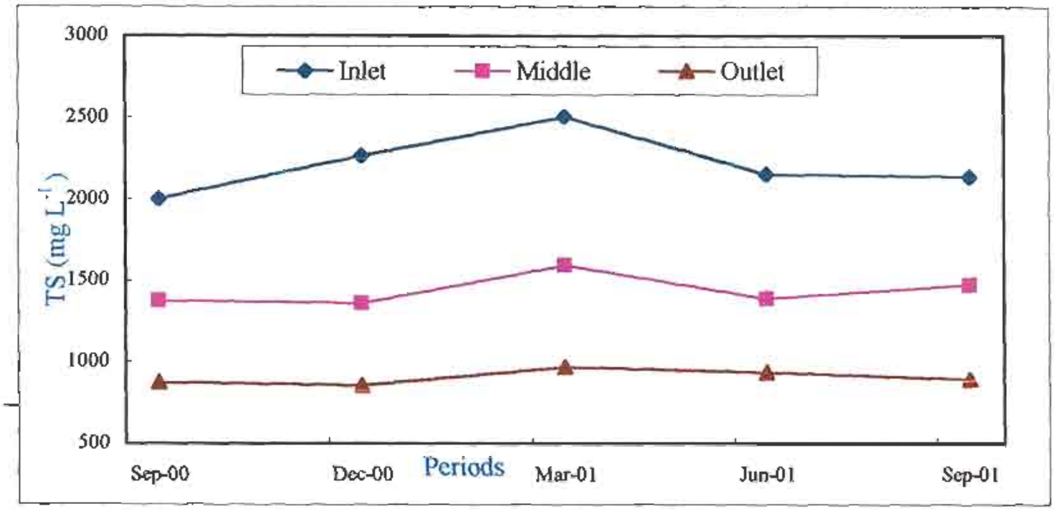


Fig.10. pH of Bilt-IPCL effluent at periodical intervals

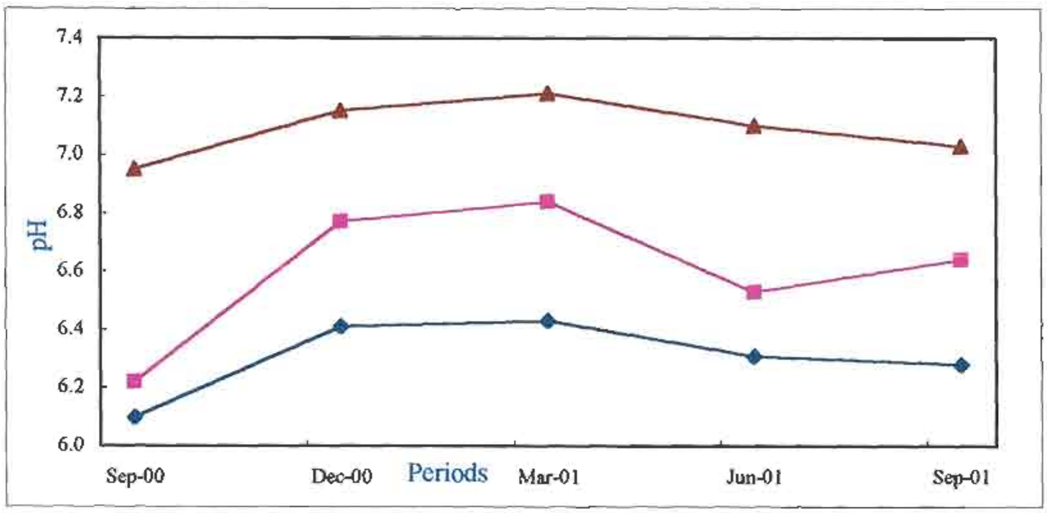
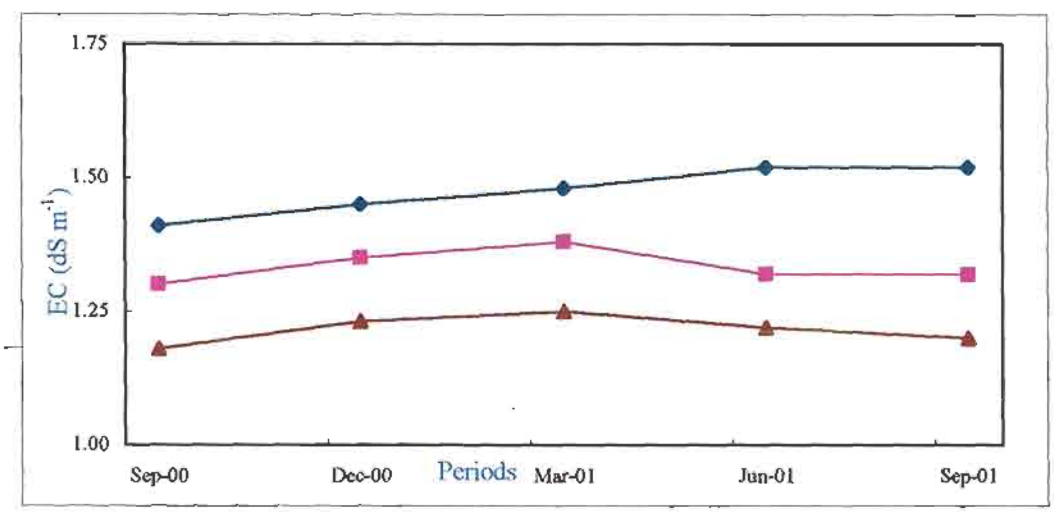


Fig.11.EC of Bilt-IPCL effluent at periodical intervals



soda, rosin, talc) in the process of paper board manufacturing and is in accordance with the findings of many workers (Somashekar *et al.*, 1984; Juwarkar and Subrahmanyam, 1987; Gomathi and Oblisami, 1992).

The organic carbon content of the treated effluent was between 0.47 to 0.58 per cent. This might be due to the presence of varying quantities of suspended and dissolved organics in the effluent water. However, earlier studies reported that paper mill effluents contain rich organic constituents (Kannan and Oblisami, 1990; Palaniswami and Sree Ramulu, 1994). Srinivasachari *et al.* (1998) also reported a similar organic carbon content in the effluent.

The dissolved oxygen (DO) varied from 2.1 to 3.7 mg L^{-1} and this very low level of DO might be attributed to the microbial utilization of DO towards the breakdown of organic compounds present in the effluent. The lowest DO content was recorded during the summer. Similar results were earlier reported by Somashekar *et al.* (1984), Oblisami and Palaniswami (1991) and Alfred, 1998).

The BOD of the effluent was 12.5 mg L^{-1}, which might be due to the treatment processes followed by the industry (Fig.12). This is in accordance with the report of Verma *et al.* (1988) and in contrast to the findings of Sastry *et al.* (1974) and Subrahmanyam *et al.* (1984) who have reported higher values of BOD. Reduction in BOD level might be due to the removal of dissolved organic compounds and lignin derivatives to some extent in the effluent during treatment processes.

Higher level of COD (107 mg L^{-1}) present in the effluent could be attributed to the presence of chemical substances (rosin, alum, caustic soda, poly aluminium chloride). The DO content was very low. But the BOD and COD values were higher as compared to treated pulp and paper mill effluent (Alfred, 1998). Considerable amount of plant nutrients N, P, K were present in the effluent, which might be due to the use of

Fig.12.BOD of Bilt-IPCL effluent at periodical intervals

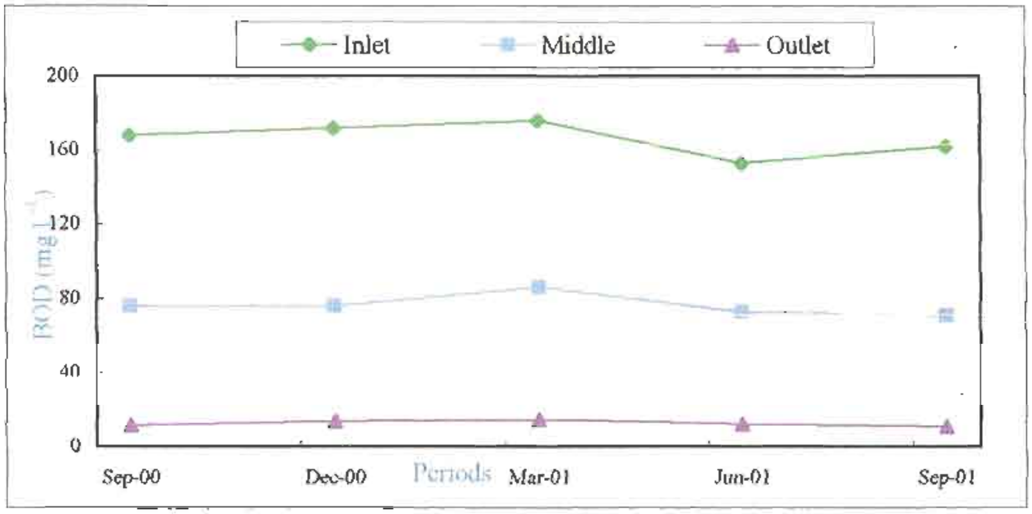


Fig.13.Chloride of Bilt-IPCL effluent at periodical intervals

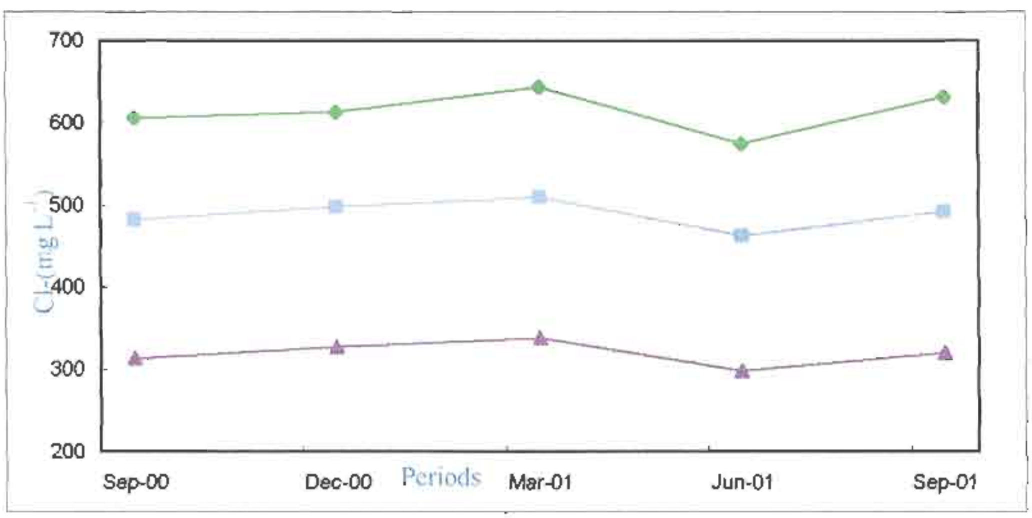
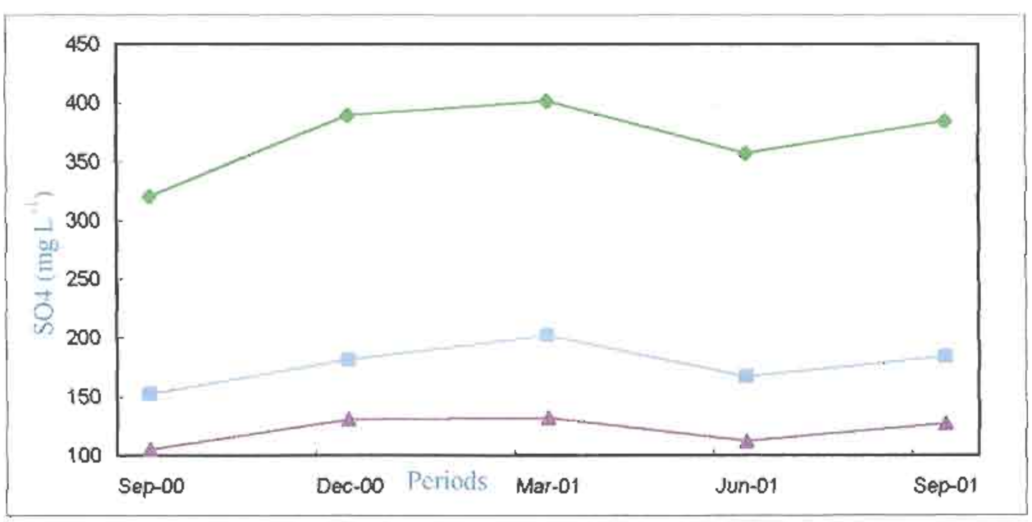


Fig.14.Sulphate of Bilt-IPCL effluent at periodical intervals



raw materials (rice bran & husk) and chemicals containing N, P and K (Urea, DAP) in effluent treatment process. These results are in line with the findings of Srinivasachari *et al.* (1998) and Udayasoorian *et al.* (1999a).

The effluent contained appreciable amounts of cations *viz.*, sodium, calcium and magnesium and anions *viz.*, chloride (Fig.13), sulphates (Fig.14) and bicarbonates. The presence of sodium, calcium and magnesium was observed due to the addition of chemicals like Rosin, Lime, Castic Soda and Polyaluminium chloride during the paper board making process. This is in line with the findings of Reddy *et al.* (1981) and Udayasoorian (1999a). Waste water having appreciable quantity of bicarbonates exhibit a tendency to precipitate calcium in soil as calcium carbonate ($CaCO_3$) and thus increase the resultant proportion of sodium to calcium and magnesium.

The microbial load of the effluent revealed the dominance of bacteria over fungi and actinomycetes, and the findings are in confirmation with the earlier findings of Chuang (1985) and Sandana (1995). The natural presence of microflora associated with the raw materials used for paperboard manufacturing could be the nutrient source of these organisms. Similar microbial populations in the effluent were reported by Hameed (1997) and Alfred (1998).

In general, the pH of the final effluent discharged through outlet was within the range (5.5 to 9.0) prescribed by the Tamil Nadu State Pollution Control Board (TNSPCB) (ISI, 1977). The suspended and dissolved solids of the effluent were well within the prescribed limit of 250 mg L^{-1} and 2100 mg L^{-1} respectively, prescribed by TNSPCB. The BOD of the effluent was within the tolerance limit of 30 mg L^{-1} for discharge of trade effluents on land for irrigation. The effluent contains relatively higher amount of N as ammoniacal nitrogen, than phosphorus, which was present in small amount. Chloride and sulphates were found to be less compared to maximum permissible limit of 600 and 1000 mg L^{-1} respectively. The phenol content at the outlet was nearly double (10.16 mg L^{-1}) as compared to the tolerance limit of 5.00 mg L^{-1}.

The per cent sodium was below the tolerance limit of 60. The per cent sodium of inlet was 41.9 after aerobic treatment and it was reduced to 37.9. The highest per cent sodium was observed in March 2001, which could be due to the hot summer season. The SAR of treated effluent (5.3) falls under "good" category, as compared to maximum permissible limit of 10 prescribed by TNSPCB (ISI, 1977). Therefore, the treated Bilt-IPCL effluent could safely be used for irrigation with proper ameliorants and drainage facilities.

5.2. Effect of effluent irrigation on soil and ground water quality in and around the factory area

5.2.1. Soil analysis

The pH of the soil increased progressively in all the villages, which was acidic to neutal in nature. The highest pH was observed in March 2001, which might be due to retention of more ions in the soil due to evaporation loss. Among the villages, Rangarajapuram recorded the highest pH value, which is located near the treated effluent irrigated area (Fig.15). The seepage of water from Mandaraikadu where the effluent is being applied directly to sugarcane crop might have increased the soil pH at Rangarajapuram. This falls in line with the findings of Rajannan and Oblisami (1979) and Kannan and Oblisami (1989) who reported that the soil reaction increased while irrigating with undiluted paper factory effluent.

