Accumulation and Movement of Available Phosphorus in Sewage Treated Delhi Soil
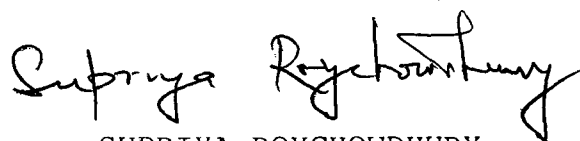
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1986

A MAN WOULD DO NOTHING,

IF HE WAITED UNTIL HE

COULD DO IT SO WELL THAT

NO ONE WOULD FIND FAULT
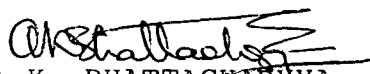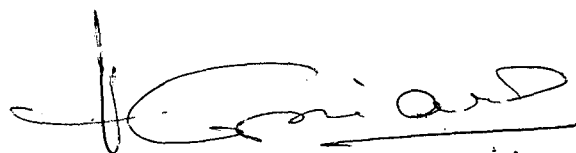
WITH WHAT HE HAS DONE.

CARDINAL NEWMAN

CERTIFICATE

This dissertation entitled "Accumulation and Movement of Available Phosphorus in Sewage Treated Delhi Soil" has been carried out at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. The work is original and has not been submitted in part or full for any other degree or diploma of any University.

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SUPRIYA ROYCHOWDHURY

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
Bray P_1	Bray and Kurtz No. 1 extractant
cm	Centimeter
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
gm	Gram
meq	Milli-equivalents
mg/l	Milligrams per litre
M.G.D.	Million gallons per day
ml	Millilitre
ppm	Parts per million

INTRODUCTION

Rapid industrial development, urbanisation and increasing population have simultaneously led to the phenomenal increase in the volume of wastewaters from the industrial as well as the domestic front. Large number of cities are being sewered causing enormous volumes of wastewater loading at a common point and this makes the problem of disposal and treatment more difficult. Rivers, lakes, streams and other water bodies were more or less capable of accommodating wastewaters a couple of decades ago and also restoring the water quality by the natural processes of dilution and dispersion. However, at present the quality and quantity of wastewaters are far beyond their assimilatory capacity.

The public have become increasingly aware of one of the major consequences of industrial development — the quantity and diversity of hazardous waste it generates. At the same time awareness has been growing that certain disposal methods used for wastewater may pose a risk to the human health and the quality of the environment.

Water is probably the most important natural resource in the world. Since without it, life cannot exist and industry cannot operate. There is a growing understanding throughout the world regarding the urgent need to conserve, recycle and reuse our limited water resources.

The science, technology and practice of water renovation and reuse have gone through a number of phases in the past one hundred years. The initial phase was motivated by two different thrusts, one based on the conservationists' concept that society's wastes should be conserved and utilised to preserve the fertility of the soil, while the other more pragmatic approach was directed towards eliminating river pollution.

Victor Hugo in his "Les Miserable" published in 1868, has eloquently deplored the dumping of the sewage of Paris into the river, running wastefully into the sea, "All the human and animal manure which the world loses, if returned to the land instead of being thrown into the sea would suffice to nourish the world."

In the second phase which continues even to this day, the driving force has been the need to conserve and reuse water in arid areas. Efforts were first made of wastewater reuse for agricultural development in the water scarce areas of California, Texas, Mexico, South Africa, Israel and India. In Israel, wastewater reuse became a declared national policy in 1955.

At present due to the ever increasing demands for more water sewage farming practices are rapidly spreading to many parts of the world which are not normally considered to be arid land. The third phase overlaps the second

and is based once again on the urgent need to reduce river and lake pollution. In areas in which expensive high levels of advanced waste treatment are required to protect waters, planners redeem it would be more logical to reuse it directly rather than dump it back to the river (Shuval, 1977).

The problem of sewage disposal is more acute in developing countries specially those with a large size population. Direct reuse of municipal wastewater for irrigation purposes is extensively practised in India. The warm humid climate and the negligible flow in most of the streams during the summer months makes irrigation the favoured mode of disposal of wastewaters. (Arceivala, 1977).

In India sewage farming started in 1895. Since then it is being practised in different modes using raw sewage, dilute sewage and also partially treated sewage.

Okhla Sewage Treatment Plant

In Delhi there are three sewage treatment plants at Okhla, Keshopur and Coronation Pillar of which the Okhla plant is the major wastewater treatment plant. Okhla treatment plant is in operation since 1936 and to-date it has undergone development in five stages. The present capacity of the plant is 88 M.G.D. However, it can withstand an overload of 25%.

Contaminants of domestic sewage may be categorised as : (1) Disease causing microorganisms (2) Dissolved minerals (3) Toxic chemicals (heavy metals, pesticide residues etc.) and (4) Biodegradable organic matter.

Even after the wastewater undergoes the purification process it may not be free from undesirable constituents. In terms of a land oriented wastewater disposal practice, any one category of the contaminants mentioned above may limit the soil's ability to receive the wastewater.

Since the advent of community wastewater treatment system the attention of sewage farming has been focussed on pathogenic organisms. Pathogens are subject to adverse environmental conditions once they are introduced into the soil system. They are not expected to survive for extended periods of time or multiply. However, when pathogenic organisms are undergoing decay processes the risk to the soil contamination diminishes (Page and Chang, 1981).

At high concentrations, all trace metals regardless whether they are essential or nonessential become toxic to animals and man. Unlike pathogens whose transmission relies entirely on direct contact, trace metal elements from the soil could be translocated to plant tissues through absorption. Immediate toxicity may not occur but excessive accumulation of certain metals like cadmium,

molybdenum, selenium etc. could be potentially hazardous. Long term applications of wastewater may cause a gradual build up of trace metals in the soil to levels that are phytotoxic (Lee, 1976; Page and Chang, 1981).

Studies have shown that the main problem caused by irrigating soils with secondary effluents is excessive leaching of nitrate to the groundwater in addition to the surface runoff carrying phosphorus and nitrogen compounds (Sopper, 1976). Other recent studies have shown that irrigation with domestic wastewater containing industrial wastes does not generally increase the concentration of heavy metals in the lower depth of the soil, as they get accumulated on the surface layer (Alcozar, 1981).

Inspite of the potential hazards from land application of domestic sewage, it still remains the most favoured mode of wastewater disposal due to its manifold advantages. The reclamation and reuse of municipal effluents have gained considerable popularity and momentum in the last decade primarily because of the following factors.

1. The need for more water is apparent. Shortages whether drought induced or as a result of growth have created higher demands. Reclaimed effluents can satisfy some of the demands.

2. Water pollution control regulations mandate expenditure for sewage treatment. Ironically, waste-water must be treated almost as extensively for disposal as for reuse. Treatment costs must be paid whether the water is reused or not and economics, in many cases, favours the recycling option.

3. The water is simply too valuable to use just once and then throw away.

4. Legislative directions have asked for more water conservation and wise use of resources.

5. Nutrient recycling offers increased agricultural productivity.

6. Escalating energy costs and environmental consi-derations often point to reuse as the most viable metho-dology.

7. Exploitation of the nutrients in wastewaters which would otherwise cause undesirable efects viz. eutrophication in the downstream (Heaton, 1981).

The present investigation was undertaken to assess the characteristics of raw sewage, primary treated sewage and secondary treated effluents from Okhla sewage treat-ment plant from the point of view of their suitability for irrigation as well as to evaluate the potentiality of plant nutrient availability.

A laboratory experiment under controlled conditions was set up to study the effects of these effluents on the accumulation and movement of phosphorus in the soil column at regular intervals for a period of two months. The detailed results of this experiment have been incorporated in this dissertation.

REVIEW OF LITERATURE

Phosphorus as a nutrient and its significance

Next to nitrogen the most critical element influencing plant growth and production is phosphorus. Its low content in the soil coupled with its capacity to be immobilized (fixed) makes the element doubly critical.

Phosphorus in seeds is stored mainly as phytin, the calcium-magnesium salt of inositol hexaphosphoric acid. This compound is hydrolysed enzymatically during germination and the inorganic phosphate released thereby is used by the developing seedling. Phospholipids which act as storage material in seeds and in growing plants are involved in metabolism. They play an important part in selective permeability and ion transport. Like nitrogen, phosphorus is a constituent of every living cell (nucleotides).

In plant metabolism phosphorus plays a direct role as a carrier of energy. Phosphates in several organic linkages split off by hydrolysis releasing energy. The most important carrier of higher energy phosphate is adenosine triphosphate (Black, 1973).

Phosphorus and root development

Phosphorus is sometimes said to stimulate root growth, the implication being that phosphorus has some special efects on the growth of roots. It has been observed that phosphorus uptake is influenced by root

morphology (Schenk, et al., 1979). As expected phosphorus starved plants tend to have a stunted root system (Barber, 1984).

Effect on growth, colour, quality and composition

Phosphorus hastens the ripening process of plants. It promotes seed formation and maturity of crops. Phosphorus favours pollination which affects quality in corn. It strenghthens and improves the quality of plants by stimulating the production of a more vigorous plant growth thus making it more disease resistant.

Deficiency symptoms

If phosphorus is deficient, cell division in plants is retarded and growth is stunted. Plants develop a dark green or bluish green colour which may be coupled with tints of bronze or purple. Phosphorus deficiency produces certain effects that are similar to the effects of nitrogen deficiency (Black, 1973).

Distribution of phosphorus in soil

Both organic and inorganic forms of phosphorus occur in soil and their relative amounts vary considerably. More than half the portion of total phosphorus is in organic form, especially on the surface of the soil. Of the organic phosphorus compounds identified so far inositol phosphates forms the major part, to a lesser

degree nucleic acids and phospholipids also occur in soil(Barber, 1984).

Inorganic compounds occur almost exclusively as orthophosphates and may be grouped as (a) compounds containing calcium phosphates and (b) those containing aluminium and iron phosphates.

Effect of pH on phosphate ions

The ionic form of phosphorus is dependent on pH and presence of other cations (Fe^{+++}, Al^{+++}, Ca^{+++}). In acidic solution $H_2PO_4^-$ ion dominates but as the pH is raised, first HPO_4^{--} ion and finally PO_4^{---} ion is released under highly alkaline condition. It has been observed that these ions are further controlled by the presence of iron and aluminium compounds in acid soils and calcium compounds in alkaline soils. At pH 7.0 both $H_2PO_4^-$ and HPO_4^{--} ions are found (Russel, 1975; Brady, 1984).

Pathways of phosphorus transformation in soil

Natural source of soil phosphorus is parent material (rock phosphate); most parent materials contain mainly calcium phosphate which undergoes hydrolysis during soil development to supply phosphorus to the soil solution. This soluble phosphorus may be adsorbed to mineral surfaces, precipitated with various cations, or be incorporated into the biomass and soil organic matter.

During the weathering of soils, bases and silica are lost, aluminium and iron oxyhydroxides are generated allowing the formation of secondary aluminium or iron phosphates (Hsu, 1977). In unfertilised soil, low solubilities of natural phosphates and minimal environmental inputs into the soil results in a very stable total phosphorus balance during transformations. The relative abundance of primary, calcium bound, and secondary inorganic phosphates and of organic phosphorus can be used to follow weathering processes in soils (Smeck, 1973; Walker and Syers, 1976).

Available phosphorus depends on the amounts of different forms of phosphorus present in the soils. Apatites are quite insoluble at an elevated pH, but become increasingly mobilised as hydrolytic reactions proceed, pH falls and base saturation is reduced. Organic matter production is frequently limited by phosphorus availability and solubilisation of primary inorganic phosphorus is accompanied by organic matter and organic phosphorus accumulation (Walker and Syers, 1976).

Formation of less crystalline secondary inorganic phosphorus maintains labile plant available phosphorus in soils of intermediate weathering state (Murrman and Peech, 1969; Mattingly, 1975) until low pH and high aluminium or iron activity causes the formation of sparingly soluble, crystalline or occluded aluminium and

iron phosphates. In such soils available phosphorus is low and is dependent on the mineralisation of organic phosphorus.

Organic phosphorus

Organic phosphorus is of great significance as a potential source or sink of plant available phosphorus. It must be mineralised to inorganic phosphorus in order to contribute to the available pool.

Drying, particularly at high temperatures and for long periods, stimulates mineralisation of organic matter and inorganic phosphorus (Enwezor, 1967). On the basis of this in areas of the tropics having distinct wet and dry seasons rapid mineralisation of organic phosphorus should be favoured. Phosphorus studies conducted on tropical and sub-tropical soils showed significant' corre-lations between organic phosphorus and phosphorus uptake (Somani et al., 1971).

Organic phosphorus mineralises at approximately the same rate as soil organic matter. Numerous studies have shown that increase in inorganic phosphorus fractions are associated with mineralisation of organic phosphorus; specially temperature above $30^{\circ}C$ and high pH favours the transformation (Enwezor, 1967).

Studies made by Adepetu and Corey (1976) show that organic matter and organic phosphorus are highly corre-

lated with mineralised phosphorus, as is total phosphorus of which organic phosphorus is the dominant component. Mineralised phosphorus not absorbed by plants resulted in the increased levels of inorganic phosphorus. Thus phosphorus mineralised from organic source is by far the most important factor in determining phosphorus availability.

Importance of organic matter in the cycling of soil phosphorus is well recognised and several research workers have fractionated soil organic phosphorus and suggested that labile organic phosphorus (Hedley et al., 1982), soluble organic phosphorus (Dalal, 1979) and inositol monophosphate make significant contributions to plant nutrition.

Seasonal variations and its effect on organic phosphorus

During a two year sampling period organic phosphorus content of surface soils was found to be lower in summer than in winter months. No consistent seasonal variations in inorganic, organic and available phosphorus were shown in sub surface soils. Smaller fluctuations of soil temperature and moisture, low microbial activity could be the possible reasons for this.

The changes in organic phosphorus content resulted from variations in moderately labile organic phosphorus, while the amount of organic phosphorus in more labile

and resistant pools remained fairly constant, this pool could be the result of dynamic equilibrium between mineralisation and replenishment from moderately labile organic phosphorus. This equilibrium is controlled by available phosphorus content (Sharpley, 1985). If available phosphorus content falls below a certain level for a given soil, labile organic phosphorus gets mineralized to supply the same. The labile organic pool is then replenished rapidly by moderately labile organic phosphorus (Abbot, 1978; Dalal, 1979).