The EC of the soils in around the factory area was high (0.05-0.10 dS m^{-1}) compared to river water irrigated soil. Mandaraikadu (factory site) recorded the highest EC values because of the continuous effluent irrigation. Rangarajapuram also recorded

Fig.15. pH of soil samples in and around the Factory area

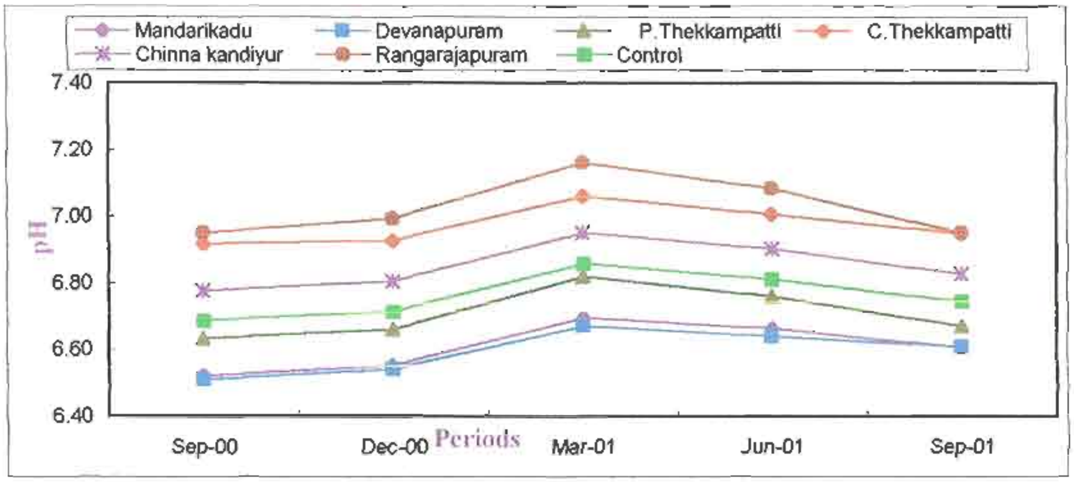


Fig.16. EC of soil samples in and around the Factory area

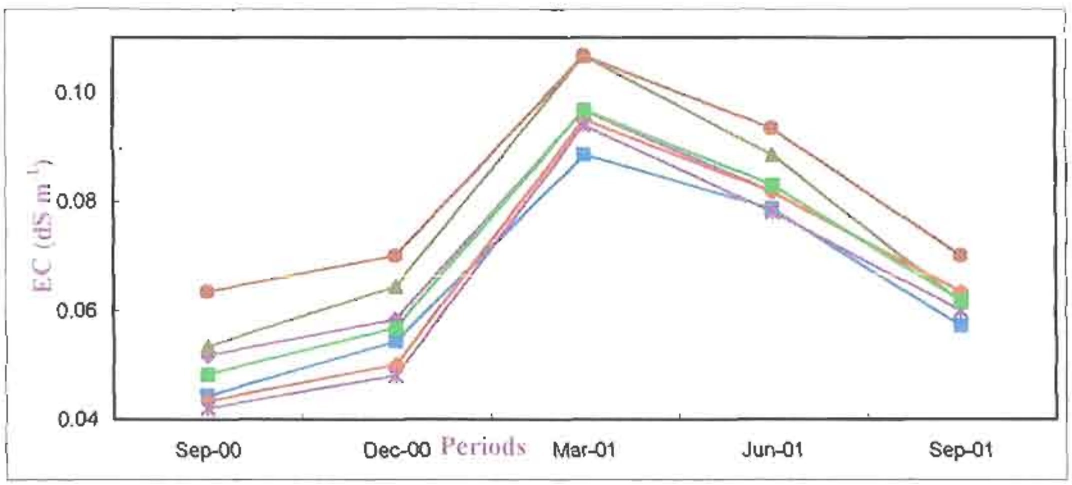
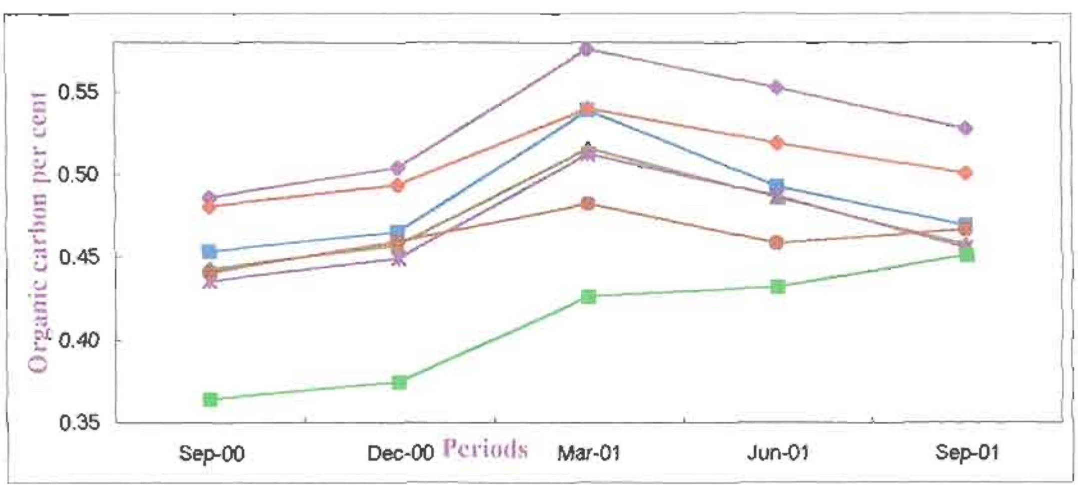


Fig.17. Organic Carbon per cent of soil samples in and around the Factory area



the highest EC values because of the fact that it is located very close to factory site. Due to high evaporation loss in summer (March 2001), the soil EC increased invariably in all the villages. During monsoon season, the soil EC decreased due to leaching of soluble salts (Fig.16). The increase in soluble salt content in the soil could be ascribed to the salt content of effluent. Reddy *et al.* (1981) have also reported that continuous irrigation with pulp and paper mill resulted in increased soluble salts in soil. Similar observations were reported by Udayasoorian *et al.* (1999a) in TEWLIS area near Karur where the treated paper mill effluent was continuously used for irrigation over eight years.

Soil samples in and around the factory area recorded more organic carbon (0.46-0.53 per cent) compared to river water irrigated soil. Among the villages, Mandaraikadu (factory site) recorded higher organic carbon content than other villages (Fig.17). A gradual increase in soil organic carbon content in these villages might be due to accumulation of suspended and dissolved organics present in the effluent which inturn contribute to the built up of organic matter. Similar observations were made by Udayasoorian *et al.* (1999) in TEWLIS area where the treated paper mill effluent was used for irrigation.

Available nutrient status (except available K) of the soil in and around the factory area was higher when compared to river water irrigated soil. An increasing trend on available nutrient status was observed invariably at all the villages due to the impact of continuous effluent irrigation at Mandaraikadu from where the seepage water containing more of N and K pollutes the other villages also. An increasing trend due to combined effluent irrigation over a period of 15 years was reported by Palaniswami and Sree Ramulu (1994) and Udayasoorian *et al.*, (1999).

Soil exchangeable cations (Na, Ca, Mg and K) were increased in considerable quantity in and around the factory area when compared to river water irrigated soils. The exchangeable cations increased with duration of effluent irrigation (Fig.18). The fast movement of soluble ions present in effluent through seepage water to other nearby villages might have been the reason for increased exchangeable cations. Higher concentration of exchangeable cations under effluent irrigation was reported by a number of workers (Sastry *et al.*, 1974; Reddy *et al.*, 1981; Gomathi and Oblisami, 1992). Effluent irrigation for over three years increased exchangeable cations in soil (Palaniswami, 1989).

The ESP of soil samples in and around the factory area was above 30. Presence of higher proportion of sodium in soil samples might have reflected on the increased values of ESP. Chinna Thekkampatti and Rangarajapuram showed higher ESP values when compared to the factory site of Mandaraikadu (Fig.19). This is due to the accumulation of more organics in the lower elevation, which might retained more of cations especially the sodium in soil. This is in line with the findings of Palaniswami (1989) and Alfred (1998).

The SAR of the soil was less than 4 cmol L^{-1} and falls the category of 'low' under continuous effluent irrigation over a period of one year (Fig.20). Similar findings have been reported by Pushpavalli (1990), which might be due to the built up of exchangeable calcium and magnesium in effluent irrigated soils.

5.2.2. Soil microflora

At periodical intervals in and around the factory area, the soil microbial load was found to be increased when compared to river water irrigated soils. This was due to the heterotrophic nature of these microbial groups, which would assimilate various constituents of waste water and proliferate in the soil. These results corroborates with

Fig.18. Exchangeable Na (cmol (+) kg^{-1}) of soil samples in and around the Factory area

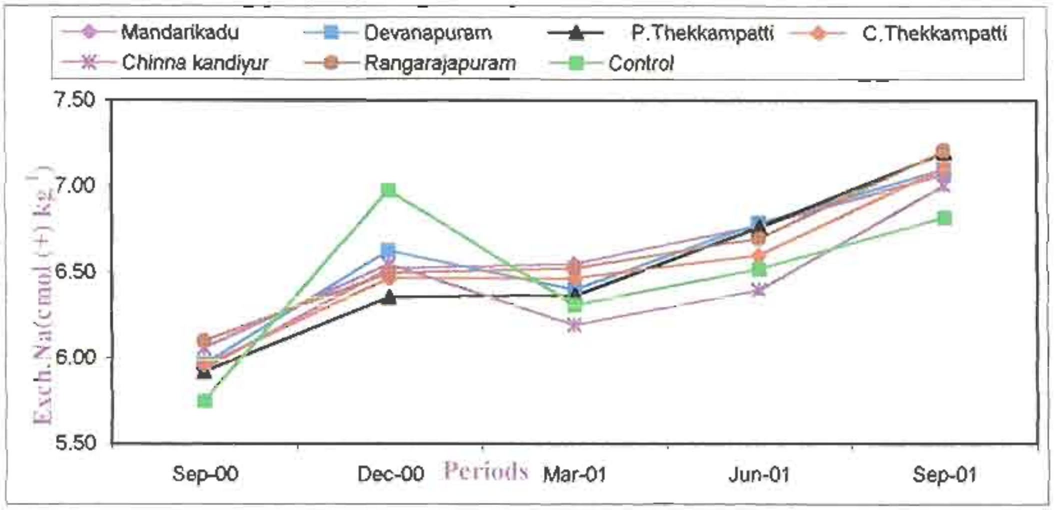


Fig.19. ESP of soil samples in and around the Factory area

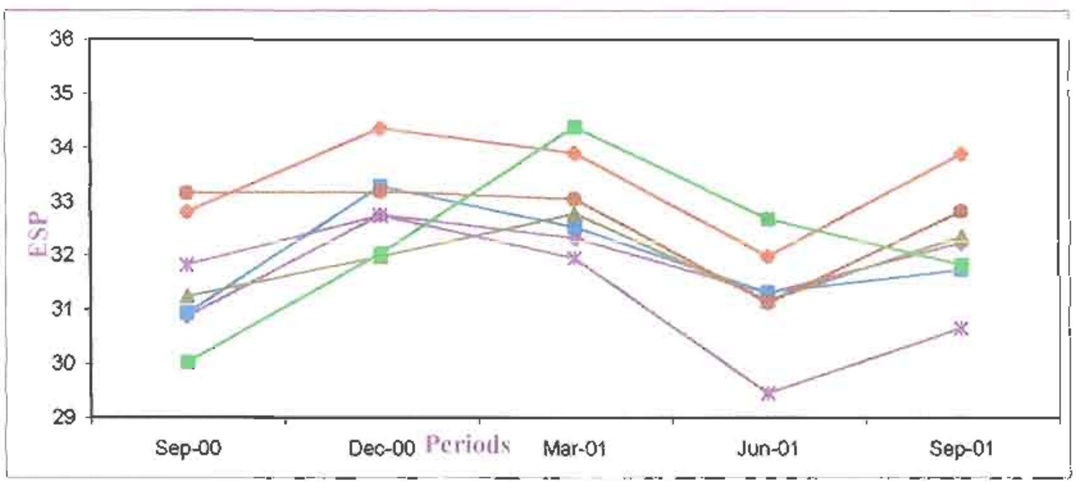
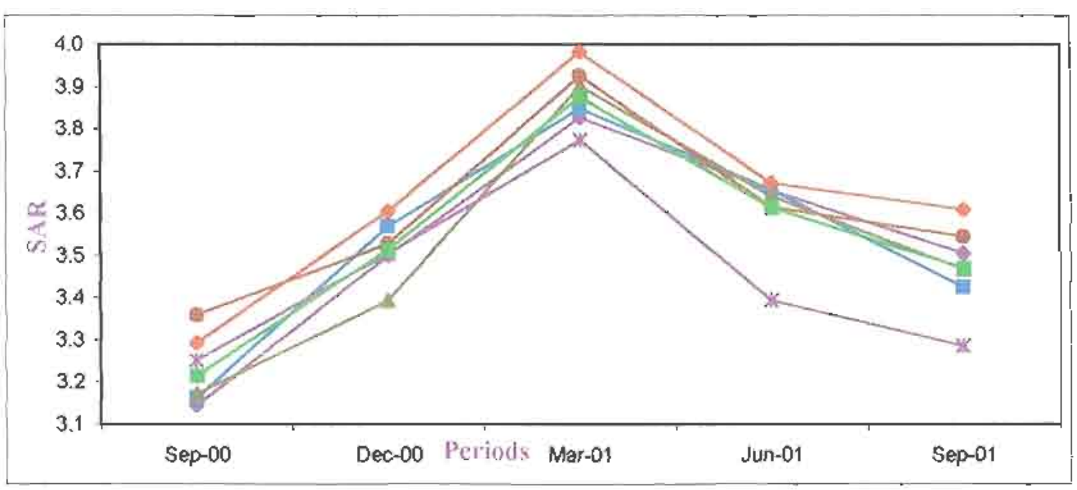


Fig.20. SAR of soil samples of in and around the Factory area



the findings of Doraisamy (1978), Sopper and Seakar (1987), Kannan (1988) and Alfred (1998).

5.2.3. Ground water analysis

Ground water investigations carried out by collecting water from observation wells at monthly intervals revealed that the pH was more than river water and saline in nature, which might be due to the application of inorganic chemicals (fertilizers) in and around the factory area. The pH of the well water increased at periodical intervals, due to leaching and movement of ions in soil. Gradual increases in pH during the month of March 2001 invariably at all the villages might be due to high temperature and no rainfall. (Fig.21).

The EC of the observation wells in and around the factory area ranged from 0.75 to 1.02 dS m^{-1} which was higher than river water (Fig.19). This confirms the movement of salt through seepage water from effluent irrigated area (Mandaraikadu) to the adjacent villages over the past several years. Even though factory site (Mandaraikadu) recorded low pH when compared to other villages, the EC was increased at periodical intervals. Sudden raise in EC (0.82-1.02 dS m^{-1}) was observed invariably in all the villages after the monsoon season because of the heavy evaporation loss during summer months (March-May 2001).

The cations viz., Na, Ca, Mg and K increased in observation wells near the effluent irrigated regions compared to river water. High Na (Fig.23), Ca, Mg and K in the effluent through leaching and infiltration might have settled in the wells of nearby villages. The sodium content was very high in P.Thekkampatti, which may be due to its location in down slope leading to the accumulation of sodium in ground water. The sodium content has increased invariably in all the villages during March – May 2001(summer) may be due to seasonal effect.

Fig.21. pH of water samples in and around the factory area

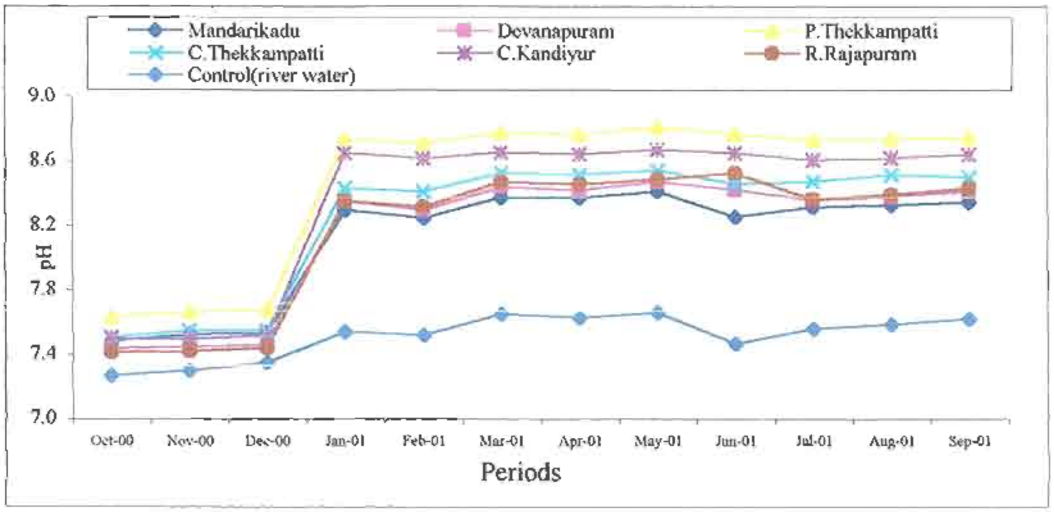


Fig.22. EC of water samples in and around the factory area

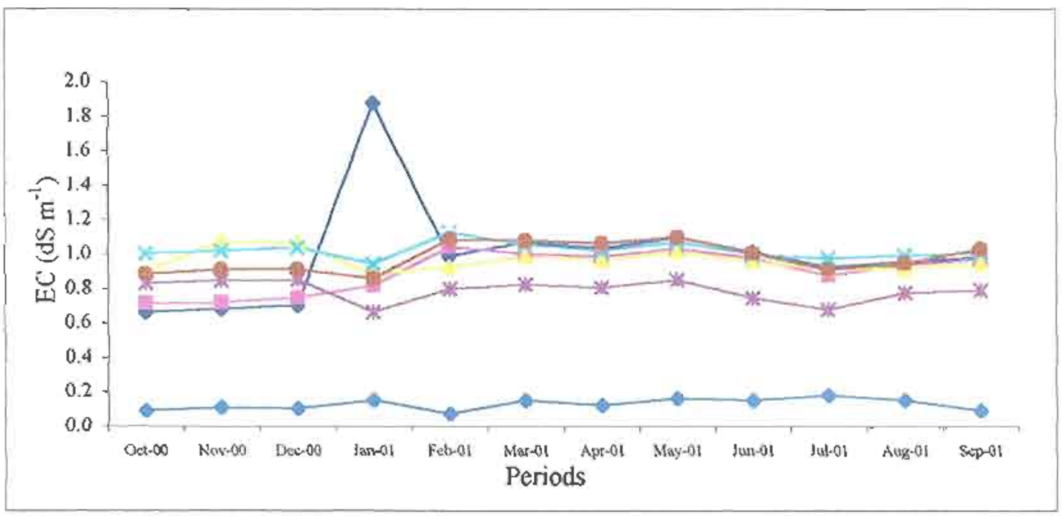
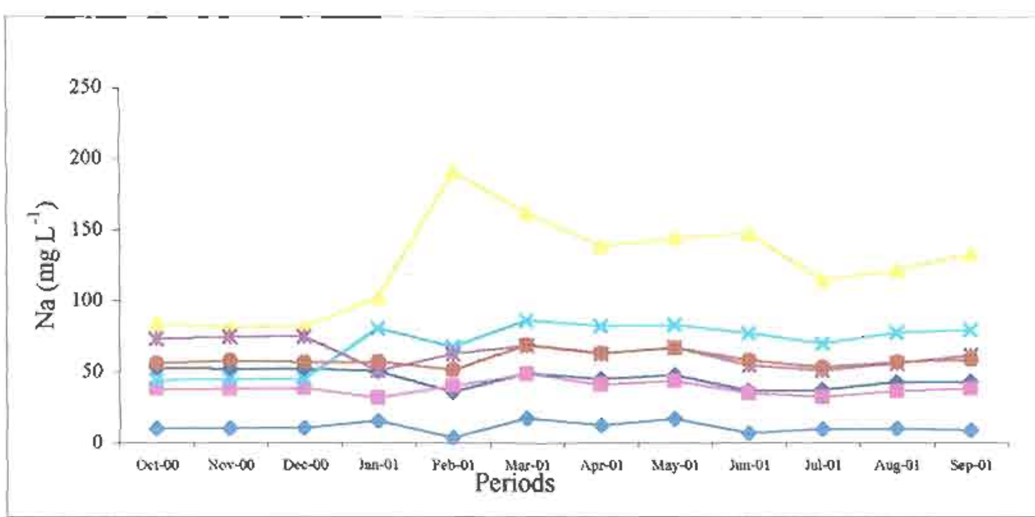


Fig.23.Na of water samples in and around the factory area



The carbonates and bicarbonates were high in almost all the observation wells near the effluent irrigated area compared to river water. The reason might be due to high EC of treated effluent. Fast movement of the soluble salts from the treated effluent influence the EC.

Trade effluent discharged on land for irrigation should have chloride and sulphate of less than 600 and 1000 mg L^{-1} as prescribed by TNSPCB (ISI, 1977). The chloride content recorded in the observation wells in and around the factory site was below the permissible limit only. However, the chloride and sulphate contents have increased in and around the factory area, when compared to river water irrigated area (Fig.24 and 25). This might be due to the movement of chloride and sulphates through seepage water. During the study period, the summer months (March -May 2001) showed an increasing trend of chloride and sulphate due to the influence of high temperature.

The per cent sodium in the well water samples increased compared to the river water. Eaton (1950) reported that per cent sodium less than 60 was 'good' and the wells in the study area have not crossed this safer limit (Fig.26).

The potential salinity (PS) of well water was analyzed 'medium' at periodical intervals, which indicated that the chlorides and sulphates gradually increased in ground water in and around the factory area. Devanapuram showed less PS when compared to other villages, which might be due to its location at the middle of the steep slope and the chances of accumulation of chloride and sulphate are remote. The well water did not cross the critical limit of 20 cmol L^{-1} reported by Doneen (1965), whereas river water had 'low' (1.0 to 1.7 cmol L^{-1}) PS.

The SAR of the ground water in and around the factory area and river water falls under 'low' category according to USDA system of classification (1954). The SAR

Fig.24. Cl^- of water samples in and around the factory area

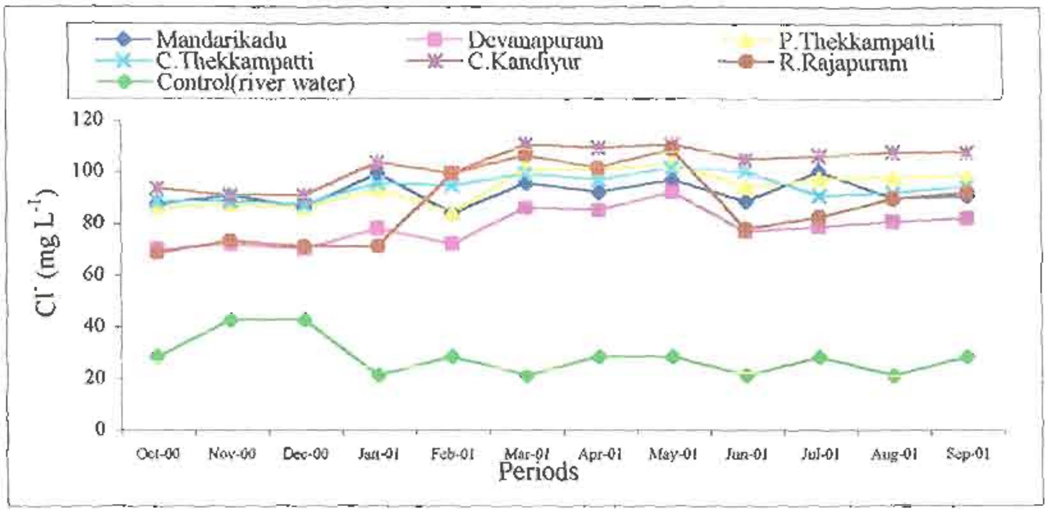


Fig.25. SO_4^- of water samples in and around the factory area

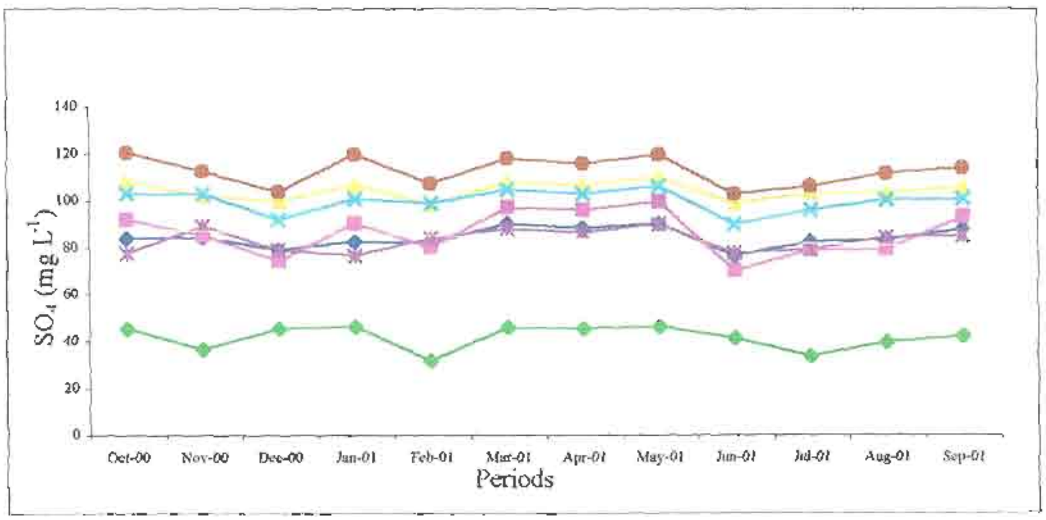
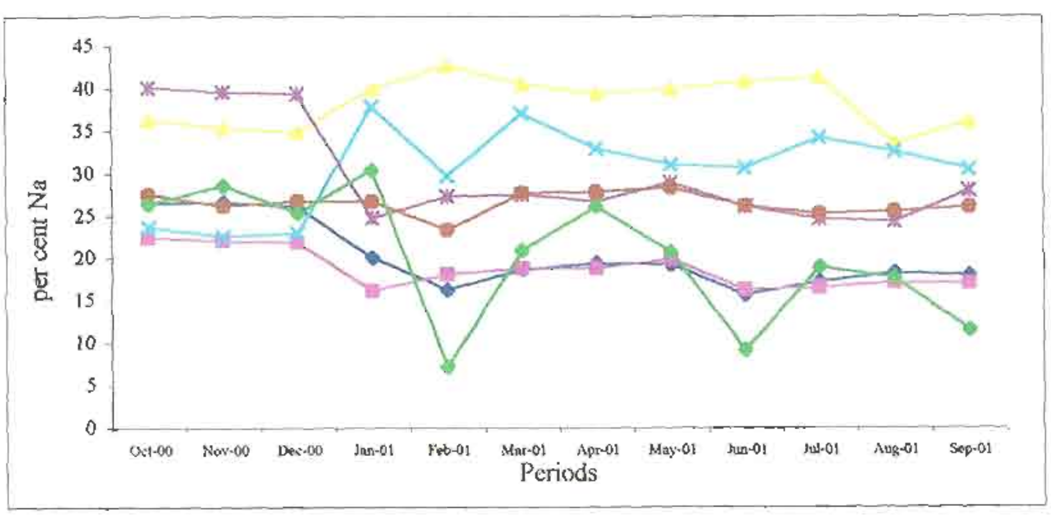


Fig.26. Per cent sodium of water samples in and around the factory area



was below 2 in both ground and river water samples. In few places the SAR goes upto 19. It reveals the accumulation of salt concentration.

Eaton (1950) classification of residual sodium carbonate (RSC) reveals that the well water falls under 'good' category (<1.25) and the ground water could be used for irrigation. The mean RSC values ranged from-1.61 to 0.45 (mg L^{-1}). The values were negative since Ca and Mg were higher than anions carbonates and bicarbonates.

5.3. Properties of treated effluent, soil, river water, and amendments used for field study

5.3.1. Characteristics of the treated effluent

The treated effluent of paper board mill contains considerable amount of total and suspended solids which was under the permissible limit. The total solid content of the treated effluent used for the present study is in line with the findings of Oblisami and Palanisami (1991) and Malathi (2001).

The pH of the effluent was 6.95. This is because of the fact that lime was used to neutralise the pH of the effluent before primary and secondary treatment process.

The electrical conductivity of the effluent was 1.22 dS m^{-1}, which could be due to the use of various organic chemicals (caustic soda, talc, rosin) at different stages of paperboard manufacturing. Similar results have been reported by Juwarkar and Subrahmanyam (1987).

The per cent sodium of treated effluent was below the tolerance limit of 60. The SAR of treated effluent (5.3) falls under "good" category, as compared to maximum permissible limit of 10 prescribed by TNSPCB (ISI, 1977). So the treated Bilt-IPCL effluent could safely be used for irrigation with proper ameliorants and drainage facilities.

5.3.2. Characteristics of river water

The Bhavani river water was used as an irrigation source (control) for field trials and compared with treated effluent irrigation. The pH and EC were well below the treated effluent values. Dissolved oxygen in the river water was higher than that of treated effluent. The BOD and COD values were less than those in the treated effluent. The microbial populations in the river water were much less than that of treated effluent. The parameters analysed in Bhavani river water for the present study were similar to the findings of Malathi (2001) on Cauvery river water.

5.3.3. Initial soil analysis characteristics

The soil used for the field study was sandy loam in texture. The soil was neutral with low EC. The available nutrient status of the soil revealed that N and P contents in the soil were low but K content was medium. The soil had low organic carbon and high ESP indicates that most of the exchange sites in the soil were with sodium ions.

5.3.4. Initial amendments characteristics

The use of solid wastes from various paper mills are not usually utilised extensively for any useful purposes. Extensive utilisation of indigenous solid wastes tends to increase the soil physical condition and helps to recycle nutrients in the soil-plant ecosystem. Solid wastes when applied to land provide an effective and environmentally acceptable option of waste disposal, which helps to condition the soil and enhance the soil nutrient properties.

The pH was neutral in FYM and Daincha, and slightly alkaline in sludge and fly ash. A similar result was reported by Hameed *et al., (*1998) and Malathi (2001). Among the materials used, the organic carbon content was more or less same. The pH of fly ash was alkaline and it adds essential plant nutrients to the soil (Kumar *et al.*, 2000).

5.4. Effect of treated effluent on survival of fingerlings

In the present study, it was found that the treated effluent affected survival per cent of *Catla catla* which is relatively sensitive to water quality. The reduction in survival per cent from 100 to 80 at higher concentration might be due to the reduced level of DO in the tested effluent. Jyoti *et al.* (1989) have also observed the same negative correlation between survival per cent and effluent concentration in the same species.

In contrast, the survival per cent of *Cyprinus rogu* was increased from 90 to 100 with higher effluent concentrations. The increase in survival per cent might be due to its capacity to survive even under reduced levels of DO besides effective assimilation of available nutrients at higher concentration of effluent by this species. Whereas in *Mrigal* the survival per cent decreased from 60 to 20 with increasing concentration of effluent. *Mirgal* was very sensitive to the treated effluent.

5.5. Effect of treated effluent on germination of field crops and vegetable crops

5.5.1. Field crops

In the present study, it was found that raw effluent affected the germination and vigour index (VI) of rice, maize, blackgram, greengram, soybean, groundnut and sunflower (Fig.27 and 28). Singh and Singh (1971) have observed a negative correlation between EC and seed germination. Dolar *et al.* (1972) reported that the growth reduction in the plant system was due to toxic effects and salts on soil structure, porosity and aeration.

The treated effluent increased the germination and growth of seedlings at lower effluent concentrations; whereas undiluted effluent affected the growth of seedlings. This increase in germination and VI might be due to the reduction in the level of toxic

Fig.27. Effect of raw and treated effluent on seedling root length (cm) of some field crops

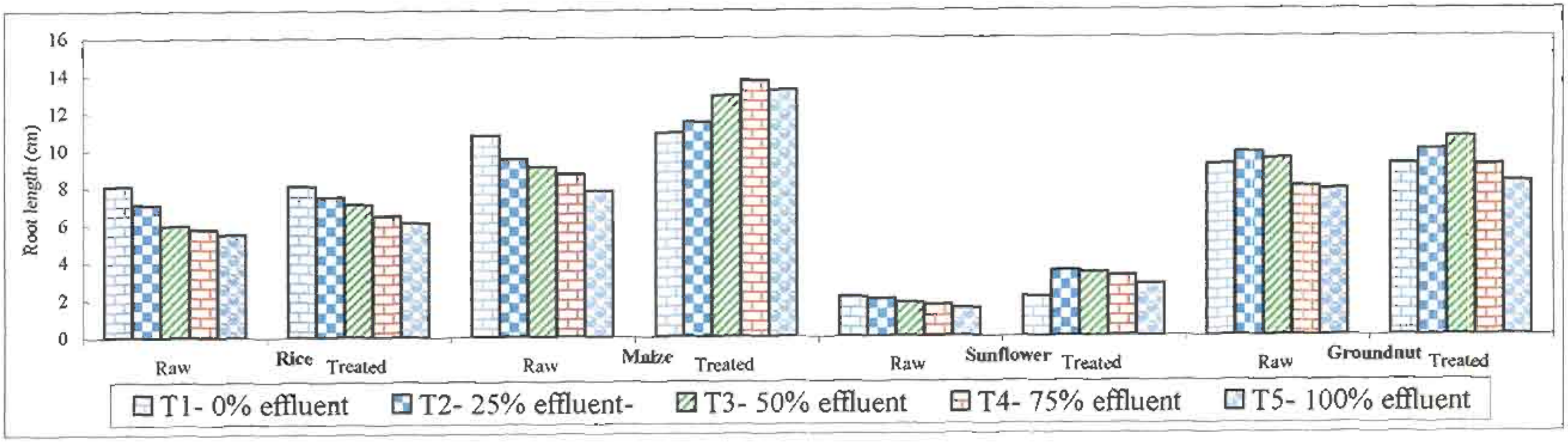
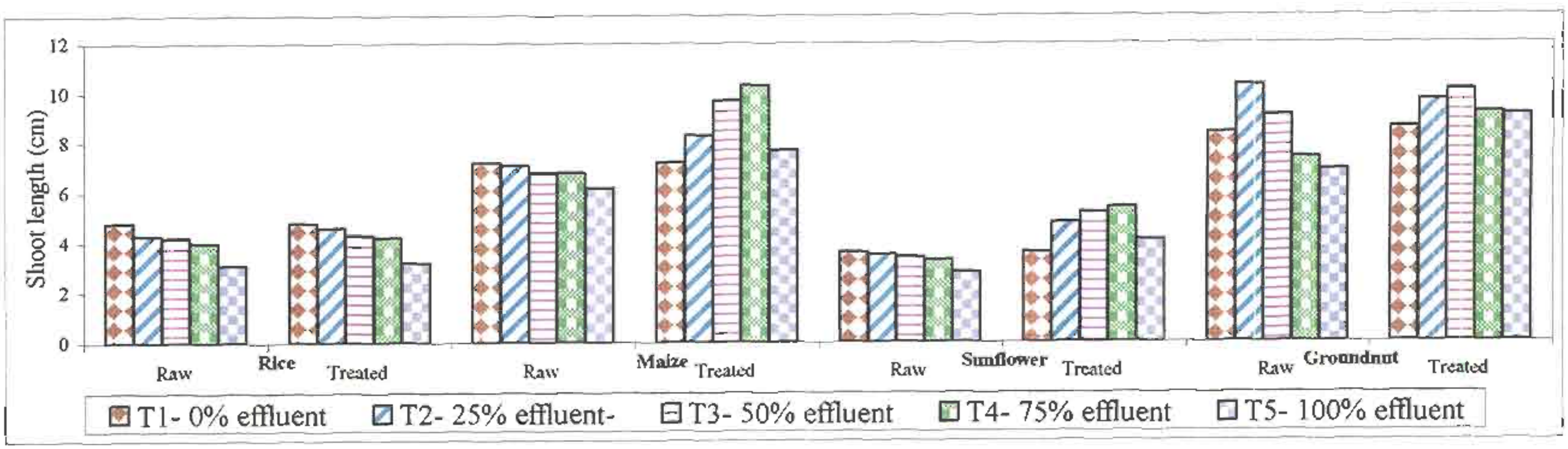


Fig.28. Effect of raw and treated effluent on seedling shoot length (cm) of some field crops.



metabolites by dilution and better utilization of nutrients present in the effluent at reduced level of toxicity.