Rates of the above transformations will be a function of soil moisture, temperature and possibly pool sizes. No distinct boundaries exist between the organic pools. Available phosphorus and organic phosphorus were related to the phosphatase enzyme activity of the surface soil. Increase of phosphatase enzyme activity increases the potential for organic phosphorus mineralisation and subsequent rise in available phosphorus production. The enzyme activity, however, is a function of organic phosphorus content, soil temperature, moisture and available phosphorus content (Sharpley, 1985).

Reactions of applied phosphorus in soils

Phosphate reactions in soils have important implications for crop growth, fertiliser efficiency and environmental pollution. Type of reaction depends on

the nature of soil.

Inorganic phosophates in soils have been classified into calcium, iron, and aluminium phosphate. In addition to this there are reductant soluble phosphates. Phosphorus in adsorbed and/or mineral form is often coated (occluded) with relatively insoluble oxides and hydroxides of iron and aluminium. The occluded phosphorus is called reductant soluble phosphate, because strong reducing agents are required to dissolve the coating of occluded phosphorus. These phosphate fractions occur in all types of soils but in different proportions according to soil characteristics.

The rapid removal of added soluble phosphorus from soil is commonly observed. Over a five year period phosphorus was transformed from initially available to metastable state to stable, relatively insoluble form in calcareous soil (Hooker, et al., 1980).

Other laboratory incubation studies, dealt with the slow reactions (in attaining equilibrium after phosphorus fertilization) of some calcareous soils from South California (Ibrahim and Pratt, 1982) and acid tropical soils (Munns and Fox, 1976). The reversion rate is influenced by duration of soil phosphorus contact, soil temperature, soil moisture and manner of incubation (Barrow, 1974a; Barrow and Shaw, 1975).

The actual mechanism of soil phosphorus reaction under prolonged contact with each other are still not clear. Views include migration of adsorbed phosphate ions from original sites, occlusion of phosphorus on these sites, or slow crystal formation (Barrow, 1974b). The role of soil properties in relation to the slow reaction is similarly unclear. No relationship with pH, Fe_2O_3, $CaCO_3$, organic carbon or textural characteristics was apparent in the study made by Ibrahim and Pratt (1982).

Phosphorus fertilization of calcareous soils results in progressively less soluble calcium phosphate. However such compounds may not dominate in the presence of other phosphorus reactive constituents such as iron oxides. Recently Ryan and co-workers (1985) have shown that sorption was related to iron oxides, especially the amorphous forms, rather than to solid phase $CaCO_3$ in calcareous soils.

Free iron oxides have an important influence in the reversion of soluble phosphorus to the less soluble form. The dominant effect of iron oxides in the initial phosphorus retention phase is due to adsorption/precipitation on amorphous surfaces while the gradual decrease with time of soil phosphorus contact is consistent with progressive crystallisation of the iron phosphate forms (Ryan et al., 1985). This is of particular relevance

to soils of arid and semi arid regions which usually contain considerable amounts of iron oxides along with soild phase $CaCo_3$.

Phosphorus sorption by soils

Phosphorus sorption occurs by surface adsorption or by precipitation when a soluble phosphorus compound is added to soils. The degree of sorption is affected by environmental factors, soil components and properties, as well as the amount of phosphorus added.

The mechanism of phosphorus adsorption on soil and homogenous soil mineral surfaces is not clearly defined. Sorption is rapid initially but slows down with the passage of time. The initial fast reaction is considered to represent true phosphorus adsorption on mineral surfaces (Munns and Fox, 1976).

The slow process of sorption at the second stage may be due to the penetration and absorption into porous solids exposing sites which adsorb more phosphorus. In soils having high concentration of soluble phosphorus for a long period, the capacity of porous solids to absorb would likely be saturated. (Ibrahim and Pratt, 1982).

Effect of magnesium on phosphate adsorption

The ability of $CaCO_3$ to adsorb phosphate has been

established (Mattingly, 1975). Magnesium ion is known to increase the solubility of $CaCo_3$ and it can alter the formation of calcium phosphate precipitate and apatite formation. This probably occurs through the substitution of Mg^{++} for Ca^{++} in the calcium phosphate and apatite precipitate, leading to the disruption of the mineral crystal lattice by the highly hydrated magnesium ions. Adding 1 to 2 ppm of Mg^{++} reduced phosphorus adsorption by $CaCo_3$ (Kuo and Mikkelsen, 1979).

Soil amendment with sewage and environmental implications

Reuse of wastewater on land provides one of the best means of sewage disposal. The advantages in the use of treated wastewater for irrigation are

a) low-cost source of water,

b) an economical way to dispose of wastewater,
    to prevent water pollution and sanitary problems,

c) an effective use of the plant nutrients contained in wastewater, and

d) providing additional treatment before being recharged to ground water reservoir.

Sewage farming is practised in many parts of the world. Nutrients like N,K and P are present in fairly high concentrations and can be utilised for plant growth and production in nutrient deficient soils.

Direct reuse of municipal and industrial wastewater for irrigation is extensively practised in India. The warm climate, practically negligible flow in most of the streams during the summer months and the need to grow more food for the over size population make irrigation the favoured mode of disposal of wastewaters (Arceivala,1977).

Land application of liquid wastes has recently gained increasing attention as a viable alternative to tertiary treatment. The fate of wastewater materials in soils is determined by a large number of processes which include physical retention, adsorption on soil surfaces, plant and microbial uptake, microbial degradation, volatilisation, leaching, chemical breakdown and precipitation.

Phosphorus as orthophosphate reacts with practically all type of soils with an almost quantitative removal from the solution (Sommers et al., 1979). Thus it prevents leaching of phosphorus into the ground water. This is not surprising as soils have very reactive surfaces containing iron, aluminium and calcium all of which form insoluble phosphates. Acidic conditions favour ferric and aluminium phosphate formation and alkaline conditions favour calcium phosphate retention (Hooker et al., 1980).

Retention of organic phosphorus compounds at colloidal surfaces may also take place and alter the chemical and biochemical stability (Iskander and Syers, 1980). Phosphorus retention by aluminium and iron apparently involves both precipitation and adsorption.

Phosphorus removal increases with the amount of clay content in the soil and as a rule phosphorus (Bray P_1) is efficiently removed in the upper zone (0-15cm) of the soil surface (Sommers et al., 1979; Latterell et al., 1982). Instant increase in phosphorus levels in the surface (0-15cm) soil layer of land receiving effluents has also been reported (Kardos and Hook, 1976; Iskander and Syers, 1980).

The biosystem of soil, organic crop residues and growing crops can effectively renovate municipal waste-water effluent. In contrast to the situation which operates with fertiliser application, land application of water invariably involves the application of phosphorus far in excess of crop removal. Since a high proportion of the phosphorus in municipal wastewater is present in available form it is unlikely that phosphorus will be a limiting factor for plant growth on wastewater land disposal sites (Iskandar and Syers, 1980).

Soils can adsorb much more phosphorus from wastewater than indicated from sorption capacities (Sawhney

and Hill, 1975). Phosphorus adsorption was found to be higher in flooded rice than irrigated pasture top soil (Kuo and Mikkelsen, 1979). These authors attributed the higher adsorption in the surface (0-15cm) soil layer to a higher amorphous iron content.

There is general agreement that the mechanism of phosphate removal involves adsorption on the soil surface and precipitation. Adsorption is rapid and the precipitation is a slow process. Under condition of irrigation with large quantities of wastewater, the system would never be in a state of equilibrium (Latterell et al., 1982).

In a field study with corn and a single dried sludge application, levels of available phosphorus (Bray P_1) in sludge treatments were two to five times greater than unamended controls at the end of two years (Epstein et al., 1976). Milne and Graveland (1972) found that available phosphorus in sludge amended soils increased after two weeks incubation under laboratory conditions but then decreased after four weeks in some of their soil samples. This decrease was attributed to phosphate fixation in soil.

Pollution effects of phosphorus

Phosphorus compounds exhibit a comparatively low

mobility in soil. Accordingly, chances that excess phosphate in comparison to the amount used for crop production, reaches the ground water in deeper layers is usually small. So soil acts as an excellent filter for phosphates, exhibiting high retention capacity. Cases of malfunctioning of soil, in its role as a medium supporting plant growth and other forms of life due to excess of phosphorus are hardly known. However, it has occasionally been inferred that excess of phosphorus in soil impaires plant growth via indirect action. For example zinc-deficiency symptoms could possibly be traced to high levels of phosphorus in a number of cases (Lone-ragan et al., 1979).

Eutrophication

Excess of phosphorus on the soil surfaces might lead to the undesirable concentration of phosphorus in the drainage water from the soil profile, resulting in eutrophication of water bodies. Eutrophication or over-fertilisation of surface waters which leads to excessive growth of nuisance algae and aquatic weeds (Algal blooms) remains one of the major environmental concerns (Browman et al., 1979). The flora and fauna of the aquatic system is badly affected and the water after sometime becomes virtually useless.

Eutrophication is a slow process in nature but it

can be accelerated to a great degree by human activities. The essential requirements for this phenomenon to occur are the presence of nutrients; carbon, nitrogen and phosphorus. Phosphorus which is required in very small amounts is the limiting nutrient for the process (Dugan, 1972).

The situation is more complicated because once eutrophication sets in, the process does not stop even after the inflow of nutrients from agricultural and urban run off etc. are checked. Due to cycling of nutrients within the bottom sediments, the level of phosphorus is maintained to continue the process of eutrophication. So phosphorus has been projected as the major essential nutrient most generally accessible as the target nutrient for the control of the offending plant gowth.

Phosphorus induced Zinc deficiency

Higher concentrations of phosphorus induce a system resembling zinc deficiency in plants. Three distinct processes involving phosphorus have been shown to decrease zinc concentration in plant tops.

1) Dilution of zinc in plant tissues by promotion of plant growth with phosphorus fertilisers.

2) Inhibition of zinc absorption by the cations added with phosphorus fertilisers.

3) Phosphorus enhancement of zinc adsorption by oxides and hydroxides of iron and aluminium in soil (Loneragan et al., 1979).

MATERIALS AND METHODS

Empty

1. Surface layer

2. 15 cm

3. 30 cm

4. 45 cm

Sand (5 cm)

Gravel (5 cm)
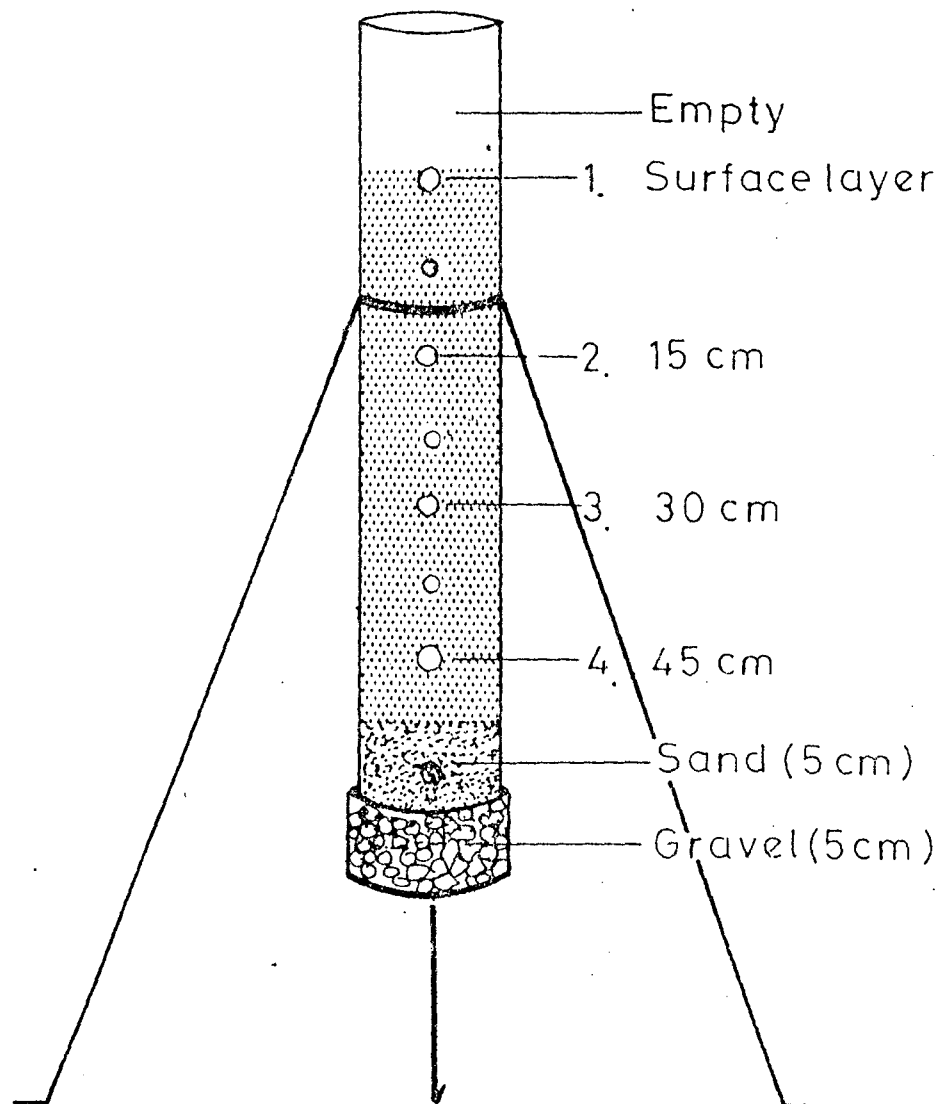
COLUMN

FIG. A.1,2,3 AND 4 ARE DEPTHS FROM WHICH

SAMPLES WERE ANALYSED.

Soil samples used in this experimental work were collected from a fallow land adjacent to the J.N.U. Campus. There was hardly any vegetation, a few shrubs and grass were mainly found. Samples were collected from the land up to a depth of 15 cm only.

The samples were mixed, air dried, powdered and seived through a 2 mm perforated seive. The seived soil sample was then filled into eight P.V.C. columns. The P.V.C. columns had the following specifications (Fig A).