The treated effluent used in the study upto 75 per cent concentration does not affect the growth and VI of maize. Reddy *et al.* (1981) reported the use of paper mill effluent irrigation for sugarcane. Subrahmanyam *et al.* (1984) also reported that crops like paddy, wheat, barley and sugarcane could be successfully grown, with practically no reduction in yield. Dixit et al, (1986) observed inhibition in germination of rice seeds with increasing concentrations of cardboard factory effluent. Somashekar *et al.* (1984) reported that the diluted effluent showed favourable effect on seedling growth of maize, cotton and paddy. The VI of the blackgram, greengram and soybean was increased with increase in dilution of the effluent. Spulnik (1949) reported that the use of sulphite mill waste water had no adverse effect on germination of sunflower seeds. Encouraging results were also found in crops like paddy, wheat and groundnut with the paper mill waste water (Khambatta and Ketkar, 1977). In the present study the growth of crops with 25, 50 and 75 per cent effluent concentration was more than the normal water for irrigation. This might be due to decrease in inhibitory compound in the effluent and, optimum levels of essential nutrients present in the effluent favoured the growth of the seedling. Subrahmanyam *et al.* (1984) and Rajannan and Oblisami (1979) also had the same opinion. Diluted effluent enhanced the growth of plants. This might be due to the decrease in the concentration of various chemicals in the effluents. The presence of root promoting phenolic compounds might have played a role in influencing the beneficial effect in terms of growth as suggested by Bose *et al.* (1973).

Undiluted treated effluent and raw effluent reduced the germination and VI of seedlings. This might be due to the toxic effects of the salts in the effluent. Excess amount of calcium and magnesium in the waste water is injurious to plants (Rajannan and Oblisami, 1979) and this might be the reason for decrease in VI of undiluted effluent.

5.5.2. Effect of raw and treated effluent on germination and growth of vegetable crops

Better germination of seeds and growth of seedlings *viz.*, bhendi, chilli, tomato, amaranthus, bittergourd, snakegourd and moringa were observed at higher concentration of treated effluents. Whereas, at lower dilutions germination and growth were reduced. A similar trend was observed in raw effluent also (Fig.29 and 30). But the germination and growth performance of the seedlings were found to be reduced in raw effluent when compared to treated effluent. Better germination and growth of seedlings in diluted treated effluent might be due to the reduction in the level of toxic metabolites by dilution. In addition, better utilization of inorganic nutrients present in the effluent by the seeds at reduced level of toxicity. The reduction in germination in raw effluent might be due to the toxic compounds like phenols and sodium present in the effluent. Similar view points were also expressed by Malathi (2001).

Rajannan and Oblisami (1979) reported that undiluted effluent affected the germination of paddy, blackgram and tomato seeds. Better germination of field bean and tomato was observed at lower effluent concentration (Sandana, 1995). Somashekar *et al.* (1984) showed the favourable effect of diluted effluent on germination and seedling growth of paddy, sorghum and cumbu. Gomathi and Oblisami (1992) reported that low concentration of the effluent had no adverse effect on the germination of tree seeds *viz.*, neem, pungam and tamarind. Kannapiran (1995) and Udayasoorian *et al.* (1999a) observed better seed germination at higher concentration of effluent (75 and 100%) for *Acacia leucophloea, Albizia lebbeck* and *Leucaena leucocephala*. Better

Fig.29. Effect of raw and treated effluent on seedling root length (cm) of some vegetable crops.

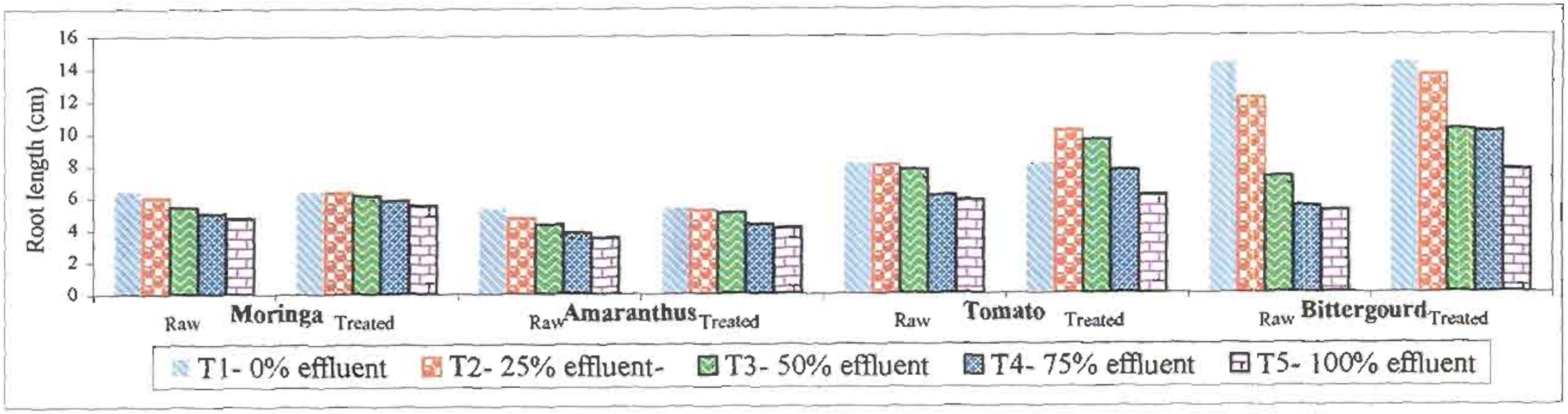
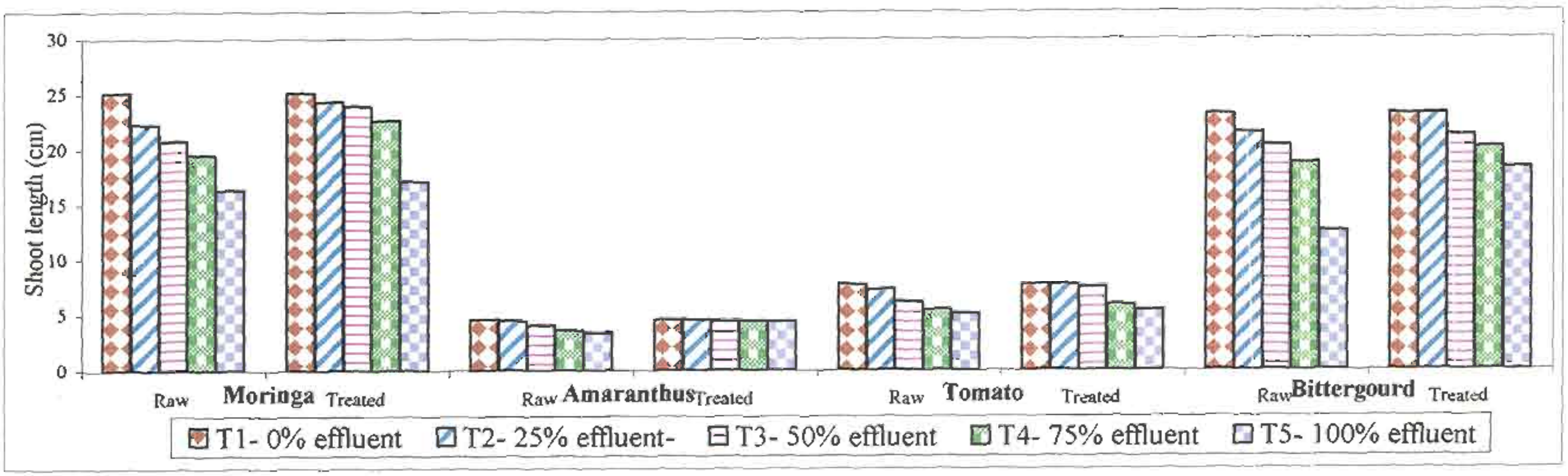


Fig.30. Effect of raw and treated effluent on seedling shoot length (cm) of some vegetable crops.



germination of rice, field bean and tomato was observed in lower effluent concentration.

Inhibition of germination and growth at higher effluent concentration might be due to ex–osmosis resulting from higher concentration of salts. Due to ex–osmosis the moisture required for the growth of seed comes out. Bishop and Wilson (1954) reported the use of pulp mill waste water for irrigation of crops like potato, corn, bean, cabbage, carrot and tomato.

5.6. Effect of effluent and amendments on nursery tree seedlings

5.6.1. Biometric characters of nursery tree seedlings

Acacia auriculiformis is the predominant leguminous tree species and *Azadirachta indica,* and *Eucalyptus tereticornis* are the predominant non-leguminous tree species of the Indian Peninsula having multiple utilities. These are mainly used in afforestation of waste lands wherein growth conditions are not favourable for other species. The principle behind the selection of these three hardy species except *A. auriculiformis* is that the other two species are predominantly used as raw material for paper and pulp production in paper making industries. The wood of the *A. auriculiformis* has the problem of high lignin content which ultimately affects the quality of paper. Investigations are under way to reduce the lignin content in the wood so that *A. auriculiformis* could also be used as raw material for pulp and paper production in future.

In the present study, Bilt-IPCL solid wastes except sludge with effluent irrigation had no deleterious effect on these tree seedlings. Among the three seedlings tried, *A. auriculiformis* did not thrive under sludge application whereas the *A. indica* and *E. tereticornis* could withstand the adverse effect of sludge. It is clearly understood that non leguminous tree seedlings withstand the effluent and solid wastes as amendments.

Kannapiran (1995) observed better seed germination and growth of seedling at higher concentration of raw paper mill effluent (75 and 100%) for *Acacia leucophoea, Albizia lebbeck* and *Leuceana leucocephala*.

Under drought or stress conditions, the tree species having maximum root length are termed as 'survival of the fittest'. The root length is taken as an index for evaluating the drought tolerance of a tree species.

In the present investigation, FYM + fly ash, FYM and FYM + sludge recorded longer roots than other solid wastes. This might be due to contribution of more readily available nutrients from these sources. In *E. tereticornis*, sludge inhibited the root growth due to toxicity caused by alkaline pH and higher soluble salt concentration. *Acacia auriculiformis* was sensitive to high alkalinity caused by sludge, which further aggravated the transplanting shock, and thereby the establishment of the seedling was total failure. Very hard surface could be formed due to sludge addition, which reduces the infiltration and root penetration. Sludge exhibited podzolanic properties i.e., reaction with water to form cemented soil layer, resulting in reduced infiltration and root penetration. Such an effect, besides high soluble salts and alkalinity might have been the cause for poor root length in *A. indica* and *E. tereticornis* and total elimination of *A.auriculiformis*. The appreciable level of root length under FYM + fly ash might be due to high moisture holding capacity which enhanced the growth and penetration of the roots. Therefore, the fly ash combined with FYM could safely be used as nursery mix.

Plant height is an important tool to analyse the site quality, acclimatization of tree species to the existing environment, growth pattern of species, and plant environment interaction. The present study revealed significant differences in shoot length due to effluent irrigation at all growth stages of tree seedlings. Neelay and Dhondizal (1985) reported that pulp and paper mill effluent when used for irrigating tree species, resulted in an increase in height of *Eucalyptus camandulensis, Pongamia pinneta, Acacia auriculiformis, Leuceana leucocephala* and *Dendrocalamus strictus.*

Among the amendments, FYM + fly ash recorded the longest shoot. The shoot length under FYM was comparable to that under FYM + fly ash. The reason for this could be attributed to the fact that both FYM + fly ash and FYM were rich in essential plant nutrients (Table 63). In *E. tereticornis*, the shortest shoot length was recorded in sludge. This might be due to the alkaline nature of sludge and also due to higher proportion of soluble salts in the root zone. Singh and Singh (1971) observed a negative correlation between EC and growth of tree seedlings. The salts present in sludge inturn might affect the aeration essential for survival and growth of tree seedlings. Dolar *et al.* (1972) also were of the opinion that the reduction in growth system was due to the toxic effects of salts and heavy metals on soil structure, aeration and porosity.

Farm yard manure + fly ash with effluent recorded the highest shoot followed by FYM with effluent irrigation than with river water combination. This might be due to the enrichment of soil by the addition of the above amendments, which contained appreciable amount of plant nutrients and also due to the ameliorative effect of these amendments on the effluent. Combined use of the effluent along with amendments might have provided enough nutrients with better physical and microbial environment, thus improving the soil fertility. The above findings are in line with those of Kladivko and Nelson (1979), Reddy *et al.* (1981) and Pushpavalli (1990). Kannapiran (1995) also observed better shoot length at higher concentration of untreated effluent in *Acacia nilotica, Albeizia lebbeck* and *Leuceana leucocephala*.

The dry matter production (DMP) increased as the seedling growth advanced. At 120 DAT, the DMP was higher by three times in all the three species. Among the amendments, FYM + fly ash recorded higher DMP followed by FYM and FYM + sludge. The DMP was very high in *A. auriculiformis* probably due to the genetic nature of the species having broad leaves and thick stem. In non-leguminous, the DMP was very high in *E. tereticornis* than *A. indica*.

Effluent irrigation recorded higher DMP compared to river water for the reason that it could provide higher amount of essential nutrients (Table 83).

FYM + fly ash and FYM along with effluent increased the DMP than the rest of treatment combinations (Fig.31). This might be due to the ameliorative effect of these amendments, which could alleviate the ill effects of effluent irrigation resulting in higher DMP. Similar findings were reported by Sandana (1995) in tomato, Pushpavalli (1990) in sugarcane and Hameed and Udayasoorian (1998) in *A. nilotica*, *C. equisetifolia* and *E. tereticornis.*

The collar diameter (CD) is an indicator of site quality, species growth pattern etc. Generally, in trees, the diameter increment is very slow in the initial stages, while in later stage it would be at its maximum.

In the present study, CD increased progressively as the seedling growth advanced. Among the amendments, FYM + fly ash recorded higher CD followed by FYM and FYM + sludge. *A. indica,* and *E. tereticornis* recorded higher CD than *A. auriculiformis* because of the genetic nature of this tree species. Effluent irrigation recorded higher CD compared to river water because of higher amount of nutrients present in the treated effluent. Increased CD of *Eucalyptus camendulensis, Acacia auriculiformis, Leuceana leucocephala* and *Dendrocalamus strictus* due to paper and pulp mill effluent irrigation was reported by Neelay and Dhondizal (1985). Similar

Fig.31. Effect of effluent and amendments on dry matter production of *A.auriculiformis.*

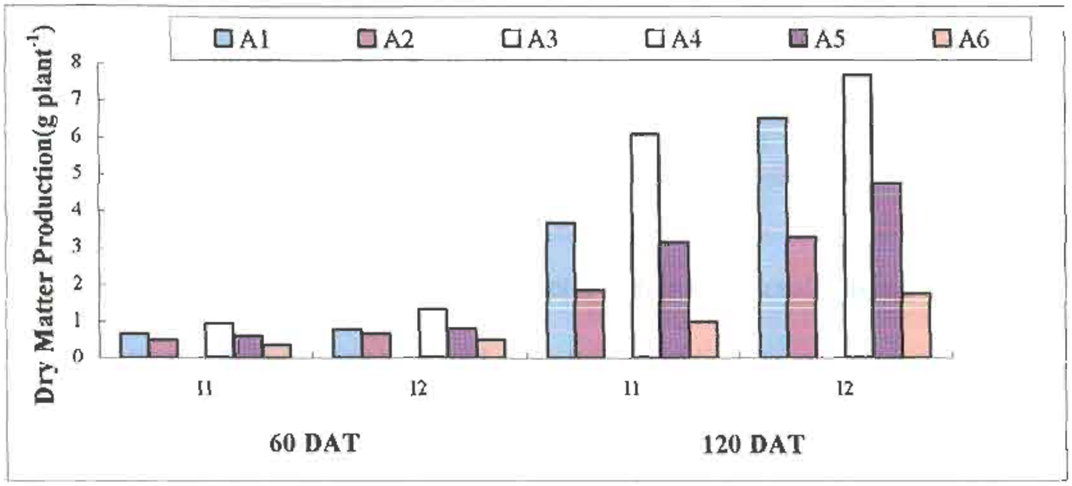


Fig.32. Effect of amendments on Organic carbon per cent of soil under *A.auriculiformis.*

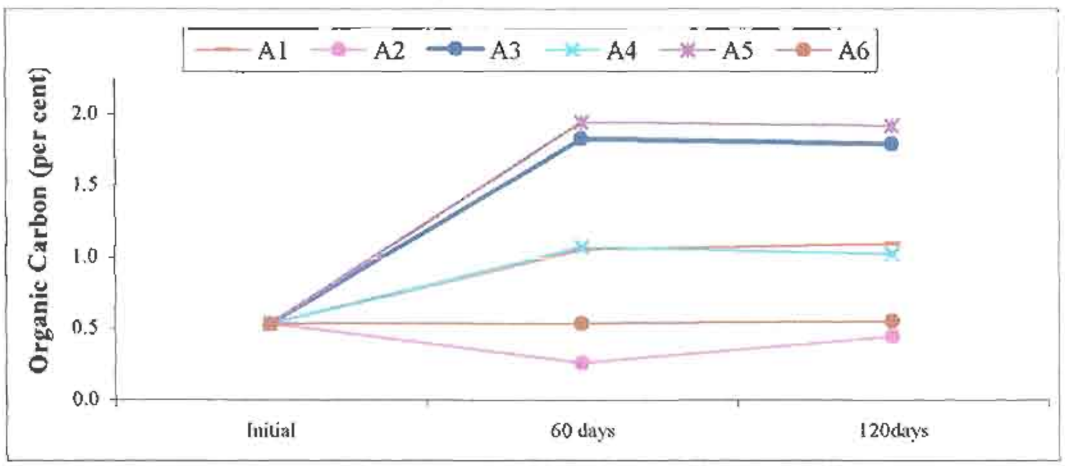
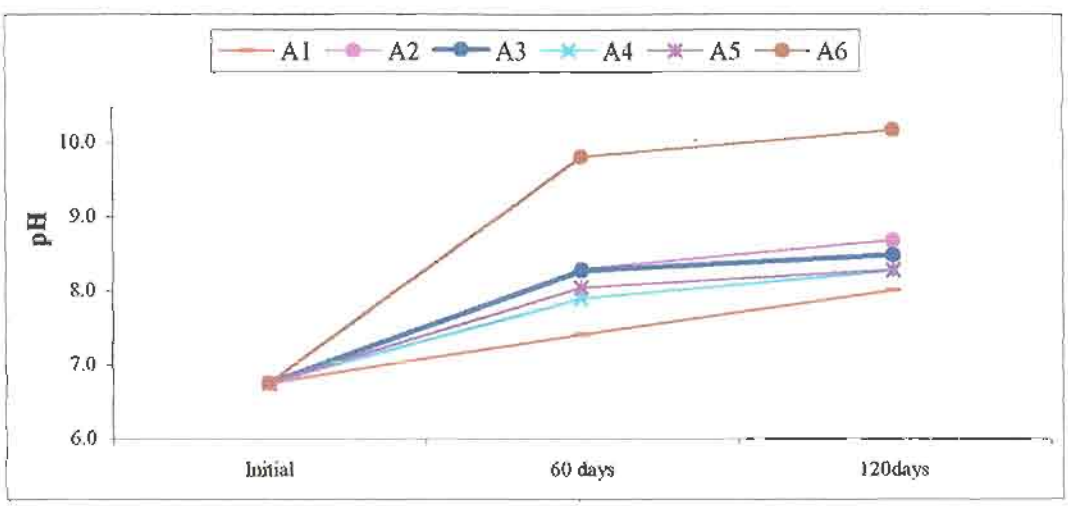


Fig.33. Effect of amendments on pH of soil under *A.auriculiformis.*



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash);
A4-S (sludge); A5-FA+S; A6-FA+GM (greenmanure) ; A7-S+GM; A8-FA+S+GM.

observation has been reported by Kannapiran (1995) in A. nilotica, Albizia lebbeck and Leuceana leucocephala and Neelay and Dhondizal (1985) in Eucalyptus canaldulensis, Pongamia pinnata, Acacia auriculiformis, Leuceana leucocephala and Dendrocalamus strictus. The least CD observed in sludge in combination with river water irrigation might be due to low nutrients status of sludge.

The vigour index (VI) is the parameter obtained by multiplying germination per cent with total length of the shoot and root. It is an indication of better establishment of the tree seedlings. Farmyard manure + Fly ash recorded the highest VI in all tree species at both the stages of seedling growth due to enhanced shoot and root growth. The next best amendments were FYM, FYM + sludge and fly ash. The least was recorded in sludge. Kannapiran (1995) observed higher VI in FYM amended soils. The appreciable VI in FYM than FYM + sludge was due to its high moisture retention capacity and high nutrient status which were responsible for higher germination. The effluent irrigation recorded higher VI when compared to river water. This might be due to the richness of plant nutrients in treated Bilt-IPCL effluent.

The volume index (VOI) is a good indicator of quality and ability of the seedlings to survive under adverse conditions. Farm yard manure + fly ash with effluent had higher VOI as compared to rest of the treatment combinations. Among the Bilt-IPCL solid wastes used as amendments, FYM + sludge, and fly ash with effluent was comparable with that of FYM with river water. This clearly showed that sludge and fly ash could be used in place of FYM in the preparation of nursery mix. Maximum VOI was recorded under normal nursery mix (FYM) as in Acacia nilotica, Albezzia lebbeck and Pongamia pinnata by Kannapiran (1995).

5.6.2. Effect of effluent and amendments on Chemical properties of soil

Progressive increase in soil pH with advancement of seedling growth was noticed in all amendments receiving effluent irrigation as compared to river water irrespective of tree species. It might be due to continuous irrigation with effluent, which was alkaline in nature. Similar increase in soil pH due to effluent irrigation was reported by Vasconcelos and Cabrel (1993). The increased pH due to the amendment addition in the present study corroborates with the findings of Olaniya *et al.* (1991) who reported that when organic materials like sludge or compost were applied on land, the organic matter of soil increased resulting in a change in soil pH (Fig.32).

The EC of the soil increased at all stages of crop growth due to continuous effluent irrigation irrespective of the amendments as compared to river water irrigation. The increase in soluble salt content in the soil could be ascribed to the salt content of effluent. Besides, the effluent also contained organic polyelectrolytes, which bind divalent cations, increasing the EC of the water and soil (Metzger *et al.*, 1983). Among the treatment combinations fly ash + sludge either with effluent or river water irrigation increased the soil EC, which might be due to higher Ca and Mg contents of the fly ash and sludge.

There was a gradual increase in the OC content of soil irrigated with effluent irrespective of the amendments while the same decreased with river water irrigation. The increase in organic matter content of the treated effluent irrigated soil might be due to higher concentration of suspended solids, which could contribute to the build up of organic matter. This is in agreement with the findings of several workers (Somashekar *et al.*, 1984; Juwarkar and Subrahmanyam, 1987; Kannan and Oblisami, 1990). Among the treatment combinations, FYM + sludge with effluent irrigation recorded higher values than FYM with effluent (Fig.33). This clearly showed that FYM could be replaced by sludge in the normal nursery mix.

The FYM + sludge either with effluent or with river water irrigation registered highest available N content at all stages of seedling growth followed FYM + fly ash with effluent irrigation and the lowest was under fly ash with river water. The Bilt-IPCL sludge addition with FYM contained comparatively higher N (1.12 per cent) than FYM (0.78 per cent). The slightly higher pH recorded in FYM + sludge applied soil might have favoured increased nitrification process leading to an increase in available nitrogen content. Similar results were reported by Patra and Behera (1974). In general, the available nitrogen content decreased at later stages of seedling growth irrespective of irrigation sources. The reduction was gradual in effluent irrigated soils than in river water irrigation indicating that the tree seedling had utilized a part of nutrient added through effluent. This is in line with the findings of Hameed (1997). In contrast, an increasing trend was also observed due to combined effluent irrigation over a period of 15 years by Palaniswami and Sree Ramulu (1994).

Farm yard manure + fly ash with effluent or with river water irrigation resulted in highest soil available P content which was comparable with that of fly ash + sludge with effluent. This indicated that P contribution from fly ash + sludge was comparable with that of FYM + fly ash which was used as normal nursery mix. Mine and Graveland (1972) reported that sludge treated at low level significantly increased the available P in the soil. A gradual reduction in available P in both effluent and river water irrigated soils with advancement in growth indicated the crop removal.

Effluent irrigation recorded higher available K as compared to river water. The available K in soil was highest under FYM + fly ash either with effluent irrigation or with river water. Igbounamba (1972) observed increased availability of K in soils due to mineralization of organic matter. Favourable effect on available K content of soil due to ETP (effluent treatment plant) sludge addition was reported by Dhevagi (1996). The soil available K content decreased gradually in effluent than in river water irrigation as the age of the seedlings increased. This could be due to the fact that the K was taken by the seedlings and finally converted into plant biomass.

Among the amendments, the fly ash + sludge recorded the highest exchangeable Ca and Na followed by the sludge whereas FYM + sludge recorded the highest exchangeable Mg. Effluent irrigation added considerable quantity of cations viz., Ca, Mg and Na due to continuous irrigation than river water irrigation. The exchangeable cations increased with duration of effluent irrigation. Higher concentration of exchangeable cations under effluent irrigation was reported by number of workers (Reddy *et al.*, 1981; Gomathi and Oblisami, 1992 and Hameed *et al.*, 1998).

Sludge application increased the soil exchangeable cations invariably either with effluent or river water irrigation. The increase was higher at later period of seedling growth. This might be due to accumulation of more organics, which might retain cations in soil. Palaniswami and Sree Ramulu (1994) concluded that lime sludge contains higher proportion of cations responsible for build up of exchangeable cation in soil. Increased concentration of exchangeable cations in soil might have exerted relatively higher osmotic pressure in the roots of *A. auriculiformis* preventing the free flow of essential cationic nutrients and finally the seedling withered permanently, owing to their susceptible nature. Contrary to the soil available N, P and K, the exchangeable cation content continued to increase as the crop growth advanced which might be due to high level of Ca in effluent as well as in solid sludges.

Juwarkar *et al.* (1987) suggested that sodium toxicity could be reduced by decreasing the sodium adsorption ratio (SAR) of the effluent, which can be augmented by increasing the proportion of Ca^{2+} and Mg^{2+} to Na^{+} in the effluent by the addition of Ca and Mg salts. Gypsum may also be used to reduce the effect of high soil exchangeable sodium per cent (ESP).

5.6.3. Effect of effluent and amendments on soil microflora

The bacterial, actinomycetes and fungal populations at different stage of the seedling growth were comparatively higher in effluent irrigated along with amendments added soil than in river water irrigated soils which might be due to the prevalence of adequate amounts of nutrients in effluent and amendments. This was due to the heterotrophic nature of these microbial groups, which would assimilate various constituents of waste water and proliferate in the soil.

Among the amendments, sludge recorded the highest microbial population followed by FYM + sludge and fly ash. Fly ash had a deleterious effect on soil microflora. Among the treatment combinations, the sludge either with effluent or with river water irrigation had higher load of bacteria, actinomycetes and fungal population, which was closely followed by FYM + sludge either with effluent or river water irrigation. Increased biological activity due to application of decomposed paper mill waste at the rate of 10 to 20 t ha^{-1} was reported by Ilyaltdinov *et al.* (1990).

The microbial load increased as the crop growth advanced. This could be attributed to the root exudates, which might proliferate the microbial diversity. The present study falls in line with the findings of Sopper and Seakar (1987), Kannan (1988) and Alfred (1998) who reported higher microbial populations in soils irrigated with effluent.

5.7. Effect of effluent and amendments on field crops

Field experiment was conducted to assess the impact of paper and board mill treated effluent irrigation on the growth of maize and sunflower as influenced by different organic amendments such as FYM, fly ash, sludge, fly ash + GM, sludge + GM and fly ash + sludge + GM in combination with recommended level of NPK fertilizers. The plot receiving river water along with 100 per cent NPK served as control. The results obtained through the field experiment led to some important conclusions, which are discussed hereunder.

5.7.1. Effect of treated effluent and amendments on soil properties

The data obtained on bulk density, pH, EC and organic matter of soil indicated that there were considerable changes in these characteristics due to treatments. The texture of the soil for field trial was sandy loam.

Treated effluent irrigation enhanced the bulk density of the soil. However, relatively lower bulk density was observed in treatments, which received different amendments. This might be due to increase in volume as a result of addition of amendments. Highest bulk density was recorded in the treatment receiving sludge and this was less than the critical value of 1.52 Mg dm^{-3}. Effluent irrigation along with amendments caused changes in bulk density of the soil but the change was below the critical level. Ramasubramoniam *et al*, (2001) reported that the bulk density and particle density of soil decreased by increasing levels of fly ash application. The maximum reduction was seen when fly ash was applied with composted coir pith. Yingming and Corey (1993) observed that sludge application could alter the bulk density of soil. Pressmud and FYM slightly improved the soil properties (Kant and Kumar, 1992). The present result is in accordance with the findings of Narashimha Rao and Narashimha Rao (1992) and Sandana (1995). Such variations in physical properties of the soil might be due to the addition of organic matter in the effluent and amendments, and interaction between the various constituents of the effluent and native microflora (Baver *et al.*, 1972).

The highest pH of 8.46 was recorded in treatment receiving fly ash amendment along with treated effluent irrigation, while under river water irrigation it was 7.63. Ramasubramoniam *et al.* (2001) and Olaniya *et al.* (1991) reported that when organic materials like compost (or) sewage sludge are applied on land, the organic matter of soil increased and slight change in pH occurs. There was a progressive increase in soil pH with advancement of crop growth in the treated effluent irrigated plots while in river water receiving plots the change was not at a considerable level (Fig.34). In the present study the progressive increase in pH of the soil in the treated effluent receiving plots might be due to continuous irrigation with the effluent, and increased the salt accumulation in the soil. This was in line with the findings of Oblisami and Palanisami (1991); Narashimha Rao and Narashimha Rao (1992); Vasconcelos and Cabrel (1993), and Dhevagi (1996).

Due to amendments, the EC increased continuously in the treated effluent irrigated plots (0.47-0.55 dS m^{-1}), while there was not much difference in the EC values of river water receiving treatments. The highest EC value was recorded in treatment receiving fly ash, whereas the lowest was recorded in FA+S+GM receiving treatments (Fig.35). The higher EC in effluent receiving treatments might be due to salt accumulation because of continuous irrigation with the effluent. Effluent might contain organic polyelectrolytes, which bind divalent cations, increasing the EC of the water and soil (Metzger *et al.*, 1983).

The organic matter showed significant differences and the highest value was recorded in the treatment having sludge and sludge + GM. The organic matter content

Fig.34. Effect of effluent and amendments on soil pH under maize and sunflower

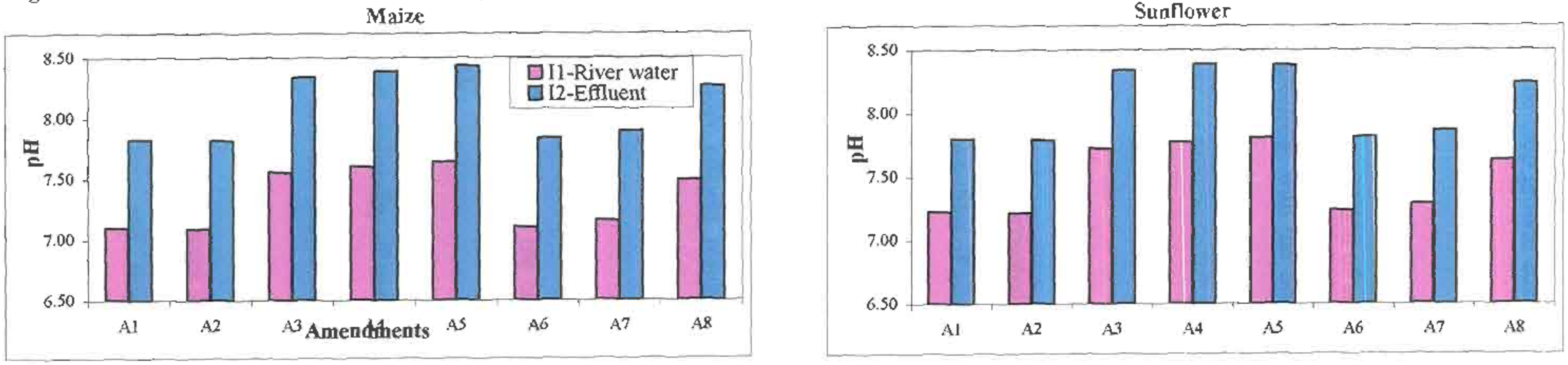
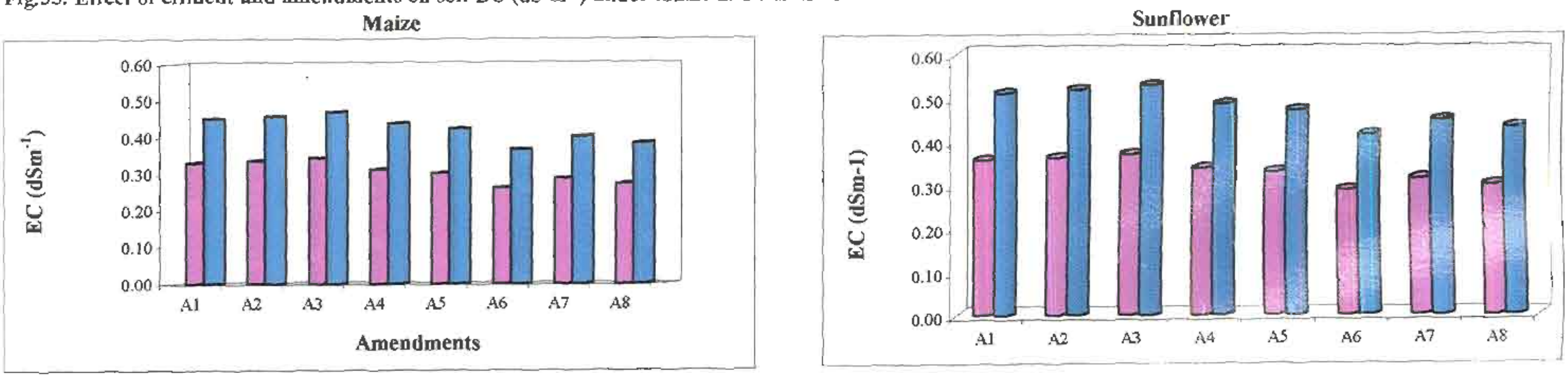


Fig.35. Effect of effluent and amendments on soil EC (dS m^{-1}) under maize and sunflower



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash); A4-S (sludge); A5-FA+S; A6-FA+GM (greenmanure); A7-S+GM; A8-FA+S+(

decreased as the crop growth advanced. Mineralization during the crop growth period and absorption of nutrients by the growing crop led to this effect of decreasing organic matter content. The increase in organic matter content in the treated effluent irrigated soil might be due to addition of suspended and dissolved solids present in the effluent. This is in agreement with the findings of several workers (Somashekar *et al.*, 1984; Juwarkar and Subrahmanyam, 1987; Kannan and Oblisami, 1990; and Udayasoorian *et al.*, 1999a).