SOIL COLUMN

1) Height of the P.V.C. columns   60 cm

2) Inner diameter   15 cm

3) Consisted of holes at an interval of   7.5 cm

4) Thick wire mesh were attached at the bottom of the columns.

The bottom of the columns were packed with gravel upto a hieght of 5 cm, over which fine grains of sand up to 5 cm were poured. Next, the seived soil was gradually filled in eight such soil columns, two each for the application of raw sewage, primary treated sewage, final treated sewage and tap water. These columns filled with soil samples were stabilised by the controlled application of tap water for a period of forty

eight hours.

ANALYSIS OF SOIL SAMPLES

1. pH of Soil

pH of the soil was measured with the help of pH meter (Philips) using 1:5 soil : water suspension.

2. Electrical Conductivity

This was determined using the same soil : water suspension (i.e. 1:5) with the help of Systronics direct reading E.C. meter.

3. Mechanical Analysis.

Mechanical analysis was done by hydormeter method as described by piper (1966)

4. Available Phosphorus:

Available phosphorus was determined by Colorimetric method using the sensitive "Molybdenum Blue Method" with L-ascorbic acid as the reductant.

Principle:

This method is based on the formation of hetero-polyphosphomolybdate compound when an acid molybdate is added to a solution containing orthophosphate. Reduction of this complex gives the characteristic molybdenum blue colour. The intensity of the blue colour

is proportional to the phosphate concentration. A colorimeter is used to measure the intensity of the blue colour.

Instrument used   Spectronic 1001

Make   Bausch and Lomb.

Wave length used   882 nm

This single beam spectrophotometer was used to determine the phosphorus concentration of unknown samples with the help of standard phosphorus solutions.

Method employed

The method selected for the determination of phosphorus was proposed by John (1970). This is a modification of the method suggested earlier by Murphy and Riley, (1962) and the adaptability of this method for various types of soil and the tolerance to interfering ions commonly encountered in soil and plant analysis has been well established.

Soil samples extracted with different extractants such as Bray P_1, Olsen's bicarbonate, Truog's solution, Morgan method etc were analysed by the above method using L-ascorbic acid and the results have been very satisfactory.

Extraction reagent

Bray and Kurtz No. 1 solution ($0.03N$ HF_4 in $0.025N$ HCL) was used as extractant for the present study. This was prepared by dissolving 1.11 gm of ammonium fluoride in one litre of $0.025N$ HCI

a) Standard phosphate solution (50 ppm of P)

0.2195 gm of potassium dihydrogen phosphate dried at $40^\circ C$ was dissolved in distilled water and the volume was made up to one litre to give a stock solution containing 50 ppm of phosphorus. From this, dilute standard solutions of concentrations varying from 0.1 to 1 ppm of phosphorus were prepared when required.

b) Stock solution

20 gm of ammonium molybdate was dissolved in about 300 ml of distilled water. Then added slowly 450 ml of $10N$ H_2SO_4 with stirring, to which 10 ml of 0.5% solution of antimony potassium tartrate was added. This was diluted to one litre with distilled water and stored away from direct sunlight.

c) Mixed reagent

Mixed reagent was prepared by adding 1.5 gm of L-ascorbic acid to 100 ml of stock solution.

Procedure for standard curves

20 ml of standards varying from 0.1 to 1 ppm were transferred to 25 ml volumetric flasks. 2.5 ml of mixed reagent was added and the volumes were made up to the mark. The blue colour development was determined between 30 and 60 minutes in 1001 spectrophotometer and absorbance measured at 882 nm.

Procedure for soil samples

2 gm of dry soil sample was shaken with 20 ml. of extractant (Bray and Kurtz No. 1) for one minute, filtered immediately through Whatman No. 42 filter paper. 5 ml of this clear filtrate was diluted to 20 ml in a 25 ml volumetric flask, 2.5 ml of mixed reagent was added, it was shaken and the volume made up to the mark (25 ml). First the standard phosphorus solutions were fed into the 1001 colorimeter and the absorbance noted using wave length 882 nm. Following this the soil sample extractants were inserted and the concentration of phosphorus obtained directly with the help of the instrument. All measurements were made between 30 to 60 minutes after the addition of mixed reagent i.e. development of blue colour.

5. **Organic Carbon.** (Walkley – Black method)

Principle

Organic matter in soils is oxidised by a known volume of acidified standard potassium dichromate and the excess of dichromate is back titrated with (N/2) ferrous ammonium sulphate using diphenylamine as indicator.

Reagents

a) **Standard potassium dichromate (1N)**

Prepared by dissloving 12.257 gm of $K_2Cr_2O_7$ in distilled water and the volume diluted to 250 ml.

b) **Ferrous ammonium sulphate (N/2)**

98 gms ferrous ammonium sulphate was dissolved in distilled water 15 ml of concentrated H_2SO_4 was added to it and the volume was made up to 500 ml with distilled water. This was standardised with standard 1N $K_2Cr_2O_7$ solution

c) **Diphenylamine indicator**

0.5 gm of reagent grade diphenylamine was dissolved in 20 ml of water and 100 ml of conc H_2SO_4.

d) **85% H_3PO_4**

e) **Solid NaF**

Procedure

a) Oxidation of Organic matter:

2 gm of soil sample was placed in a 500 ml conical flask. Next exactly 10 ml (1N)$K_2Cr_2O_7$ solution was pipetted into the soil sample and the two were mixed by swirling the flask. Then 20 ml of concentrated H_2SO_4 was added and mixed by gentle rotation for about one minute. The mixture was allowed to stand for 30 minutes. A standardisation blank (without soil) was run in the same way.

b) Back Titration

The above mixture was then diluted to 200 ml with water. 10 ml of 85% H_3PO_4, 0.2 gm of NaF, and about 1.5 ml of diphenylamine indicator were added. The solution was back titrated with (N/2) ferrous ammonium sulphate solution from a burette. The colour was dull green at the beginning, then shifted to a turbid blue, at the end point this colour changed sharply to a brilliant green, giving a one drop end point.

Calculation

% of organic carbon in soil $\dfrac{(a-b) \times 0.003 \times 100 \times 1.724}{w}$

where

a = Volume of (N/2) ferrous amm. sulphate required for blank titration.

b = Volume of (N/2) ferrous amm. sulphate for for soil samples.

x = Strength of ferrous amm. sulphate

w = Weight of soil in gm.

1.724 is the Van Bemmelen factor

Carbon to organic matter factor is based on the assumption that soil organic matter has 58 percent carbon.

6. Available Nitrogen

The alkaline permanganate digestion method suggested by Subbiah and Asija (1956) was employed to assess the availale nitrogen content of soil.

Principle

Soil when digested with alkaline permanganate solution releases

a) ammonia from ammonium compounds (inorganic) present in the soil and

b) ammonia from soil organic nitrogen pool by the process of oxidation and hydrolysis

Reagents :

a) <u>Potassium permanganate</u> (0.32%)

3.2 gm of $KMnO_4$ was dissolved in 1000 ml of distilled water.

b) <u>Sodium hydroxide solution (2.5%)</u>

25 gm of NaOH was dissolved in 1000 ml of distilled water.

c) <u>Boric acid solution</u> (2%)

20 gm of boric acid was dissolved in 1000 ml of distilled water.

d) <u>Mixed Indicator</u>

0.1 gm of methylene blue was dissolved in 50 ml of 95% ethanol and 0.2 gm of methyl red was dissolved in 100 ml of 95% ethanol and the two were mixed 10 ml of this mixed indicator was added to 1000 ml of 2% boric acid solution giving the indicator boric acid solution.

e) <u>Standard sulphuric acid (0.02N)</u>

<u>Procedure</u>

20 gm of soil was taken in a kjeldahl flask. It was moistened with 20 ml of distilled water, 100 ml of

0.32% $KMnO_4$ solution and 100 ml of 2.5% NaOH solution were next added. The contents of the flask were distilled and about 75 ml of the distillate collected in 20 ml of boric acid-indicator solution. The boric acid was then titrated against standard 0.02N H_2SO_4 to a pale lavender end point. A blank was also run simultaneously.

Calculation.

1 ml of 0.02N H_2SO_4 = 0.28 mg of 'N'

$$ppm \ of \ Nitrogen = \frac{(a - b) \times 0.28 \times 1000}{w}$$

where

    a = Sample titration value

    b = Blank titration value

    w = weight of soil in gm.

7. Cation Exchange Capacity

Cation exchange capacity of the soil was determined by neutral (N) ammonium acetate extraction method (Jackson, 1973).

Reagents

    a) Ammonium Acetate (1N)

This solution was adjusted to pH 7

    b) Ethyl Alcohol (95%)

c)   <u>Potassium Chloride</u> (10%)

The pH of this solution was adjusted to 2.5

d)   <u>Boric Acid Solution</u> (2%)

This solution contained mixed indicator (methylene blue and methyl red)

e)   <u>Sodium hydroxide solution</u> (40%)

f)   <u>Standard sulphuric acid</u> (0.01N)

<u>Procedure</u>

5 gm of soil and 33 ml of ammonium acetate (1N) were taken in a 50 ml plastic centrifuge tube. It was shaken for 5 minutes and then centrifuged for about 10 minutes and the supernatant liquid rejected. This process was repeated two more times. Next the soil was treated exactly in the same manner with ethyl alcohol and the decanted liquid rejected. Finally 33 ml of KCl(10%) was added to the soil residue and subjected to the same treatment three times, but in this case each time the decanted extract was collected in a 100 ml volumetic flask. The volume was made up to 100 ml with the KCl extract.

The extract collected (100 ml) was transferred to a Kjeldahl flask and was diluted to about 200 ml with distilled water. 25 ml of 40% NaOH solution was added

to it and the ammonia distilled was collected in 50 ml of boric acid-indicator solution. Finally this was back titrated against standard H_2SO_4 (0.01N). As a blank, an equal portion of KCl solution was run simultaneously.

Calculation

$$C.E.C. (meq/100gm\ soil) = \frac{100/v \times a \times 100}{w}$$

where,

v = volume of extract distilled from total of 100ml

a = ml of (N) H_2SO_4 required for titration

w = weight of the soil in gm.

ANALYSIS OF SEWAGE SAMPLES

Sewage samples were collected from Okhla Sewage Treatment Plant, New Delhi on three different occasions at an interval of 21 days. From three specific points, samples of raw sewage, primary treated and secondary treated sewage were collected in polythene jars. A portion of these were preserved at $4^{o}c$ for analysis and the rest were utilised for application to the soil columns.

1. pH and Electrical Conductivity

pH and electrical conductivity were measured by the same instruments used for soil samples.

2. Chemical Oxygen Demand (COD)

Principle :

Most of the organic matter is destroyed when boiled with a mixture of potassium dichromate and conc. sulphuric acid producing carbon dioxide and water. A sample is refluxed with a known volume of standard $K_2Cr_2O_7$ solution in sulphuric acid medium and the excess of the dichromate is titrated against ferrous ammonium sulphate. The amount of dichromate consumed is proportional to the oxygen required to oxidise the oxidisable organic matter.

Reagents.

a)   Standard potassium dichromate (0.25N)

3.0647 gm of $K_2Cr_2O_7$ was dissolved in distilled water and the volume was made up to 250 ml.

b)   Ferrous ammonium sulphate (0.25N)

24.5 gms of ferrous ammonium sulphate was dissolved in distilled water, 20 ml of conc. H_2SO_4 was added and the volume diluted to 250 ml. This ferrous ammonium sulphate solution was standardised using standard $K_2Cr_2O_7$ solution.

c)   Ferroin Indicator

0.695 gm of $FeSO_4$ and 1.485 of 1,10-phenanthroline were dissolved in 100 ml of distilled water.

d)   Silver sulphate solution

2.5 gm of Ag_2SO_4 was dissolved in 250 ml. of conc. H_2SO_4.

Procedure

COD was determined by the method given in the 'standard methods for the examination of water and wastewater'(APHA, 1980).

20 ml of the three effluent samples in duplicate were placed in 500 ml flat bottom flasks having short and narrow size necks. These were attached to condensers and the assembly placed on a hot plate. 0.5 gm of $HgSO_4$,

10 ml of standard $K_2Cr_2O_7$ solution and 30 ml of Ag_2SO_4-H_2SO_4 mixture were added to the samples in the flasks. The contents were refluxed for two hours, then the flasks were cooled and 80 ml of distilled water added to each flask. The excess of dichromate was titrated against ferrous ammonium sulphate using ferroin indicator to a wine red end point. Two blanks with 20 ml of distilled water were also run simultaneously.

Calculation

$$COD(mg/1) = \frac{(x - y) \times c \times 8000}{\text{vol. of sample (ml)}}$$

where,

   x   = Blank titre value

   y   = Sample titre value

   c   = Normality of ferrous ammonium sulphate.

3.   Dissolved Oxygen (D.O.)

Standard iodometric method was employed for D.O. The analysis was done as suggested in "Standard methods for the examination of water and wastewater" (APHA, 1980).

Principle

Iodometric test is a precise and reliable titrimetric procedure for D.O. analysis. The test is based

on the addition of divalent manganese solution followed by strong alkali to the sample in a BOD glass stoppered bottle. D.O. present rapidly oxidises an equivalent amount of the dispersed divalent manganous hydroxide to higher oxidation state (brownish-orange in colour). This brownish orange colour indicates the presence of oxygen. In the presence of iodine and subsequent acidification, higher manganese hydroxide revert to divalent state, and liberate iodine equivalent to the original D.O. content of the sample. The iodine liberated is titrated with a standard solution of sodium thio-sulphate using starch as indicator.

Reagents

a)   Manganous sulphate solution

36.4 gm of $MnSO_4.H_2O$ was dissolved in distilled water, filtered and the volume made up to 100 ml.

b)   Alkali-Iodide-Azide reagent

50 gm of NaOH and 15 gm of KI were dissolved in distilled water and volume made up to 100 ml. To this 1 gm of sodium azide (NaN_3) dissolved in 40 ml of distilled water was added and the contents were mixed.

Standard sodium thiosulphate solution (0.0125N)

3.15 gm of $Na_2S_2O_3.5H_2O$ was dissolved in distilled

water and the volume diluted to one litre. This solution was standardised against KIO_3 solution.

Standard potassium iodate (0.0125N)

0.446 gm of KIO_3 previously dried at $120^{O}C$ was dissolved in distilled water and diluted to one litre.

Starch indicator

A smooth paste was made with 5 gm of soluble starch in water. It was then poured into 100 ml of boiling water with constant stirring.

Procedure

To the 300 ml capacity BOD bottle filled with effluent sample, 2 ml of $MnSO_4$ and 2 ml of alkali-iodide azide reagents were added, dipping the pipette a little below the surface. The stopper was replaced carefully to exclude air bubbles and the contents were mixed by inverting the BOD bottles about 15 times. Percipitate formed was allowed to settle down to obtain a clear supernatant liqiuid. Next 2 ml of conc. H_2SO_4 was added immediately after removing the stopper. It was restoppered and the contents mixed gently to dissolve all the precipitate. 100 ml was taken in a conical flask and immediately titrated the liberated iodine with standard

thiosulphate solution to a pale yellow straw colour. 2 ml of starch solution was added and the titration continued till the blue colour disappeared.

Standardisation of $Na_2S_2O_3$ solution

10 ml of standard potassium iodate (0.0125N) was pipetted into a conical flask containing about 100 ml of distilled water, 2 ml of conc. H_2SO_4 and 2 gm of potassium iodide were added and the iodine liberated was immediately titrated against sodium thiosulphate solution using starch as indicator.

Calculation

Dissolved oxygen content (mg/l) $= \dfrac{a \times 10}{b}$

Where

    a   =   Vol. of thiosulphate required for 100 ml of sample

    b   =   Vol. of thiosulphate required for 10 ml of 0.0125N potassium iodate.

4. ## Biological Oxygen Demand

It is the amount of oxygen required by micro-organisms for the biochemical degradation of organic matter. BOD determination consists of measuring the D.O. on the first day and then placing the samples under incubation at $20^{\circ}C$ for 5 days and again measuring the D.O. on 5th day. The difference between the D.O. value gives the BOD.

Apparatus

1) Incubation bottles : 300 ml capacity with ground glass stoppers

2) Incubator : Incubator which has provisions to maintain $20 \pm 1^{O}C$.

Reagents

a) Phosphate buffer

10.625 gm of KH_2PO_4 was dissolved in 175 ml of distilled water in which 2.2 gm of NaOH was added and the pH adjusted to 7.2. To this solution 0.5 gm of $(NH_4)_2SO_4$ was added and the volume made upto 250 ml.

b) Calcium chloride solution

6.875 gm of anhydrous calcium chloride was dissolved in 250 ml of distilled water.

c) Magnesium sulphate solution

6.250 gm of $MgSO_4 \cdot 7H_2O$ was dissolved in 250 ml of distilled water.

d) Ferric chloride solution

0.125 gm of $FeCl_3 \cdot 6H_2O$ was dissolved in one litre of distilled water.

e)   Dilution water

10 litres of distilled water was aerated for 48 hours by bubbling compressed air to attain D.O. saturation. To this 10 ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride were added. The above trend of adding the nutrients was followed.

Procedure

15 ml, 30 ml and 60 ml from each of the three effluents (raw, primary and secondary sewage) were transferred to 1000 ml volumetric flasks and the remaining volume was made up by the addition of dilution water. This corresponds to 1.5%, 3% and 6% solutions of the effluent samples. From the 1000 ml volumetirc flasks containing the diluted samples three 300 ml BOD bottles were gradually filled up, without entrapping air bubbles in the bottles. One bottle was kept for determining initial (zero day) dissolved oxygen and the other two were incubated at $20^{\circ}c$ for five days. The D.O. content of the incubated bottles were determined on the fifth day. The method employed for D.O. determination has been described earlier. Three blanks were also prepared using dilution water only and analysed acccordingly along with the samples.

Calculation

$$\text{BOD mg/l} \qquad \frac{(D_1 - D_2) - (B_1 - B_2) \times 100}{\% \text{ of sample}}$$

where

D_1 = D.O of diluted sample on 0th day

D_2 = D.O. of diluted sample on 5th day

B_1 = D.O. of diluted blank on 0th day

B_2 = D.O. of diluted blank on 5th day

5. Organic Carbon

Organic carbon content of the sewage samples were determined by the same method (Walkley – Black) as described for soil samples.

Procedure

25 ml of the sewage sample was taken in 500 ml conical flask and exactly 10 ml of (1N) $K_2Cr_2O_7$ solution and about 20 ml of conc. H_2SO_4 were added to it. The mixture was allowed to stand for 30 minutes and then diluted to 200 ml with distilled water. 10 ml of H_3PO_4 followed by four drops of diphenylamine indicator were added and the solution was back titrated with (N/2) ferrous ammonium sulphate solution to a brilliant green end point. A blank with 25 ml of distilled water was also run in the same manner.

% of Organic Carbon $\quad\quad \dfrac{(a - b) \times .003 \times n \times 100}{v}$

where

a = Blank titration value

b = Sample titration value

n = Strenth of ferrous ammonium sulphate

v = Volume of the effluent sample

6. <u>Avaliable Nitrogen</u>

The same alkaline permanganate digestion method was followed as described for soil samples. 50 ml of the sewage samples were taken in the Kjeldahl flasks for estimating their available nitrogen content.

7. <u>Water soluble orthophosphate</u>

Soluble orthophosphate in the effluent samples were determined by the ascorbic acid method described earlier. The procedure given in 'The standard methods for the examination of water and wastewater' APHA, (1980) was followed.

The effluent samples were filtered and 5 ml of clear filtrate from each sample was transferred to 25 ml volumetric flasks. These were diluted to 20 ml with distilled water 2.5 ml of mixed reagent

was added to each sample and shaken to obtain the blue colour. The concentration of phosphorus was determined with the help of standards and measurements made by 1001 Spectrophotometer at wave length 882 nm. All measurements were made between 30 to 60 minutes after the addition of mixed reagent.

OUTLINE OF THE EXPERIMENT PERFORMED.

Duplicate soil columns were treated with domestic sewage for a period of 60 days. Samples were periodically drawn from the soil column at different depths and important parameters analysed. Details are given below.

1.	Commencement of experiment	18-2-86
2.	Source of effluents	Okhla Sewage Treatment Plant, New Delhi
3.	Types of sewage samples used	Raw sewage, Primary treated sewage, Secondary treated sewage
4.	Quantity added	One litre/24 hours
5.	Frequency and dates of effluent collection	(21 days) 18.2.86, 11.3.86 and 2.4.86
6.	Frequency and dates of samples drawn from the soil colums	(15 days) 4.3.86, 19.3.86, 3.4.86 and 18.4.86

7.	Depth from which samples were analysed	Surface layer, 15 cm, 30cm and 45 cm.
8.	Parameters analysed	pH, Electrical Conductivity organic carbon, available nitrogen and available phosphorus. (Bray P_1)
9.	Control treatment.	Tap water.

EXPERIMENTAL   RESULTS

FIG. B

LAY OUT PLAN OF OKHLA SEWAGE TREATMENT PLANT

1. Raw Sewage
2. Primary Treated Sewage Effluent
3. Final Treated Effluent
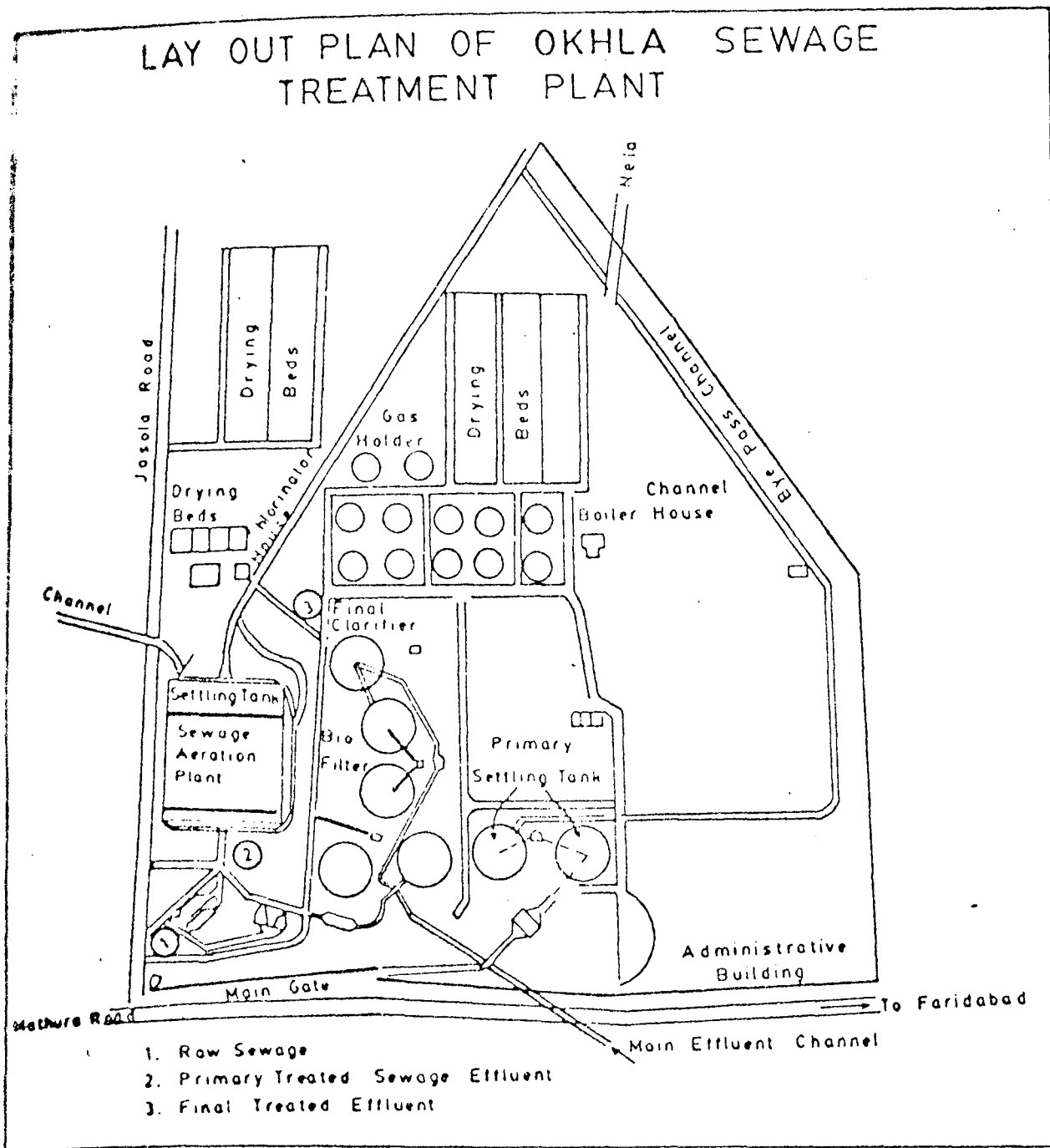
ORIGINAL SOIL

Physical and chemical properties of the soil used for the present study have been presented in table 1. The soil contained Sand 57.4%, Silt 30.43% and Clay 12.17%. The pH of the soil was in the alkaline range (8.45). Water holding capacity was 34.5%; Electrical Conductivity 0.095 mmhos/cm, and Cation Exchange Capacity 8.2 m eq/100 gm. The levels of available nitrogen and Bray P_1, extractable phosphorus were 56 and 7.33 ppm respectively. Organic Carbon content of the soil was 0.26%.

SEWAGE EFFLUENTS

Characteristics of the effluent collected on three different occasions have been presented in tables 2,3 and 4. Some noticeable periodic variations were observed in the levels of the different parameters estimated. The average of the three values for each effluent showed the following trends.

The pH values of raw, primary and secondary trea-ted sewage were 7.46, 7.48, 7.76 respectively, which indicated almost no variation in pH of the three efflu-ents. The Electrical conductivity values 1.05, 1.14 and 1.08 respectively in the above order showed similar

trends.

COD values were 274.1, 172.3 and 58.1 mg/1 for raw, primary, and secondary sewage respectively and the corresponding BOD values were 120.6, 60.8 and 16.7 mg/1. Organic carbon content in the order mentioned above were 0.0145%, 0.0063%, and 0.003% respectively. The levels of available nitrogen in raw sewage, primary and secondary treated sewage were 26.8, 21.6 and 16.05 ppm and values of soluble orthophosphate were 5.03, 4.2 and 1.76 ppm respectively in the above order.

In evaluating the properties of effluents and assessing the efficiency of conventional treatment stages reveals that primary treatment has not remarkably affected the pH or electrical conductivity. In contrast BOD, COD, organic carbon and inorganic constituents like nitrogen, phosphorus etc were significantly modified by the different treatment processes.

EFFECT OF SEWAGE EFFLUENTS ON THE SOIL COLUMNS

pH : Periodic changes in pH of the soil at different layers of the soil columns have been presented in table 5. There has been a decrease in soil pH within 15 days of sewage application.

While the decrease was noticeable (from 8.45 to

7.45) in the case of raw sewage application, it was progressively less with the other two treatments including the control treatment with tap water. Again, while the surface layers experienced considerable change in the pH values, the changes in the subsequent layers were negligible.

It was also observed that pH values increased with depth in the soil columns irrespective of the type of effluent applied. Subsequent observation showed that the pH values almost invariably increased till the end of the incubation period. The final values in the surface layers of the columns treated with raw sewage and primary treated sewage were 7.5 and 7.6 respectively.

At the end of the experiment, the values of pH in the 2nd (30 cm) and 3rd layers (45 cm) were almost the same as the original soil. In the control treatment where only tap water was applied, there was no appreciable change in the soil pH.

ELECTRICAL CONDUCTIVITY

The variations of electrical conductivity with time in soil columns under the appplication of sewage effluents have been presented in table 6. Within 15 days, the electrical conductivity values did not change

appreciably. Only in the surface layers there was a slight increase in the electrical conductivity values. However, in the tap water treatment the electrical conductivity values slightly declined. It was observed that electrical conductivity increased progressively thereafter till the end of the experiment. While the increase in the surface layers were remarkably high, that in the subsequent layers were comparatively less.