All the available nutrients in treated effluent irrigated soil showed a significant change over river water irrigated soil. Treatment receiving treated effluent irrigation resulted in higher quantities of available nutrients. Available N content was more in fly ash + GM (T_6) and the lowest was recorded in control (T_1). Rajannan and Oblisami (1979) reported that paper factory effluent irrigation increased the available nutrient status of red and black soils. Moura (1987) reported that the irrigation with the cardboard factory effluent resulted in improved soil fertility. Palaniswami and Sree Ramulu (1994) reported increased available nitrogen content of soil due to effluent irrigation. The differences in respect of available P and K also followed the same trend as that of available N in all the crops. This is in line with the findings of Udayasoorian *et al.* (1999a).

Highest availability of nutrient status in the soils receiving amendments clearly indicated the efficient utilization of inorganics in the presence of organics. This corroborates with the findings of Bache Byron and Heathcote (1969) who reported that application of organic manures increased the organic carbon, available nitrogen and exchangeable calcium and magnesium in soils. The available phosphorus and potassium were higher in treatment receiving fly ash + sludge + GM and this may be due to the rich amount of organic matter, calcium, phosphorus and organic nitrogen present in the amendment.

The highest available P content was seen due to the treatment fly ash @ 15 t ha^{-1} with 12 t ha^{-1} lime. The rise in pH consequent to the addition of Ca and Mg may be responsible to the solubilization and release of available P by the replacement of adsorbed phosphate ions (Ramasubramoniam and Chandrasekaran, 2001). The higher amount of potassium in the treated effluent irrigated plots might be due to addition of K present in the effluent. Igbounamba (1972) reported that the increased availability of nutrients in soils, where the mineralisation of the organic matter is more. Somashekar *et al.* (1984); Pushpavalli (1990); Palaniswami (1989); Oblisami and Palanisami (1991) and Sandana (1995) reported the similar result, which is in line with the present findings. The available nutrient status decreased at reproductive stage indicating the absorption and conversion of nutrients into plant biomass.

Effluent irrigation added considerable amount of exchangeable Ca, Mg and Na due to continuous irrigation with effluent than river water (Prasanthrajan.,2001).There was an increase in available calcium, magnesium and sodium contents of the soil under treated effluent irrigation. The available calcium and magnesium were the highest in treatments receiving fly ash (T_3) and fly ash + sludge + GM (T_8). This is in accordance with the findings of Kannan (1988); Oblisami and Palanisami (1991), and Dhevagi (1996).

Malathi (2001) reported higher exchangeable Na content of soil under effluent irrigation at all the stages of vegetable crops owing to the contribution from the irrigation sources which could be gauged from the higher sodium content of effluent as compared to the well water or river water.

The available micronutrients did not show much difference. However, more of micronutrients were present in the treated effluent irrigated plots. This might be due to higher organic matter content and also addition of these nutrients continuously through effluent as well as solubilizing action of the nutrients due to continuous moist condition. The activity of Fe content was reduced due to application of fly ash along with lime. Available Mn, Zn and Cu content were also increased due to fly ash addition. (Ramasubramoniam *et al.*, 2001). The content of micronutrients was appreciably higher than the critical limits fixed for these elements. During reproductive stage the availability decreased and it showed that part of the nutrients might be used for the grain production. Available Fe content of the soil decreased by addition of fly ash and it did not affect the Zn content of the soil significantly (Ramasubramoniam and Chandrasekaran, 2001).

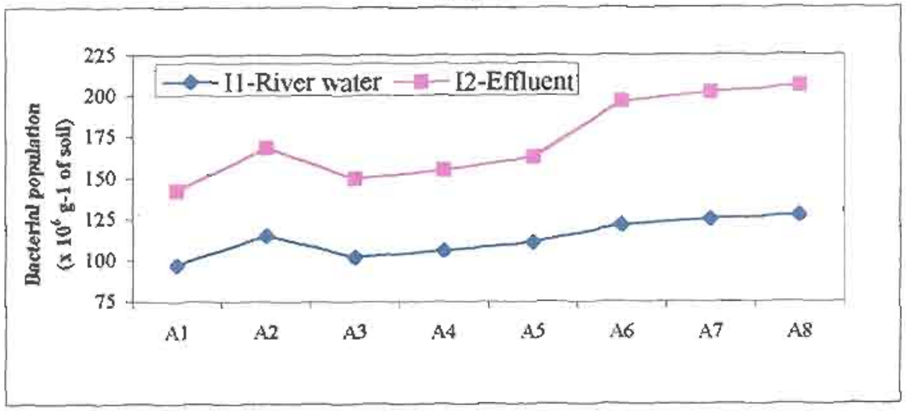
5.7.2. Effect of treated effluent and amendments on biological properties

The microorganisms stimulate the growth of plants by mobilization of nutrients and production of phyto effective metabolites, protecting the plants from pathogens, degrading toxic substances and increasing the stress tolerance, as well as by forming and stabilizing soil structure. The bacteria, actinomycetes and fungal populations were comparatively higher in treated paper board mill effluent irrigated soils than in well water irrigated soils (Prasanthrajan, 2001).

In the present investigation, higher microbial count was observed in the effluent irrigated soils of both maize and sunflower.The effect was more on bacteria, fungi followed by actinomycetes, *Azotobacter, Azospirillum* and *Rhizobium* (Figs.36,37,38 and 39).

Fig.36. Effect of effluent and amendments on soil bacterial population under maize and sunflower

Maize



Sunflower

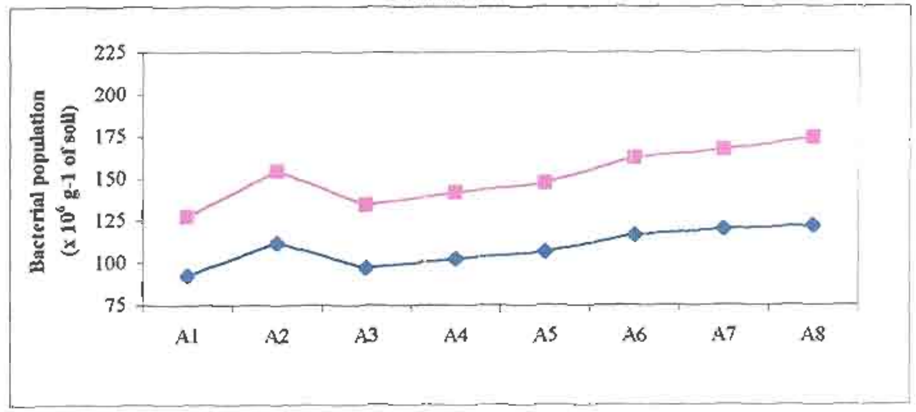
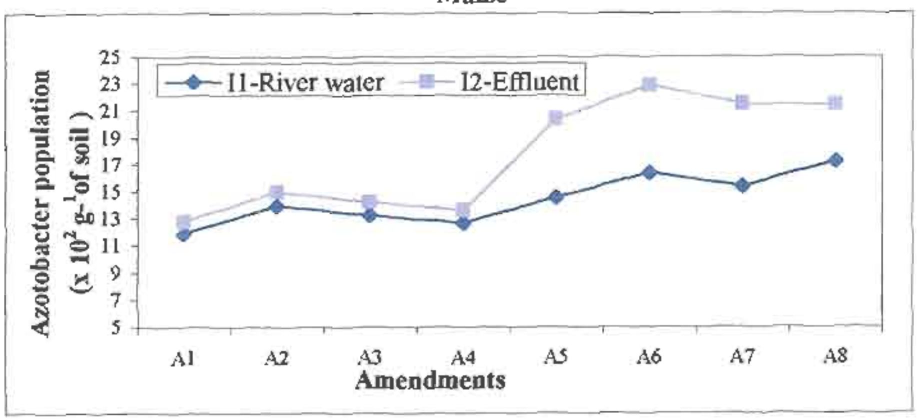
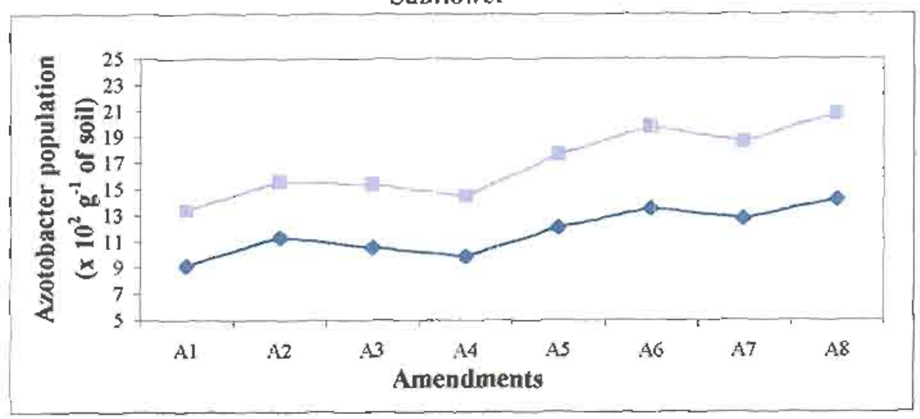


Fig.37. Effect of effluent and amendments on soil azotobacter under maize and sunflower

Maize



Sunflower



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash); A4-S (sludge); A5-FA+S; A6-FA+GM (greenmanure); A7-S+GM; A8-FA+S+C

Fig.38. Effect of effluent and amendments on soil Azospirillum population under maize and sunflower

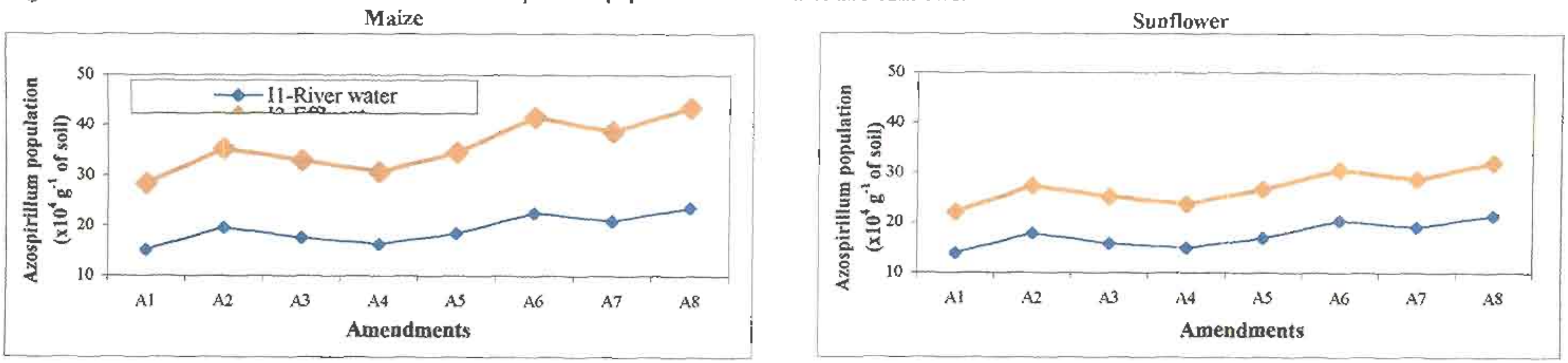
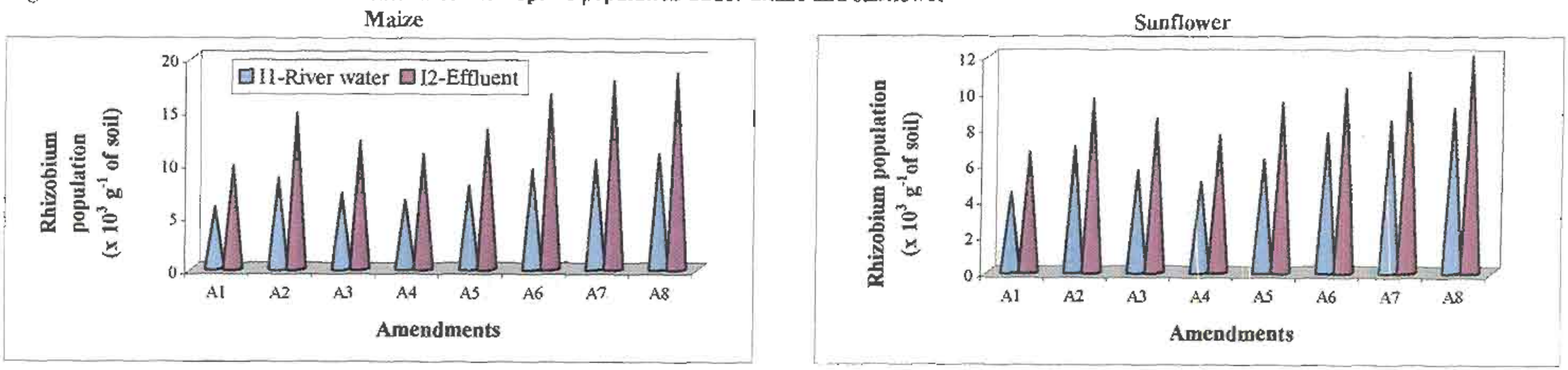


Fig.39. Effect of effluent and amendments on soil rhizopium population under maize and sunflower



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash); A4-S (sludge); A5-FA+S; A6-FA+GM (greenmanure); A7-S+GM; A8-FA+S+C

232

The addition of organic matter would have provided the source of N for the multiplication of microbes and subsequent increase in the nutrient availability (Ramasubramoniam *et al.*, 2001). Effluent irrigated plots showed more population and this might be due to the enrichment in the nutrient contents of the soil under effluent irrigation. Rajannan and Oblisami (1979) and Somashekar *et al.* (1984) also had the same opinion. This increase could be contributed to the heterotrophic nature of these microbial groups, which would assimilate various constituents of the waste water and proliferate in the soil. Chauhan and Kaur (1991) and Kannapiran (1995) observed that diluted effluent was found to increase the microbial population. The soil population of *Rhizobium* spp., a symbiotic N_2-fixing bacterium was not affected by effluent irrigation (Kannan and Oblisami, 1992).

The microbial count was higher in amendment received treatments. This might be due to the increase in organic matter content and nutrient status of soil which inturn increased the physical and chemical properties of the soil and provide a favourable environment for the growth of microbes and mineralization processes. The addition of sludge to soil improved soil physical properties which inturn enhanced the survival and growth of rhizobia. Bolton *et al.* (1985) and Hasbe *et al.* (1985) observed that organic fertilizer caused a greater increase in soil microbial biomass than inorganic fertilizer. Ilyaltdinov *et al.* (1990) and Brendecke *et al.* (1994) reported that the application of decomposed paper mill waste at the rate of 10-20 t ha^{-1} improved the soil biological activity. Sandana (1995) observed marked differences in microflora of soil under the effluent irrigation along with amendment.

As the stage of the crop advanced, microbial population increased and this might be due to excretion of more of root exudates. At reproductive stage the root exudates might decrease, and inturn the population also decreased even though the effluent irrigation was continued.

In the present investigation there was an increase in amylase, invertase and cellulase activity in soils with an increase in the period of effluent irrigation and this increase might be due to increased microbial population, which help in mineralization and degradation of organic matter. Chunderova (1970) reported that invertase activity was not altered by changes in soil pH and it was closely related to the humus content. Tateno (1988) reported that enzyme activities in natural soil are limited by substrate supply and not by the amounts of enzymes. Dhevagi *et al.* (2000) reported that increase in organic matter content, which serve as a nutrient source for microorganisms, might increase the enzyme activity in the effluent irrigated soil.

The humic acid in organic matter fraction enhanced the protein synthesis, which simultaneously increased the soil invertase activity. The increase in soil invertase activity might be due to the higher content of the soil under effluent irrigation. The soil organic matter under effluent irrigation is degraded by the extracellular enzymes of microorganisms and utilizes the products as their energy source and the hydrolytic enzymes originate from the soil microorganisms (Mahmood *et al.*, 1985).

Soil cellulase activity is known to be influenced by the addition of organic matter. Lahdesmaki and Piispanen (1988) have shown increased cellulase activity in soil due to degradation of cellulose in the effluent. Increased activities of amylase, invertase and cellulase were reported by Kannan (1988); Gomathi (1989) and Oblisami and Palanisami (1991). As the stage of crop advanced, the activity decreased and this might be due to the reduction in microbial load at harvest stage.

5.7.3. Effect of treated effluent and amendments on field crops

Significant influence on germination per cent, vigour index, plant height and plant dry weight of maize and sunflower crop has been observed in the present study. In fact higher germination percentage, VI, plant height and plant dry weight were noted in the treatment receiving effluent irrigation amended with FA + S + GM. This might be due to amendment application, which would have improved the plant growth. Combined use of industrial effluent along with amendments might provide a soil having enough nutrients with better physical and microbiological environment, thus improving the soil productivity. This is in accordance with the findings of Kladivko and Nelson (1979); Reddy *et al.* (1981); Palaniswami (1989) and Pushpavalli (1990) who reported that the application of gypsum along with effluent increased the growth parameters such as germination, shoot length, root length and dry matter production of sugarcane. Application of fly ash and other wastes increased rice grain and straw yield from 33.33 to 56.27 and 33.20 to 57.20 per cent respectively over control. (Ramasubramoniam and Chandrasekaran, 2001)

Veena *et al.* (1992) observed better growth of plants viz., brinjal, onion, sunflower, banana and pulp wood such as *Eucalyptus* when paper mill sludge was applied along with effluent irrigation. Gomathi and Oblisami (1992) also reported the use of pulp mill waste water for irrigation by mixing with water for the crops like neem, pungam and tamarind without any inhibitory effect. Growth was lower in treatment receiving sludge, which might be due to the alkaline pH and particle size distribution, which greatly influenced the physical properties of soil.