It was a general observation that the electrical conductivity values decreased with depth barring a few cases. After 60 days the values of electrical conductivity in all the layers of the column treated with secondary sewage effluent were considerably higher than the other treatments.

ORGANIC CARBON

The periodic changes in organic carbon content of the soil under the application of sewage effluents have been shown in table 7. and fig.13. Within 15 days only the surface layers of the columns treated with raw sewage showed a slight increase in the organic carbon content. In almost all the other layers the values were either the same or slightly less than that in the original soil.

Within 30 days the surface layers of the column treated with raw sewage showed an appreciable increase

in organic carbon(0.58%). A slight increase was also observed in the surface layers of the columns where primary treated sewage was applied. No variations were observed in all the other layers.

At the end of the treatment the organic carbon increased slightly in the surface layers of the effluent treated columns. However, in the surface layer of the column treated with raw sewage the value was appreciably high (0.64%). In the subsequent layers of the same column the increase was less pronounced and the values decreased with depth. It was a general observation that in all other layers the values suffered minor losses. In contrast the values in the check treatment with tap water decreased in all the layers within 15 days and then no variation was observed till the end.

AVAILABLE NITROGEN

The periodic changes in available nitrogen of the soil amended with sewage effluents have been presented in table 8 and Fig.14. From the very beginning the values showed a marked increase in the effluent treated columns. In the surface layer of the column treated with raw sewage, the available nitrogen was more than doubled (177 ppm) within 15 days. In the other layers of this column the increase was comparatively less.

In the surface layers of the columns amended

with primary and secondary treated sewage the values increased to 75 and 68 ppm respectively within 15 days. The increase progressively decreased with depth in all the columns irrespective of the type of treatment.

It was observed in general that the values reached a peak within 30 days in the surface layers of the columns where raw sewage and primary treated sewage were applied and the peak values of available nitrogen were 184 and 84 ppm respectively. Thereafter the values showed a slight decrease in these columns till the end of incubation period.

In the surface layer of the column where secondary treated sewage was applied the highest value was obtained within 45 days (72.8 ppm). However, this value declined to 61.6 ppm at the end of the experiment. Almost all the values decreased with depth. The control treatment showed a decrease compared to the original value in all the layers and unlike the other columns the values decreased with time. However, the decreasing trend along the depth in these columns were maintained till the end as in the other treatments.

AVAILABLE PHOSPHORUS

The variations in available phosphorus with time in the soil columns treated with different effluents have been presented in table 9. and Fig.15.

EFFECT OF RAW SEWAGE

Within 15 days the surface layer of the soil column treated with raw sewage showed a remarkable increase in available phosphorus (42 ppm). The other layers of this column also showed some increase. However, within 30 days the values invariably decreased in all the layers but thereafter the values increased till the end. The increase was appreciably higher (88.6 ppm) in the surface layer at the end of the experiment.

EFFECT OF PRIMARY TREATED SEWAGE

Almost similar trends were observed in the columns under this treatment but the values were much lower in this case. Within 15 days the surface layer showed an appreciable increase (36 ppm) and this value ultimately increased to 44.6 ppm at the end of the experiment. The other layers of this column showed an increase within 15 days after which almost all the values gradually decreased till the end of the incubation period.

EFFECT OF SECONDARY TREATED SEWAGE

The trend under this treatment was slightly different. Within 15 days there was an increase in the value of available phosphorus in all the layers. Subsequently, the surface layer showed a maximum value

(28 ppm) within 45 days but this value dropped slightly (26.2 ppm) at the end of the experiment. No regular trend was observed in the other layers but their values finally decreased to about 4.5 ppm.

EFFECT OF CONTROL TREATMENT WITH TAP WATER

The values of available phosphorus in the control treatment increased in all the layers within 15 days. However, the values gradually declined with time in all the layers and the final values were in between 4 and 5 ppm at the end of the experiment.

T A B L E - 1

Physico-Chemical Properties of Experimental Soil

PARAMETERS		MEAN VALUE
1. Particle Size Analysis	% sand	57.40
	% silt	30.43
	% clay	12.17
2. pH		8.45
3. Water Holding Capacity		34.5%
4. Electrical Conductivity		0.095 mmhos/cm
5. Organic Carbon		0.2586%
6. Available Phosphorus (Bray P_1)		7.33 ppm
7. Available Nitrogen		56 ppm
8. Cation Exchange Capacity		8.2 meq/100gm

T A B L E - 2

Physico-Chemical Characteristics of Effluents
Collected on 18-2-86

	Parameters	Raw Sewage	Primary Treated Sewage	Secondary Treated Sewage
1.	pH	7.50	7.58	7.74
2.	Electrical Conductivity (mmhos/cm)	1.05	1.05	1.20
3.	COD (mg/l)	247.50	217.80	69.30
4.	BOD (mg/l)	108.40	66.25	15.20
5.	Organic Carbon (%)	0.0126	0.0063	0.003
6.	Available Nitrogen (ppm)	26.80	22.40	17.36
7.	Available Phosphorus (ppm) (soluble orthophosphate)	4.94	4.52	1.64

Data represent average of duplicate samples.

T A B L E - 3

Physico-Chemical Characteristics of Effluents
Collected on 11-3-86

	Parameters	Raw Sewage	Primary Treated Sewage	Secondary Treated Sewage
1.	pH	7.50	7.66	7.94
2.	Electrical Conductivity (mmhos/cm)	1.02	0.95	1.20
3.	COD (mg/l)	270	160	70
4.	BOD (mg/l)	112.90	61.10	20.29
5.	Organic Carbon (%)	0.0168	0.0058	0.0036
6.	Available Nitrogen (ppm)	28.56	22.96	15.68
7.	Available Phosphorus (ppm) (soluble orthophosphate)	5.61	4.98	1.93

Data represent average of duplicate samples.

T A B L E - 4

Physico-Chemical Characteristics of Effluents
Collected on 2-4-86

	Parameters	Raw Sewage	Primary Treated Sewage	Secondary Treated Sewage
1.	pH	7.40	7.20	7.60
2.	Electrical Conductivity (mmhos/cm)	1.08	1.26	1.02
3.	COD (mg/l)	305	140	35
4.	BOD (mg/l)	140.50	55.30	14.90
5.	Organic Carbon (%)	0.0144	0.007	0.0024
6.	Available Nitrogen (ppm)	25.20	19.60	15.12
7.	Available Phosphorus (ppm) (soluble orthophosphate)	4.55	3.12	1.73

Data represent average of duplicate samples.

T A B L E - 5

Periodic Changes of pH in the Soil Columns Under
the Application of Sewage

EFFLUENT TYPE	DEPTH IN cm	15 days	30 days	45 days	60 days
RAW	Surface Layer	7.45	7.60	7.55	7.50
	15	7.90	8.20	8.15	8.20
SEWAGE	30	8.00	8.15	8.30	8.35
	45	8.10	8.25	8.25	8.40
PRIMARY	Surface Layer	7.65	7.75	7.60	7.65
	15	8.30	8.25	8.00	8.25
TREATED	30	8.20	8.30	8.25	8.45
SEWAGE	45	8.20	8.30	8.30	8.45
SECONDARY	Surface Layer	8.20	8.00	8.15	8.35
	15	8.10	8.20	8.30	8.45
TREATED	30	8.25	8.30	8.40	8.40
SEWAGE	45	8.00	8.35	8.35	8.50
TAP	Surface Layer	8.20	8.30	8.45	8.65
	15	8.35	8.30	8.45	8.50
WATER	30	8.30	8.40	8.50	8.55
	45	8.40	8.50	8.60	8.55

* pH in original soil - 8.45

Data represent average of duplicate samples.

T A B L E - 6

Periodic Changes of E C (mmhos/cm) in Soil
Under the Application of Sewage

EFFLUENT TYPE	DEPTH IN cm	15 days	30 days	45 days	60 days
RAW	Surface Layer	0.110	0.270	0.450	0.60
	15	0.090	0.120	0.180	0.27
SEWAGE	30	0.095	0.120	0.210	0.24
	45	0.085	0.150	0.180	0.24
PRIMARY	Surface Layer	0.112	0.240	0.420	0.63
TREATED	15	0.097	0.150	0.180	0.30
SEWAGE	30	0.090	0.180	0.210	0.27
	45	0.095	0.120	0.210	0.30
SECONDARY	Surface Layer	0.120	0.240	0.480	0.75
	15	0.110	0.210	0.450	0.60
TREATED	30	0.110	0.270	0.510	0.63
SEWAGE	45	0.120	0.240	0.480	0.57
TAP	Surface Layer	0.075	0.120	0.240	0.30
	15	0.080	0.120	0.210	0.27
WATER	30	0.075	0.125	0.210	0.24
	45	0.075	0.120	0.210	0.24

* E C of original soil - 0.095 mmhos/cm

Data represent average of duplicate samples.

T A B L E - 7

Periodic Changes of Organic Carbon (%) in Soil
Under the Application of Sewage

EFFLUENT TYPE	DEPTH IN cm	15 days	30 days	45 days	60 days
RAW	Surface Layer	0.2821	0.5818	0.6206	0.6432
	15	0.2697	0.2650	0.2456	0.2830
SEWAGE	30	0.2586	0.2586	0.2650	0.2766
	45	0.2508	0.2508	0.2586	0.2573
PRIMARY	Surface Layer	0.2586	0.2844	0.2715	0.2830
TREATED	15	0.2350	0.2327	0.2327	0.2508
SEWAGE	30	0.2586	0.2508	0.2456	0.2447
	45	0.2350	0.2508	0.2508	0.2701
SECONDARY	Surface Layer	0.2586	0.2456	0.2586	0.2766
	15	0.2468	0.2327	0.2327	0.2508
TREATED	30	0.2350	0.2508	0.2586	0.2508
SEWAGE	45	0.2350	0.2327	0.2508	0.2573
TAP	Surface Layer	0.2355	0.2456	0.2315	0.2315
	15	0.2350	0.2315	0.2350	0.2251
WATER	30	0.2468	0.2350	0.2315	0.2315
	45	0.2350	0.2456	0.2350	0.2315

* Organic Carbon of original soil - 0.2586 %

  Data represent average of duplicate samples.

T A B L E - 8

Periodic Changes in Available Nitrogen (ppm)
of Soil Under the Application of Sewage

EFFLUENT TYPE	DEPTH IN cm	15 days	30 days	45 days	60 days
RAW	Surface Layer	117.6	184.8	176.4	173.6
	15	65.8	72.8	61.6	72.8
SEWAGE	30	67.2	64.4	68.6	70.0
	45	63.0	61.6	63.0	64.4
PRIMARY	Surface Layer	75.6	84.0	77.0	78.4
	15	64.4	65.8	67.2	68.6
TREATED	30	67.2	68.6	64.4	64.4
SEWAGE	45	61.6	57.4	58.8	63.0
SECONDARY	Surface Layer	68.6	70.0	72.8	61.6
	15	67.2	61.6	61.6	54.6
TREATED	30	61.6	57.4	56.0	49.0
SEWAGE	45	61.6	54.6	50.4	50.4
TAP	Surface Layer	53.2	50.4	49.0	44.8
	15	50.4	51.8	50.4	46.2
WATER	30	51.8	49.0	44.8	43.4
	45	50.4	47.6	42.0	43.4

* Available Nitrogen in original soil - 56 ppm

  Data represent average of duplicate samples.

T A B L E - 9

Periodic Changes in Available Phosphorus (ppm)
of Soil Under the Application of Sewage

EFFLUENT TYPE	DEPTH IN cm	15 days	30 days	45 days	60 days
RAW	Surface Layer	42.0	32.75	51.7	88.65
	15	14.2	6.47	8.02	12.17
SEWAGE	30	13.2	5.7	9.25	10.20
	45	12.05	5.7	6.1	6.1
PRIMARY	Surface Layer	36.1	21.55	38.1	44.65
TREATED	15	11.82	6.22	7.02	7.80
SEWAGE	30	11.55	5.12	5.72	6.22
	45	11.4	5.2	5.82	4.1
SECONDARY	Surface Layer	14.2	17.75	28.17	26.25
	15	9.87	5.72	6.42	4.35
TREATED	30	10.91	6.67	5.75	4.5
SEWAGE	45	10.72	6.0	5.97	4.17
TAP	Surface Layer	10.55	6.2	6.07	4.4
	15	10.05	6.9	5.6	4.45
WATER	30	10.05	5.75	5.77	4.85
	45	9.85	5.82	5.82	4.85

* Available Phosphorus in original soil - 7.33 ppm

Data represent average of duplicate samples.

T A B L E - 10

Correlation Coefficients between available Phosphorus
and other Soil Parameters in Sewage amended Soil

	Days	Correlation Coefficient 'r'	Significance level
P x C	15	0.6842	$p < 0.01$
	30	0.8423	$p < 0.001$
	45	0.7940	$p < 0.001$
	60	0.9175	$p < 0.001$
P x N	15	0.8573	$p < 0.001$
	30	0.8793	$p < 0.001$
	45	0.8495	$p < 0.001$
	60	0.9220	$p < 0.001$
P x pH	60	-0.589	$p < 0.01$
P x EC	60	0.309	Not significant
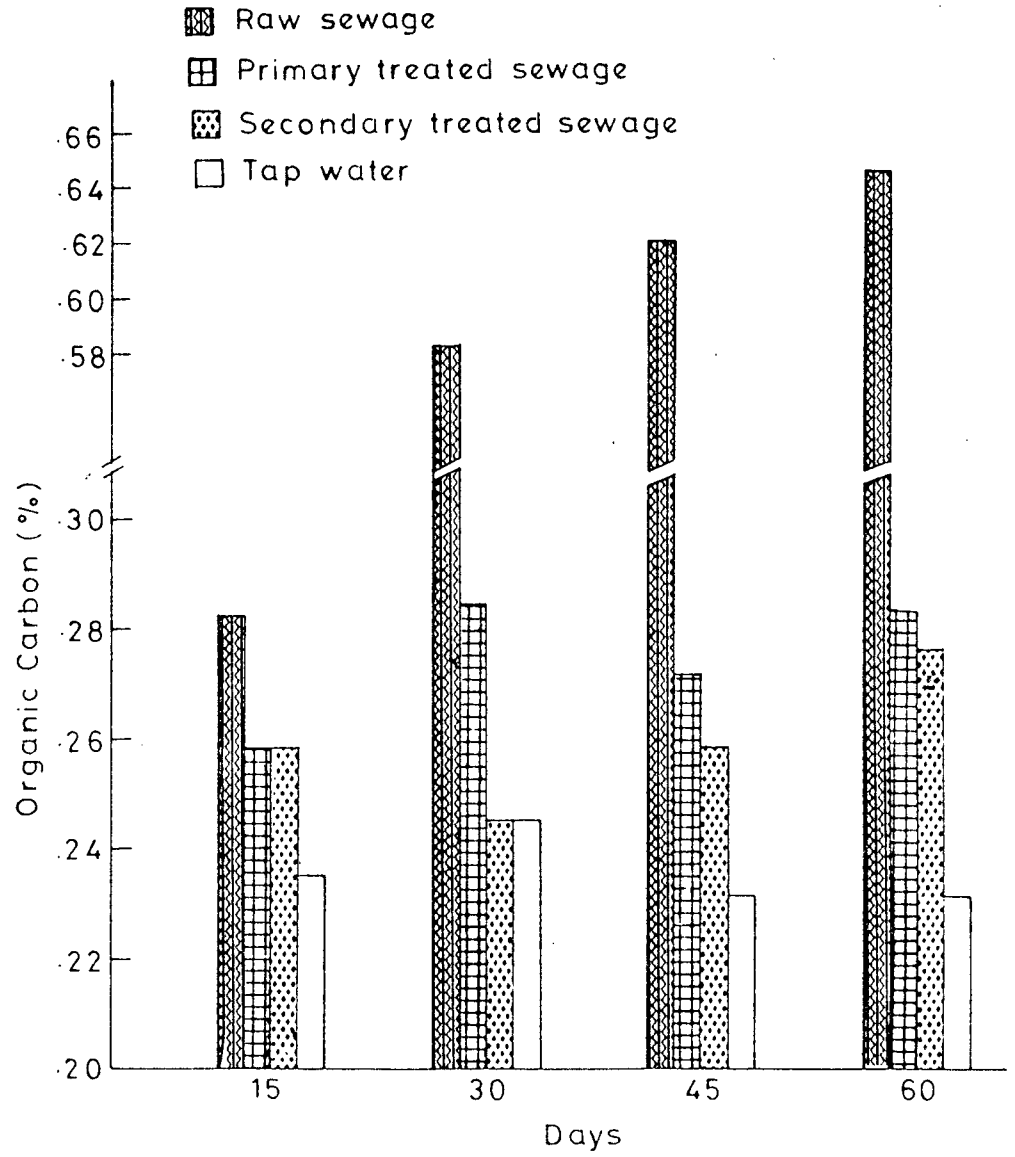
FIG : 1 CHANGES OF ORGANIC CARBON IN THE

SURFACE LAYER OF SEWAGE TREATED SOIL COLUMNS.
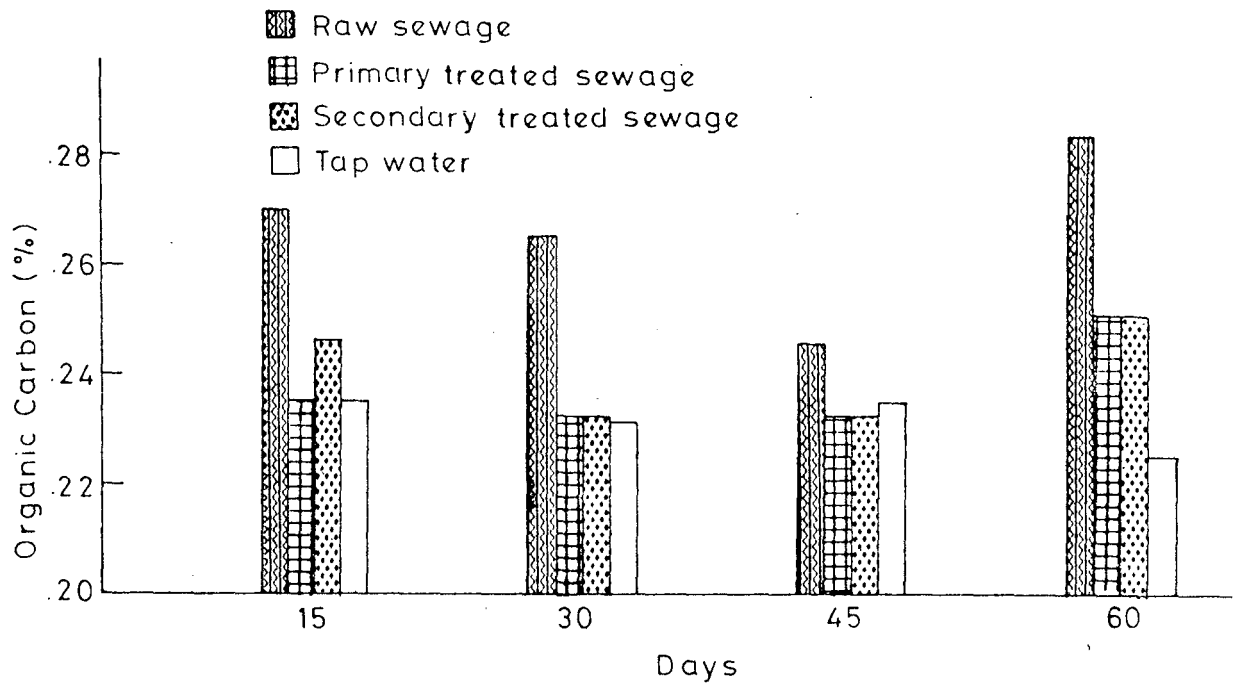
FIG.2   CHANGES IN ORGANIC CARBON AT A DEPTH OF <u>15 cm</u> IN

SEWAGE TREATED SOIL COLUMNS
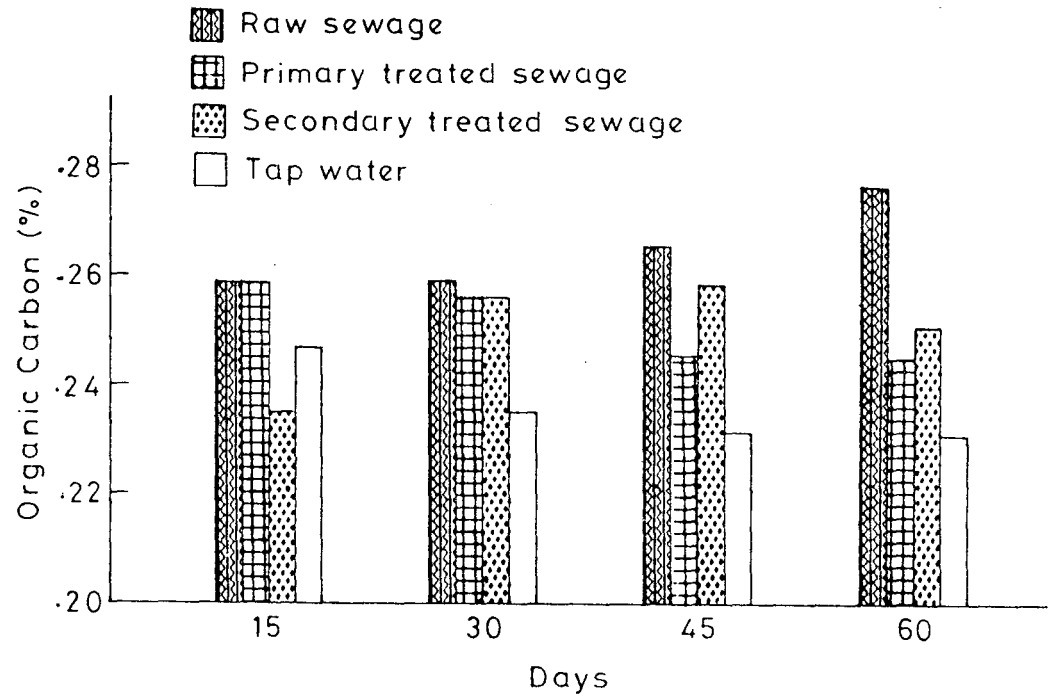
FIG.3 CHANGES IN ORGANIC CARBON AT A DEPTH OF 30 cm IN

SEWAGE TREATED SOIL COLUMNS.
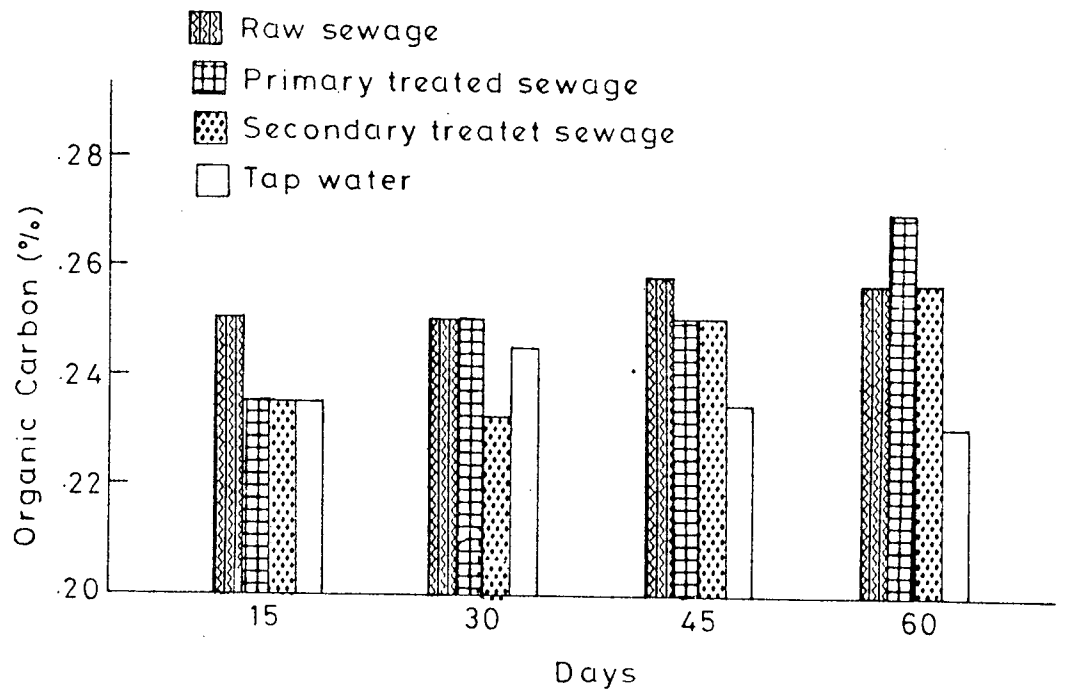
FIG. 4 CHANGES IN ORGANIC CARBON AT A DEPTH OF
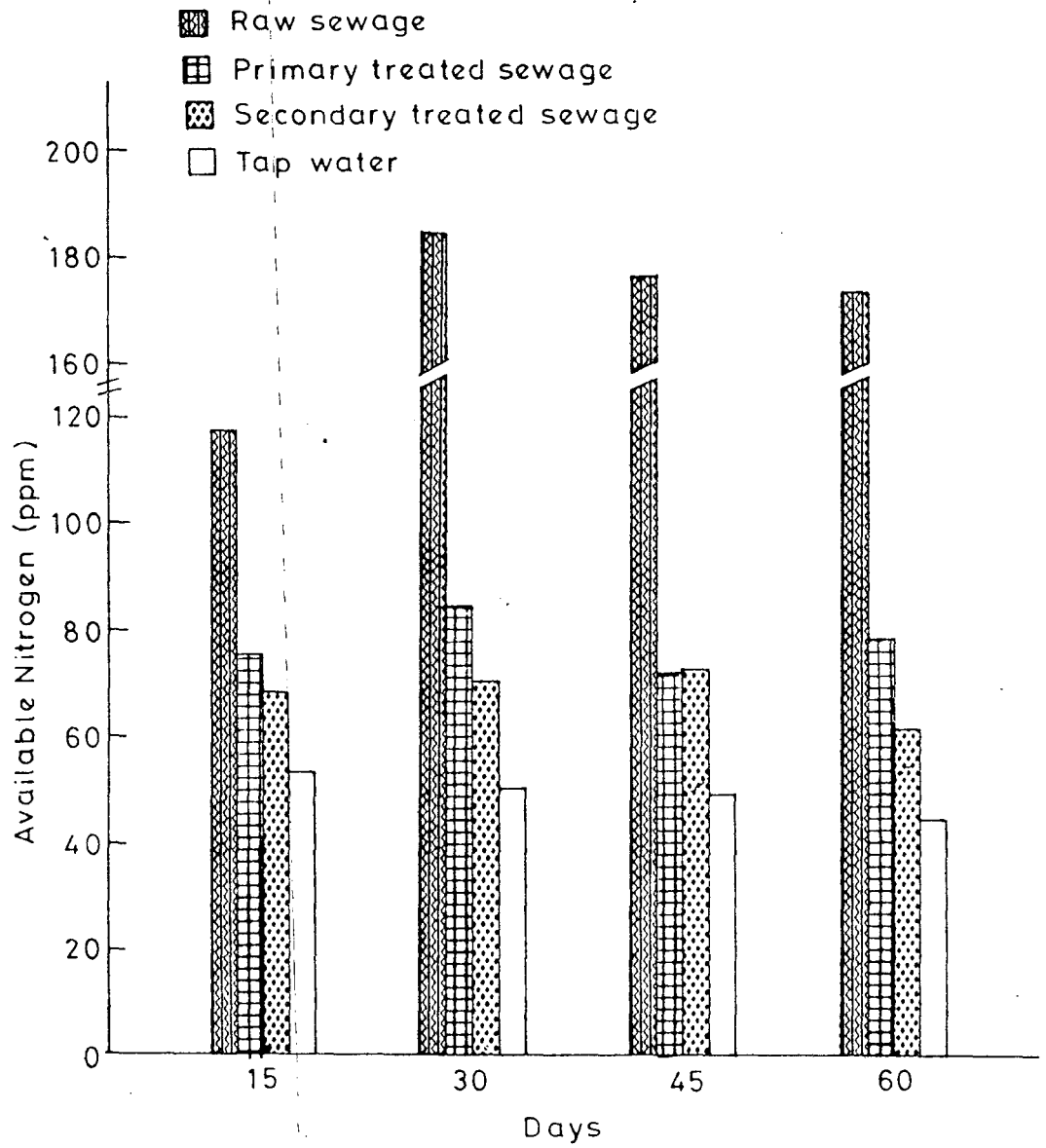45 cm IN SEWAGE TREATED SOIL COLUMNS