Sandana (1995) showed that different organic amendments along with effluent irrigation to tomato revealed considerable increase in biometric characters.

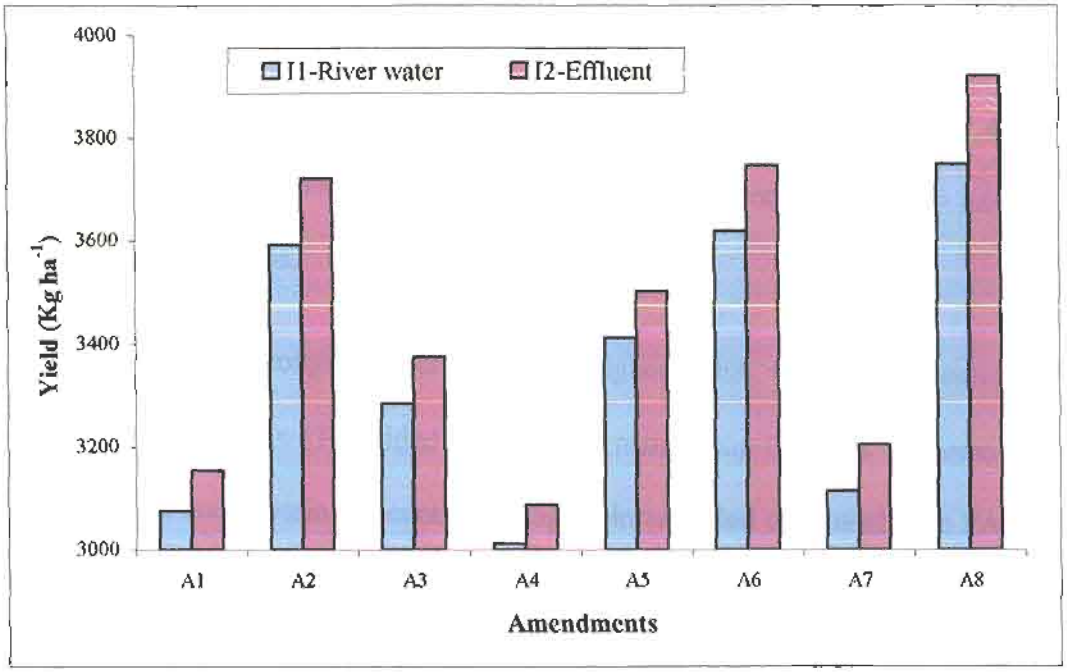
With respect to nutrient content, marked differences were noticed due to influence of treatments. The available NPK was higher in treatments receiving FA + S + GM (T_8) and FA + GM (T_6) and lower values were recorded in control and sludge application. This is in agreement with Pushpavalli (1990) who reported that the sugarcane varieties raised in 15 years effluent irrigated soil receiving NPK with either PM (or) FYM (or) Gypsum as fertilizer and treated effluent as irrigation sources recorded higher values of N, K, crude protein and amino acids. Oblisami and Palanisami (1991) reported that 100 per cent effluent irrigation plus 20 tonnes gypsum ha^{-1} increased the content and uptake of N, P_2O_5 and K_2O and micronutrients.

The yield of maize and sunflower crop was higher in treatment amended with FA + S + GM and FA + GM along with effluent irrigation (Fig.40). This might be due to increased available nutrient contents, which would have led to greater utilization of nutrients by the crops resulting in higher yield. Higher microflora was observed in FA + S + GM and FA + GM receiving treatments. This microflora might have played a role in mobilizing the nutrients by way of solubilization and fixation and also through the growth promoting substances.

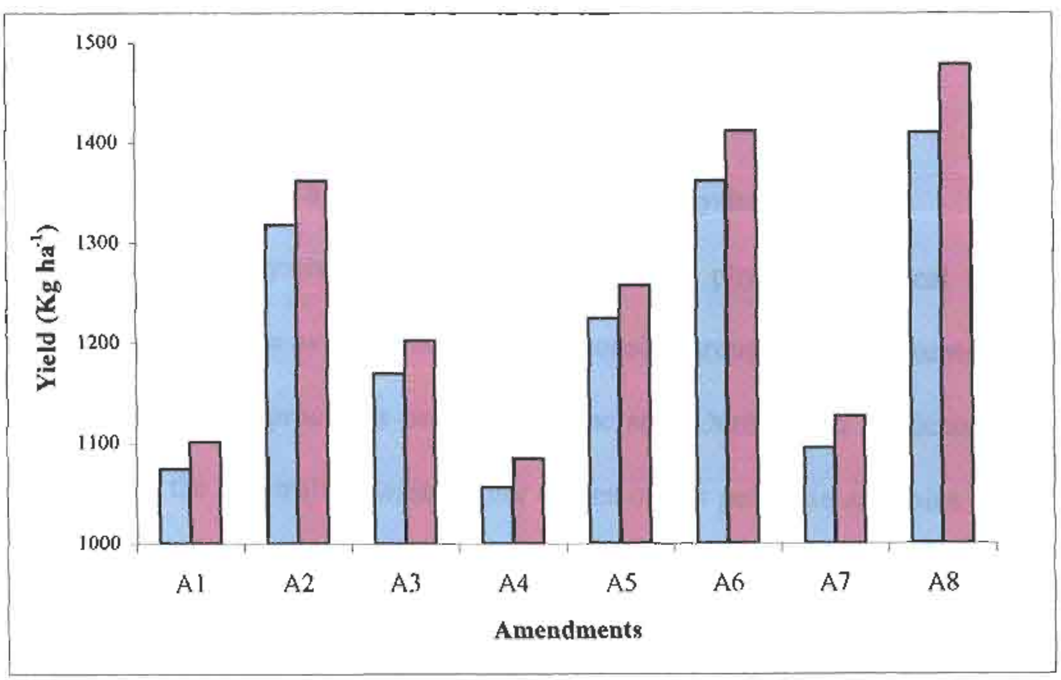
Application of composted paper board mill solid wastes and effluent irrigation positively influenced the pod yield as well as pod formation of cowpea (Prasanthrajan, 2001). The present result is in accordance with the findings of Insam *et al.* (1991) who reported a significant correlation between microbial biomass and soybean yield. Goyal *et al.* (1992) also observed a positive correlation between microbial biomass and grain yield of pearl millet. Reddy *et al.* (1981) observed that the irrigation with effluent is superior to fresh water irrespective of plant characteristics and yield of sugarcane.

Fig.40. Effect of effluent and amendments on yield of maize and sunflower

Maize



Sunflower



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash); A4-S (sludge): A5-FA+S; A6-FA+GM (greenmanure) ; A7-S+GM; A8-FA+S+GM.

Treatment receiving sludge showed lesser yield, which might be due to salts added by the amendment, that might have restricted the root growth by increasing soil osmotic pressure (Feagly *et al.*, 1994). The bulk density of sludge added soils was greater than 1.52 Mg dm^{-3} which is above the critical level (Narashimha Rao and Narashimha Rao, 1992) and this might have affected the root penetration which inturn affected the crop performance.

The protein and carbohydrate per cent were higher in FA + S + GM receiving treatment and lesser in sludge (T_4) added treatment in maize crop (Fig.41). Whereas in oilseed crops, the oil and protein per cent were higher in amended treatment with FA + S + GM. This might be due to increased available nutrient contents of soil, which would have led to greater utilization by the crops resulting in improved grain quality (Fig.42). Mane and Shitole (1989) reported that irrigation with treated effluent from paper factory stimulated the carbohydrate, protein, ascorbic acid and organic acid metabolism of methi (*Trigonella foenum-graceum*).

5.8. Effect of treated effluent and amendments on column Lysimeter

In land application system, the soil matrix provides physical, chemical and biochemical treatments to the waste water simultaneously through various sorptive, degradative and assimilative processes occurring in the soil. During land application, after passing through the soil matrix, waste water comes out as percolate and joins the ground water flow. Ground water being a major source of drinking and irrigation, the percolate should not deteriorate the ground water quality. The resultant effect of the land treatment system depends on the interactions between soil-plant-waste water ecosystem, which can be rapidly ascertained in laboratory using the lysimeter, and the results obtained are discussed hereunder.

Fig.41. Effect of effluent and amendments on carbohydrate and protein per cent of maize.

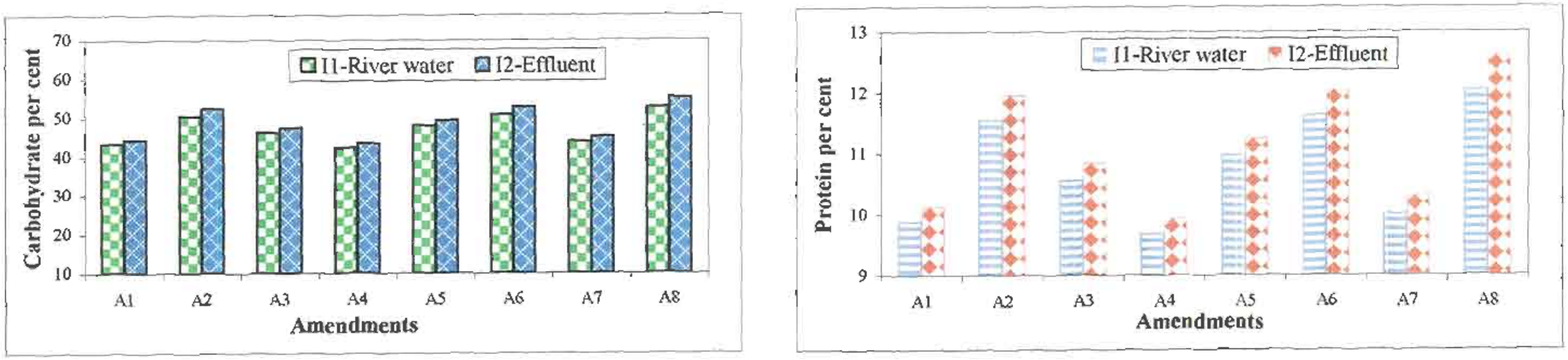
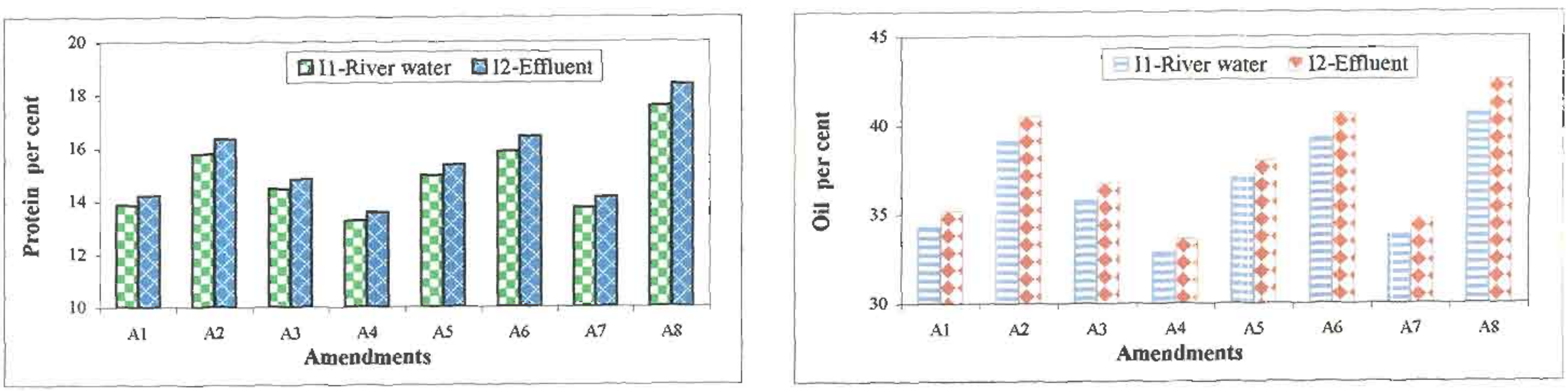


Fig.42. Effect of effluent and amendments on protein and oil per cent of sunflower.



Amendments: A1-Control (without amendment); A2-FYM; A3-FA (fly ash); A4-S (sludge); A5-FA+S; A6-FA+GM (greenmanure); A7-S+GM; A8-FA+S+GM.

The effluent used for the column lysimeter study had the pH of 6.95 and EC of 1.22 dS m^{-1}. The colour of the effluent was creamy white. This might be due to presence of several organic chemicals (Alum, Caustic soda, Polyvinyl chloride and Acetic acid) used in the waste papers converting into paperboard and the colouring pigments present, which is organic in nature (Kannan and Oblisami, 1990; Oblisami and Palanisami, 1991 and Mittar *et al.*, 1992). Considerable quantities of solids are present in the effluent and this might have contributed the build up of organic carbon. Low level of dissolved oxygen present in the effluent might be due to break down of organics in the waste stream.

The very low concentrations of major plant nutrients might be because of the use of chemicals, which do not contain such nutrients (Webb, 1985). The effluent also contained calcium, magnesium, sodium, chloride, sulphate and bicarbonate. The population of bacteria, fungi, and actinomycetes, were rich in effluent and this might be due to the association of microbes along with raw material and natural contamination during the processes.

5.8.1. Effect of treated effluent and amendments on soil from column lysimeter

The pH of the soil was higher in amended soils than effluent alone added soil. The highest pH of 8.53 was recorded in T_5 (FA + S), while in control it was 7.85 in surface soil. The increase in the pH of the soil was as a result of continuous addition of treated effluent. Several workers had the same opinion (Rajannan and Oblisami, 1979; Reddy *et al.*, 1981). There were not much variations in the EC of the soil both in surface and sub-surface soils. The highest EC value was recorded in T_4 (sludge) whereas the lowest was in control. The sub-surface of the soil showed low soil EC compared to the surface soil. This was in accordance with the findings of Somashekar *et al.* (1984); Juwarkar and Subrahmanyam (1987) and Oblisami and Palanisami (1991).

The organic carbon content of the soil showed significant variations and amendment added soil showed more organic carbon than control. The organic carbon content increased in the surface and reduced in the sub-surface of the soil column.

The exchangeable cations increased along with the treated effluent irrigation. This might be due to accumulation of more organics, which inturn retained the cations in soil. Amended soil showed more of cations than unamended soils, which might be due to retention of cations by the organics by the sorptive capacity (Zindahl and Foster, 1976). The exchangeable cations were higher in surface soil than the sub-surface soil due to increase in organic matter content which inturn would bind the cations without going into percolation. There was continuous build up in the content of sodium due to continuous irrigation with treated effluent (Olaniya *et al.*, 1992).

The available nutrient content of the soil showed significant variations and amendment added soil showed more available nutrient than the control. The available nutrients with effluent irrigation increased more in the surface and decreased in the sub-surface soil.

5.8.2. Effect of treated effluent and amendments on soil biological property of column lysimeter

In general, perceptible difference was observed in microbial population along with the treated effluent irrigation. This is in line with the findings of Oblisami and Palanisami (1991) and Dhevagi *et al.*, (2000). Effluent receiving columns showed higher microbial population than the control. This might be due to the addition of organics through the effluents.

The surface soil showed more bacterial population with a peak of 25.07 x 10^6 g^{-1} of dry soil. This might be because of more organic carbon combined with pH less than 8.5, whereas in without effluent (T_0) and control (T_1) soil the population was lesser and this might be due to lesser organic carbon content. In general the sub-surface of the soil column showed lesser population.

Higher population of bacteria, fungi and actinomycetes, was noticed in effluent irrigated columns. The enrichment in the nutrient content of the soil due to effluent irrigation might have enhanced the microbial population. This is in line with the findings of Somashekar *et al.* (1984), Kannan and Oblisami (1990) and Dhevagi (1996). Among the amendments, T_7 (sludge + GM) showed higher population, which might be due to higher pH, EC and organic carbon content. Level of activity and size of the soil microbial biomass is severely 'C' limited (Witter *et al.*, 1993). These might be the reasons for lesser microbial load in without effluent and control soil due to 'C' limitation.

In surface soil, due to higher organic matter content subjected to humification and mineralization makes the soil a storehouse for moisture. Therefore more microbial activity was recorded. The lower fungal population in Bilt-IPCL sludge might be due to alkaline pH because fungi are acid loving (Alexander, 1977).

5.8.3. Effect of treated effluent on leachates from column lysimeter

Leachate characteristics indicated that all the chemical parameter decreased when duration of effluent irrigation increased. As the incubation period increased the leachate total solids reduced drastically and amended columns showed lesser solids. This might be due to the sorption of organics in the soil itself (Subrahmanyam and Juwarkar, 1992). Khan *et al.* (1994) and Dhevagi (1996) also observed the reduction of total solids along with duration of effluent irrigation.

The pH and EC of the leachates increased and this might be due to continuous irrigation. This view is on the line of reports of Olaniya *et al.* (1992) and Dhevagi (1996). The reason for higher organic carbon content in control (T_1) soil leachate might be due to coarse texture of the soil. There was perceptible reduction in BOD and COD in leachates and this might be due to adsorption by organics. Exchangeable cations also showed reduction and this might be due to adsorption of cations by the organics in the soil and leads to reduced availability. Khan *et al.* (1994) obtained 75 per cent reduction of constituents in 154 days.