FIG. 5 CHANGES OF AVAILABLE NITROGEN IN THE
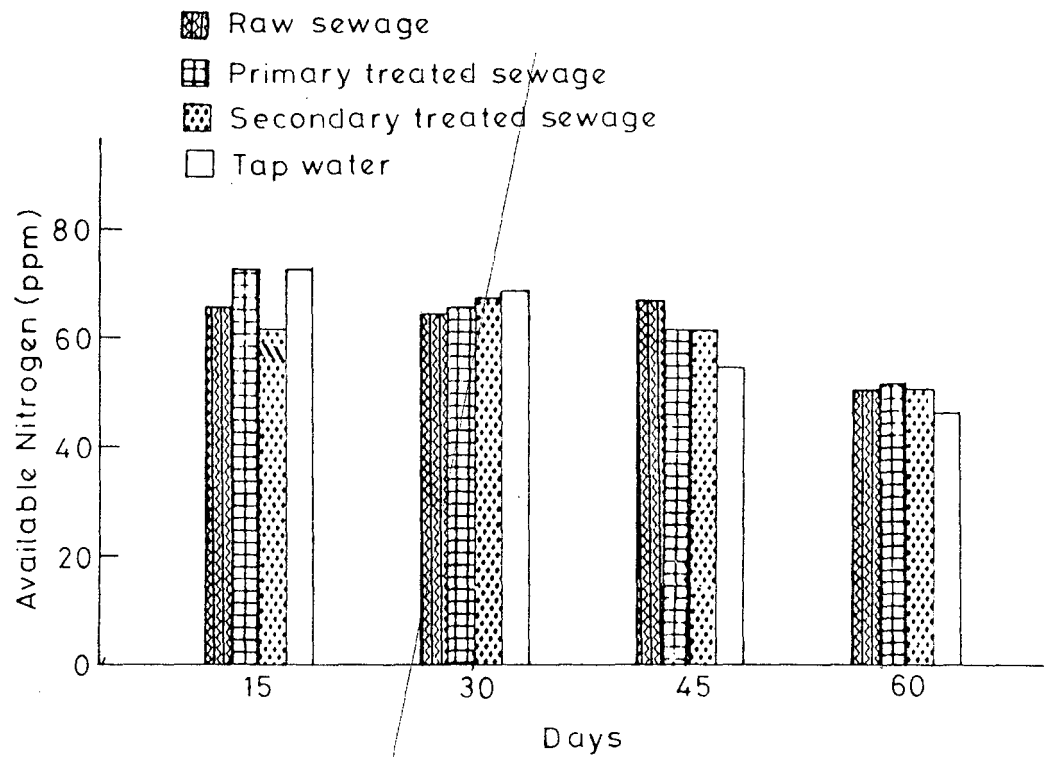SURFACE LAYER OF SEWAGE TREATED SOIL COLUMNS

FIG. 6 CHANGES IN AVAILABLE NITROGEN AT A DEPTH OF
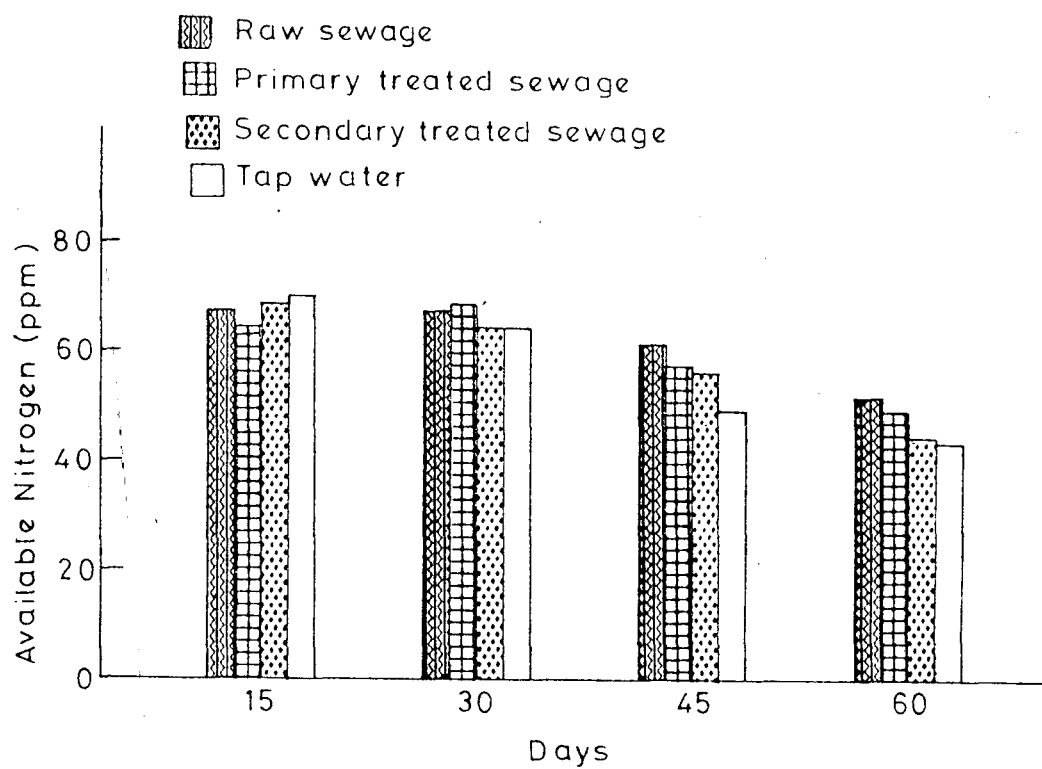15 cm IN SEWAGE TREATD SOIL COLUMNS

FIG. 7 CHANGES IN AVAILABLE NITROGEN AT A DEPTH

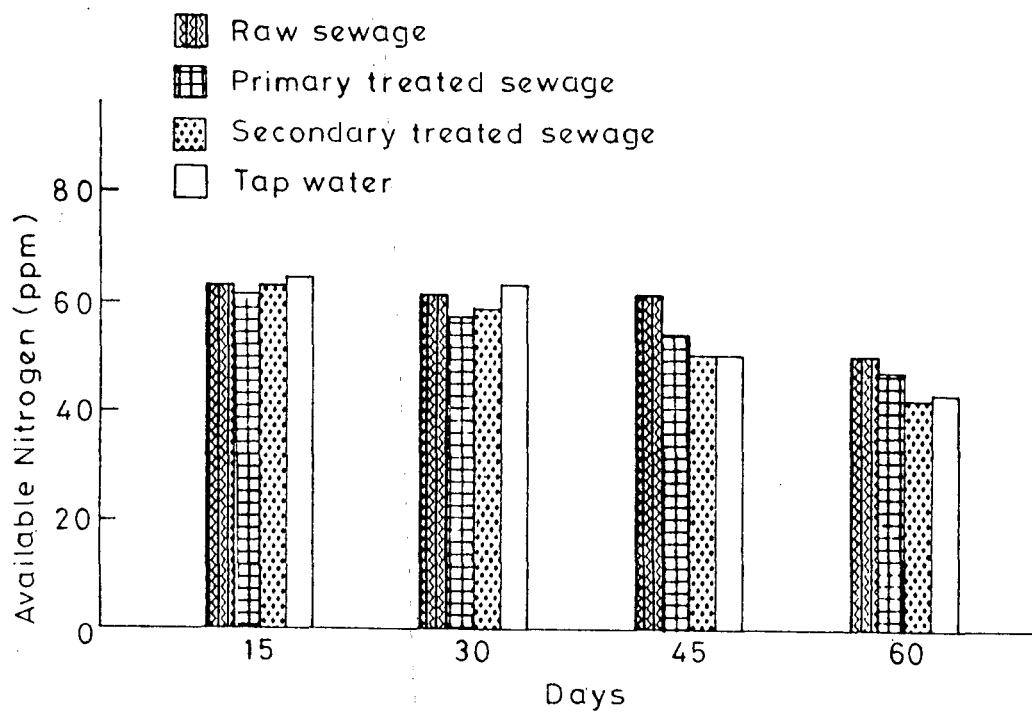OF 30 cm IN SEWAGE TREATED SOIL COLUMNS

FIG. 8 CHANGES IN AVAILABLE NITROGEN AT A DEPTH OF
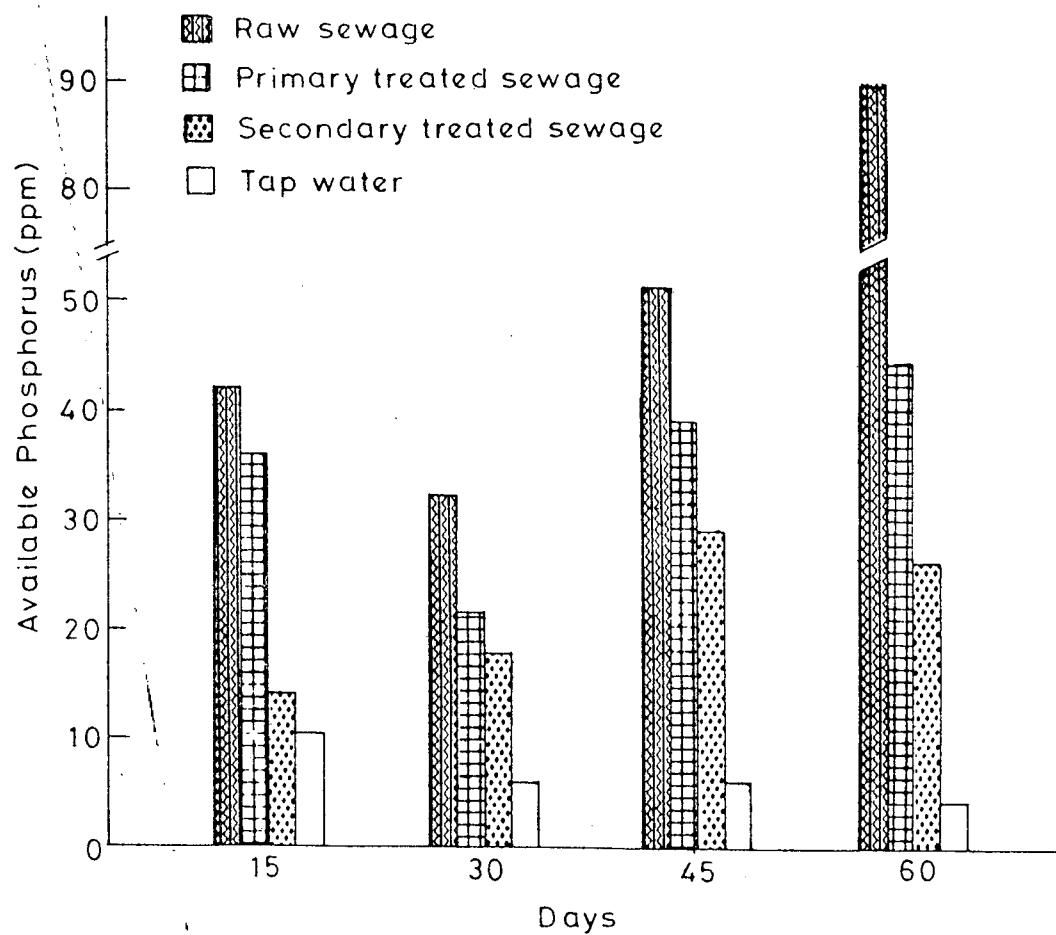
45 cm IN SEWAGE TREATED SOIL COLUMNS