The present investigation was undertaken to assess the impact of treated effluent from paper board mill when used for irrigation in dry land for the cultivation of maize and sunflower. The treated effluent irrigation resulted in the increase of soil pH, EC, available micronutrients, secondary nutrients, population dynamics of bacteria, fungi, actinomycetes, *Azotobacter, Azospirillum* and *Rhizobium*, soil enzyme activities than river water irrigation and the increase was directly proportional to the period under effluent irrigation. Due to treated effluent irrigation no adverse effect was observed in the present area of operation having sandy loam soil. The leachate showed reduced physico-chemical characteristics.

Systematically laid out trials must be carried out in the fields being continuously irrigated with the effluent for several years to understand the adverse effects if any, with chemical and microbial amendments. Characterisation of the quality of drainage water (leachate) under irrigation in level field and at different elevations in the area of operation must be taken up so as to evaluate the recycling of the paper and board mill waste water. Development of ecofriendly biotechnological techniques must be attempted to convert the sludge into valuable amendment and thereby effective recycling of this solid wastes is also made possible without any adverse effect on soil and ground water quality.

Summary and Conclusion

CHAPTER- V

SUMMARY AND CONCLUSION

There is hardly any industry that does not emit wastes into the environment. T. State-of-Art in recycling the wastes is that it could be recycled for crop production which inturn will solve the problem of disposal. An attempt has been made to utilize the treated effluent and solid wastes from paper and board mill for agriculture in a ecofriendly way as a pollution mitigation strategy.

The salient findings and conclusions that emerged out of the study are summarized below:

a. Effluent characteristics

- The treated effluent from paper board mill (Bilt-IPCL) was creamy white in colour with alkaline pH having an EC of 1.18 to 1.25 dS m^{-1}. The effluent had moderate quantity of organic carbon and dissolved oxygen content. It had considerable amount of total and dissolved solids with a BOD range of 10.6 to 14.5 mg L^{-1} that was well within the limits of pollution control regulations (30 mg L^{-1}). It had the COD of 78 to 128 mg L^{-1}.
- The treated effluent had a good amount of calcium, magnesium, ammoniacal nitrogen, sulphate, bicarbonate and polyphenols with higher level of sodium (397 mg L^{-1}), chloride (319 mg L^{-1}) and low level of N and P.
- Considerable load of bacteria, fungi and actinomycetes were recorded in the treated effluent. During summer season, the bacterial population was low (48-60 x 10^6 ml^{-1}), followed by fungal population (4-8 x 10^4 ml^{-1}).

b. Impact analysis

- The pH, EC, OC, available nutrients (NPK), exchangeable cations (Ca, Mg, Na, K), ESP, SAR and CEC were high in effluent irrigated soils in and around the factory regions compared to the Bhavani river water irrigated soils. The above soil properties increased due to continuous effluent irrigation at periodical intervals of analysis. The microbial population also increased considerably due to continuous effluent irrigation.

- Observation wells in and around the factory region irrigated by paper board mill effluent had high pH than that of Bhavani river water. The EC, total hardness, carbonates, bicarbonates, chloride, sulphates, sodium, calcium, magnesium and potassium were high in the effluent irrigated area. The sodium per cent was below 30 and the potential salinity was lesser than 6 cmol L^{-1}. The SAR was below 2 and the RSC values were almost negative. The over all rating of most of the ground water tested in and around the factory area fall under C_1S_1 category as per the USDA classification of 1954 and it is suggested that the ground water could be used for agricultural purposes.

c. Bioassay

- Bioassay experiment showed that the survival per cent of fingerlings was increased in *Cyprinus rogu* with increasing concentrations of treated effluent and decreased in *Catla catla. Mrigal* was found very sensitive to treated effluent.

d. Effluent on germination and seedling vigour

- Better germination percentage, shoot length, root length and vigour index of seedlings were observed at 25, 50 and 75 per cent of treated effluent concentrations which are comparable with that of control in field crops *viz.*, maize, sunflower, groundnut, blackgram, greengram and soybean; whereas in rice, the above parameters were reduced as the treated effluent concentration increased.

- The germination per cent, root length, shoot length and VI of vegetables were better in treated effluent as compared to raw effluent. As the proportion of water for diluting the effluent increased the performance of seedlings was better.

e. Solid wastes on soil and productivity of tree saplings

- Better shoot length, root length, dry matter production, collar diameter, VI and volume index were observed in tree seedlings under FYM + fly ash irrigated with effluent. The seedlings completely withered incase of *A. auriculiformis* due to sludge application. It is clearly inferred that non-leguminous tree seedlings withstand and grow better under treated effluent and solid wastes as amendments.
- Continuous effluent irrigation increased the soil pH and EC at all stages of crop growth irrespective of amendment addition. The soil pH was maximum under sludge + fly ash followed by sludge and fly ash and the least was under FYM. The increase in soil EC was much higher under sludge + fly ash than rest of the amendments.
- There was a gradual increase in the OC content of soil irrigated with effluent irrespective of the amendments while the same decreased with river water irrigation. Among the treatment combinations, FYM + sludge with effluent irrigation recorded higher values followed by sludge than FYM with effluent.
- The soil available N, P and K contents decreased due to river water irrigation irrespective of amendments at later stages of seedling growth. Among the amendments, FYM + sludge which was comparable with FYM + fly ash recorded higher available N and rest of the amendments were inferior to the above two. FYM + fly ash recorded higher available P and K followed by fly

ash + sludge. This revealed that fly ash and sludge could safely be used as an effective amendment in place of FYM along with effluent irrigation.

- ❖ Continuous irrigation with effluent added considerable quantity of cations *viz.*, Ca, Mg and Na than with well water irrespective of the amendments. Among the amendments fly ash + sludge recorded the highest exchangeable Ca and Na followed by sludge, whereas FYM + sludge recorded the highest exchangeable Mg followed by sludge.
- ❖ The microflora was higher in effluent irrigated soils combined with sludge, which was comparable to FYM + sludge with effluent irrigation while the rest of the treatment combinations were inferior to them.
- ❖ The performance of the nursery seedlings was better under effluent irrigation amended with FYM+FA compared to either fly ash or sludge alone with effluent irrigation. Therefore solid wastes combined with FYM could safely be used as nursery mix.

f. Effluent irrigation with amendments on crop productivity and soil fertility

- ❖ Field trial with treated effluent irrigation along with different organic amendments showed that there were perceptible changes in bulk density, pH, EC and organic matter content of the soil. Slight increase in pH, EC and organic matter content were observed in treatments received treated effluent irrigation along with amendments when compared with river water irrigation.
- ❖ The available NPK, exchangeable cations viz., Ca, Mg, Na, K and DTPA micronutrients were influenced by the treated effluent irrigation along with amendments with best performance being recorded by FA + S + GM (T_8) followed by FA + GM (T_6). River water irrigation along with amendments

showed lesser available NPK, exchangeable cations and DTPA micronutrients than the treated effluent irrigation.

- Perceptible differences were exhibited between microflora of maize and sunflower by the treatments received treated effluent along with amendments. In treated effluent the population of bacteria, *Azotobacter*, *Azospirillum* and *Rhizobium* was higher in FA + S + GM received treatments, while actinomycetes and fungal population were higher in FYM with effluent irrigation.
- The soil enzymes *viz.*, amylase, invertase and cellulase activities were higher in effluent irrigation than the river water irrigation.
- The germination percentage and VI increased in treated effluent irrigated plots when compared with river water irrigated plots with best performance by FA + S + GM followed by FA + GM.
- Better plant height and plant dry weight of the crops were observed in treated effluent irrigated plots which are comparable with that of river water irrigated plots in treatment FA + S + GM in all the crops.
- FA + S + GM along with treated effluent irrigation showed higher yield than the river water irrigation followed by FA + GM with effluent irrigation.
- The crop quality parameter viz., carbohydrate and protein content in maize, and oil and protein content in sunflower were increased under effluent irrigation along with amendment received treatments, with best performance by the FA + S + GM with effluent.

g. Column lysimeter investigation

- Column lysimeter study carried out with treated effluent revealed that the pH and EC were considerably increased in surface soil and decreased in sub-surface soil compared to without effluent irrigation.
- The exchangeable calcium and magnesium contents were higher in surface soil under effluent irrigation compared to sub-surface soil. The exchangeable sodium level increased from surface soil to sub-surface soil.
- In the soil column study, the available major nutrients were higher in surface soil along with treated effluent irrigation amended with FA + S + GM followed by the FA + GM amendment.
- The microbial load was more in the surface soil along with the treated effluent amended with S + GM whereas the fungal population was observed more in the sludge alone applied treatment.
- The total solids, pH, EC and organic carbon content of the leachate at 60 DAI were much reduced due to amendment addition compared to without amendment.
- The pollution load in terms of BOD and COD were minimal in leachates and within the limits of pollution control regulations.

The paper and board mill treated effluent could safely be used for irrigation along with appropriate amendments especially with FA + S + GM or FA + GM. The treated effluent irrigation did not cause any adverse effects on population dynamics of bacteria, actinomycetes, fungi, *Azotobacter, Azospirillum* and *Rhizobium* and these organisms play a significant role in the mineralization of the nutrients as well as in nitrogen fixation under stress conditions of treated effluent irrigation. The soil, ground water and crop quality parameters were also not affected due to treated effluent irrigation in and around the factory area during the period of investigation. However long term investigation is essential. Surface soil recorded more changes than the sub-surface soil and the leachate had lesser pH, EC and exchangeable cations.

Hence under conditions of adequate drainage, the treated effluent irrigation could be successfully practiced along with appropriate combination of FA+S+GM and the changes on soil and ground water quality parameters should be monitored continuously by the Scientists which is very much essential for timely diagnosis and to suggest suitable remedial measures to overcome adverse effects if any on soil, ground water quality and crop produces due to continuous treated paper board mill (Bilt-IPCL) effluent irrigation with around the factory area.

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* Originals not seen

Plates

Plate.1. Panoramic view of paper board mill factory

Plate.2.Treated paper board mill effluent irrigation

Plate.3. Bio-Assay studies with fingerlings of *Catla catla*

Plate.4. Bio-Assay studies with fingerlings of *Cyprinus rogu*

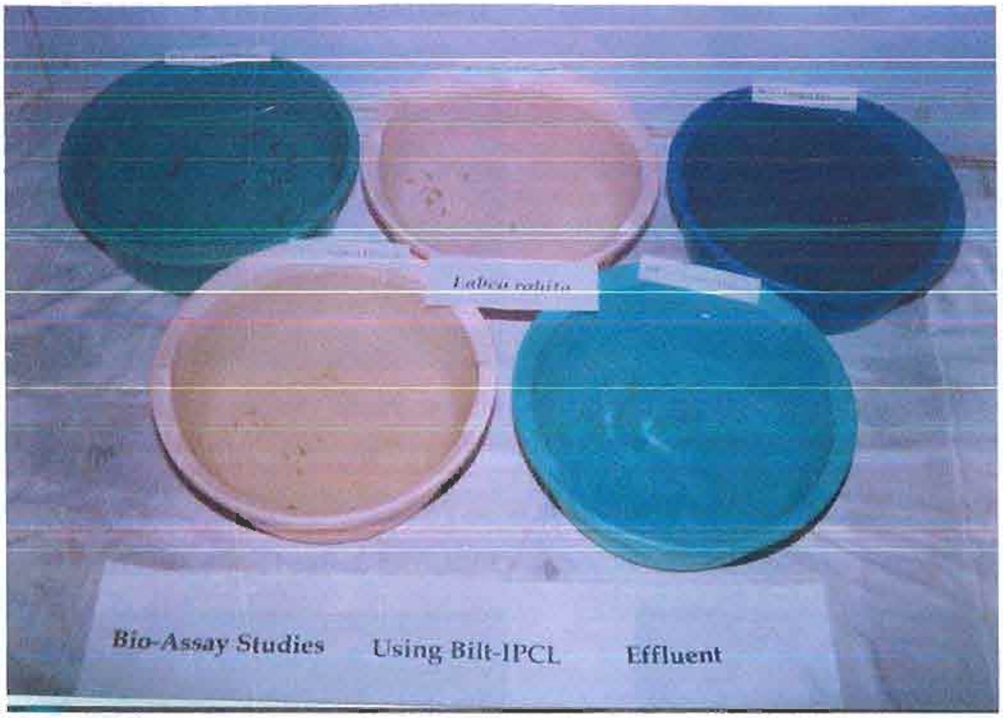
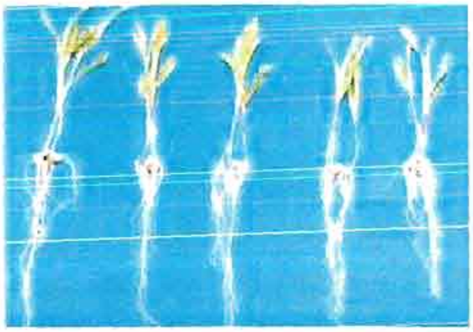


Plate.5. Treated and raw effluent on germination and growth of field crops seedlings

Maize – Treated Effluent



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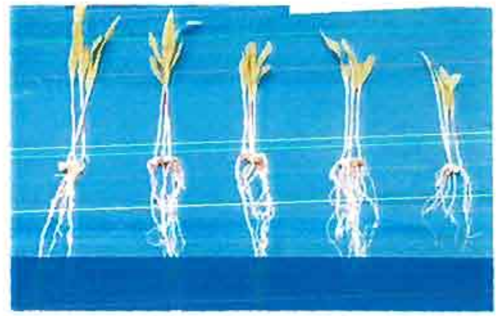
Maize – Raw Effluent



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Sunflower – Treated Effluent

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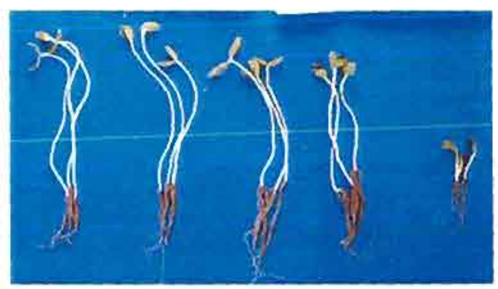
Sunflower – Raw Effluent



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Groundnut – Treated ffluent

0% EFF 25%EFF 50% EFF 75%EFF 100%EFF

Groundnut – Raw Effluent

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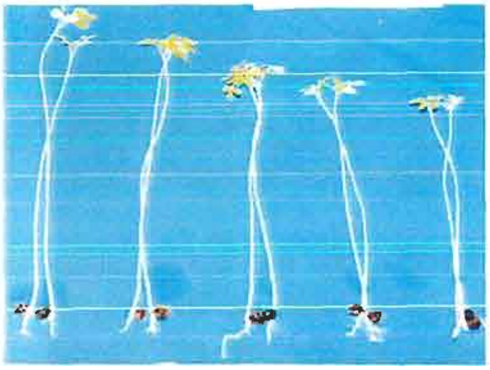
Plate.6. Treated and raw effluent on germination and growth of vegetable seedlings

Moringa – Treated Effluent



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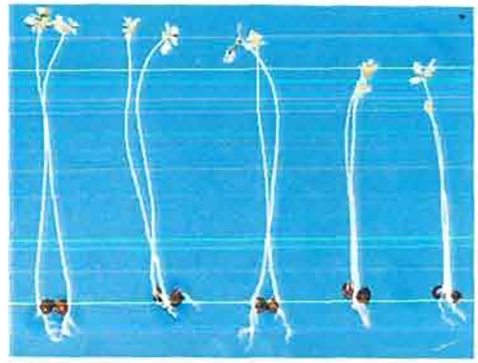
Moringa – Raw Effluent



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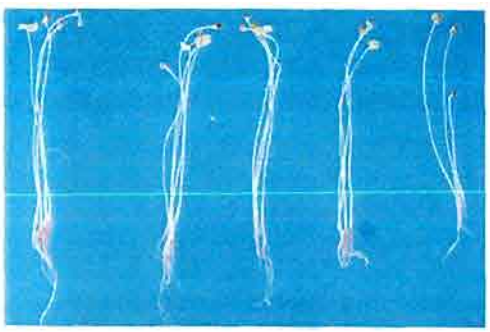
Bhendi – Treated Effluent



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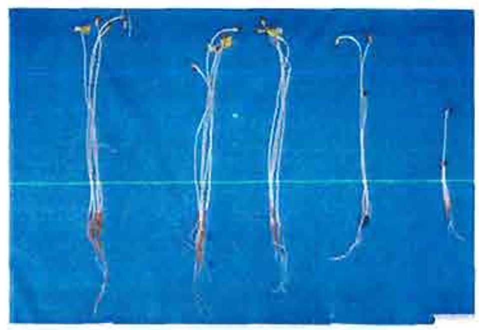
Bhendi – Raw Effluent



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Bittergourd – Treated Effluent

0% EFF 25%EFF 50% EFF 75%EFF 100%EFF

Bittergourd – Raw Effluent

0% EFF 25%EFF 50% EFF 75%EFF 100%EFF

Plate.7. Effluent and solid wastes on nursery tree saplings

Acacia auriculiformis

Azadirachta indica

Eucalyptus tereticornis

Plate.8.General view of Nursery Experiment

Plate.9.General view of Field Experiment

Plate.10.Field Experiment with Maize (CO-1)

Plate.11.Field Experiment with Sunflower (CO-4)

Plate.12. TNAU Officials' visit to experimental sites at Bilt-IPCL

Plate.13. Discussion with General Manager (Technical)