FIG. 9 CHANGES IN AVAILABLE PHOSPHORUS IN THE SURFACE LAYER OF SEWAGE TREATED SOIL COLUMNS
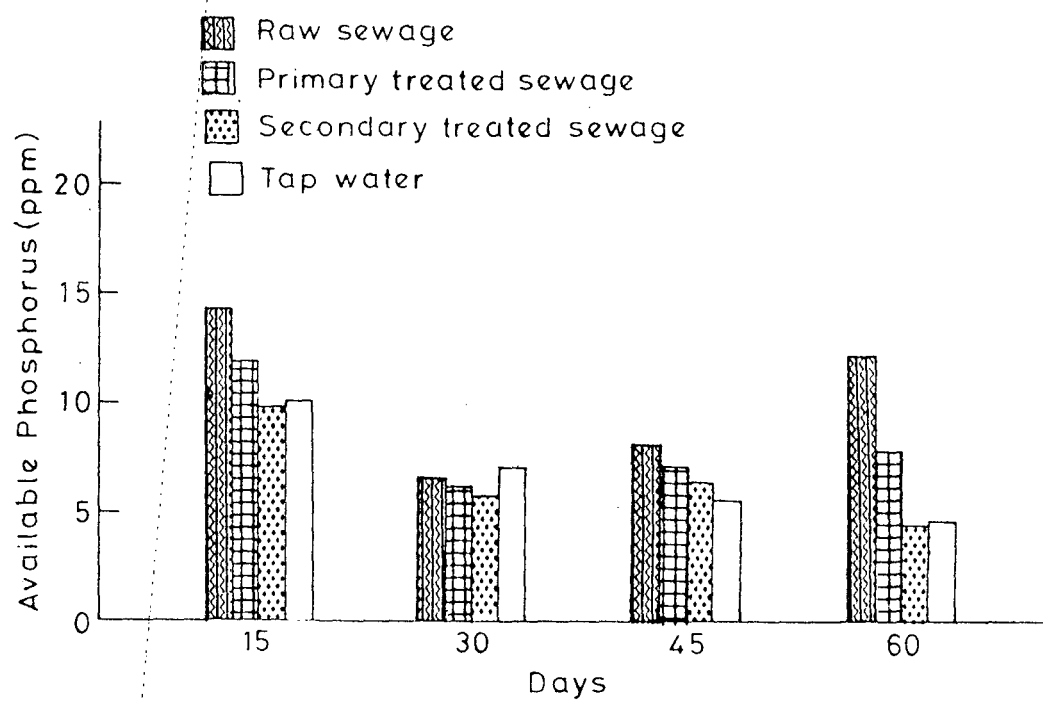
FIG. 10 CHANGES IN AVAILABLE PHOSPHORUS AT A DEPTH
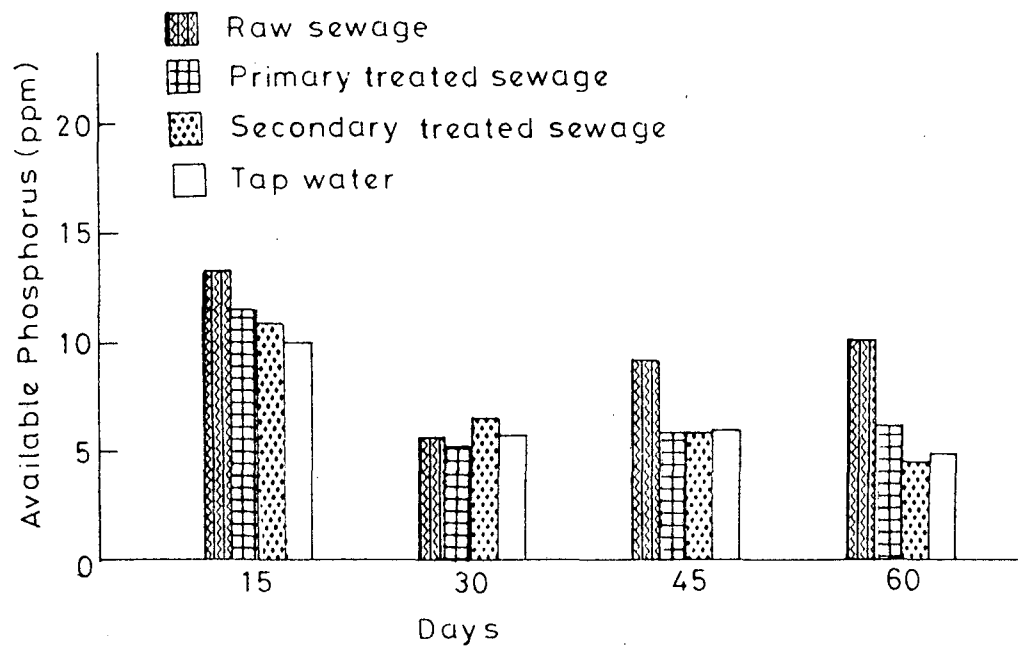OF 15 cm IN SEWAGE TREATED SOIL COLUMNS

FIG. 11 CHANGES IN AVAILABLE PHOSPHORUS AT A DEPTH
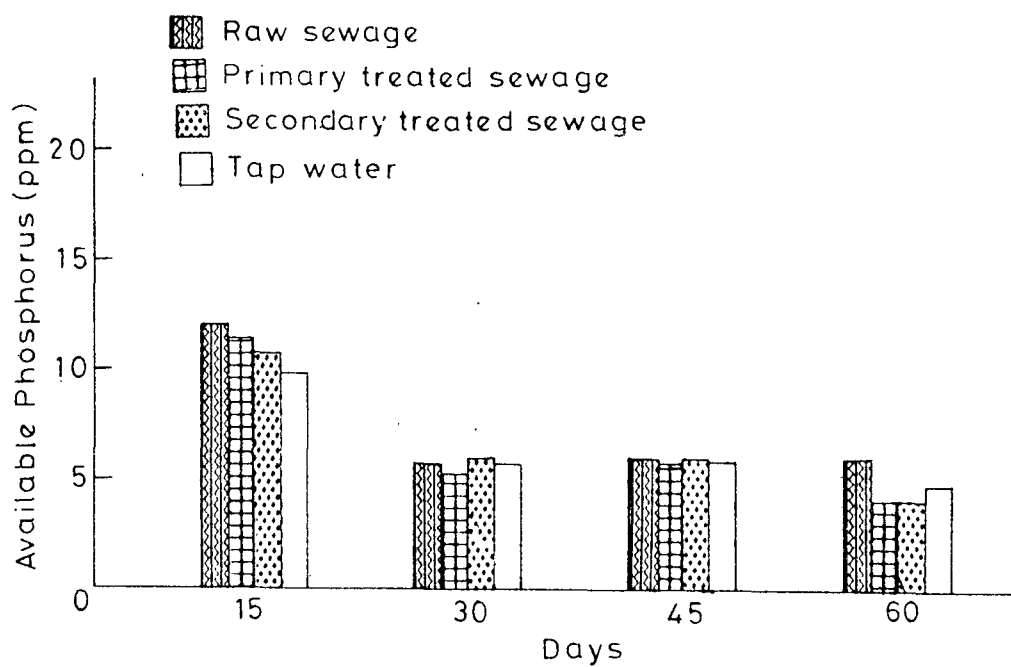
OF 30 cm IN SEWAGE TREATED SOIL COLUMNS

FIG. 12 CHANGES IN AVAILABLE PHOSPHORUS AT A DEPTH
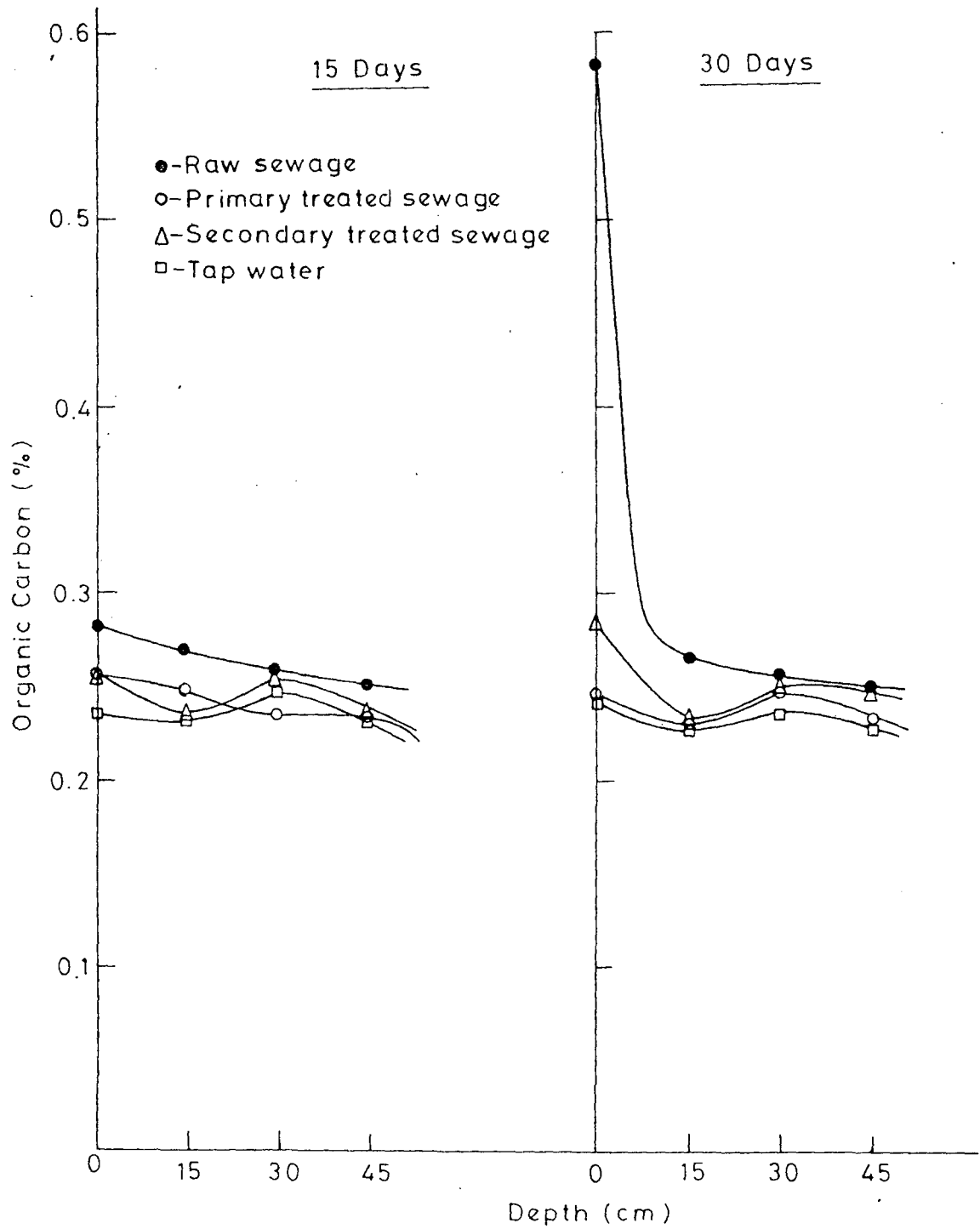OF 45 cm IN SEWAGE TREATED SOIL COLUMNS.

FIG. 13a DISTRIBUTION OF ORGANIC CARBON AS A FUNCTION
OF DEPTH IN SEWAGE TREATED SOIL COLUMNS
(15 AND 30 DAYS)

FIG. 13b. DISTRIBUTION OF ORGANIC CARBON AS A
FUNCTION OF DEPTH IN SEWAGE TREATED SOIL
COLUMNS (45 AND 60 DAYS)

FIG. 14a. DISTRIBUTION OF AVAILABLE NITROGEN AS A
FUNCTION OF DEPTH IN SEWAGE TREATED SOIL
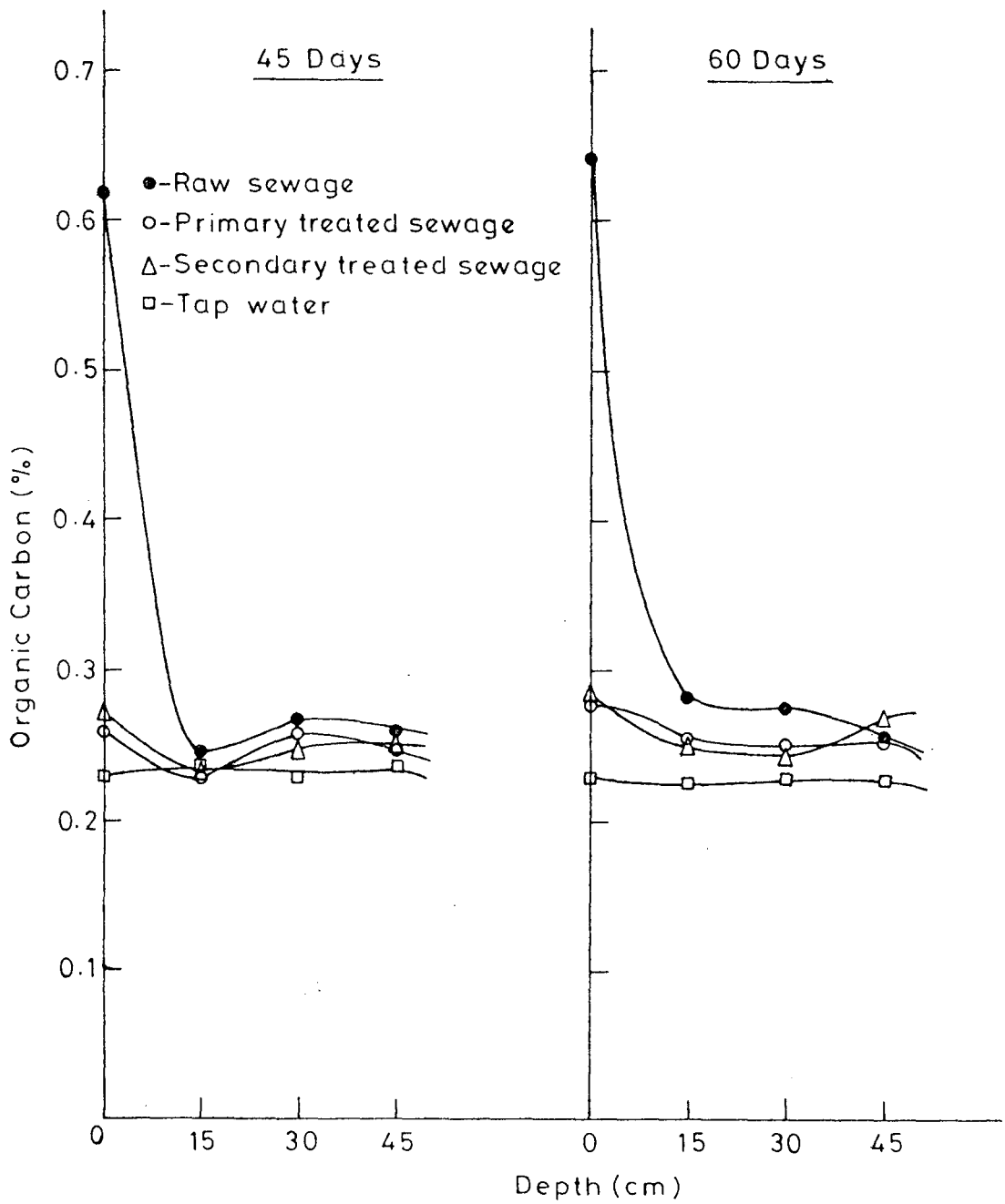COLUMNS (15 AND 30 DAYS)

FIG. 14b. DISTRIBUTION OF AVAILABLE NITROGEN AS

A FUNCTION OF DEPTH IN SEWAGE TREATED SOIL

COLUMNS (45 AND 60 DAYS)

FIG. 15a. DISTRIBUTION OF AVAILABLE PHOSPHORUS AS
A FUNCTION OF DEPTH IN SEWAGE TREATED SOIL
COLUMNS (15 AND 30 DAYS)

FIG. 15b. DISTRIBUTION OF AVAILABLE PHOSPHORUS AS A

FUNCTION OF DEPTH IN SEWAGE TREATED SOIL

COLUMNS (45 AND 60 DAYS)
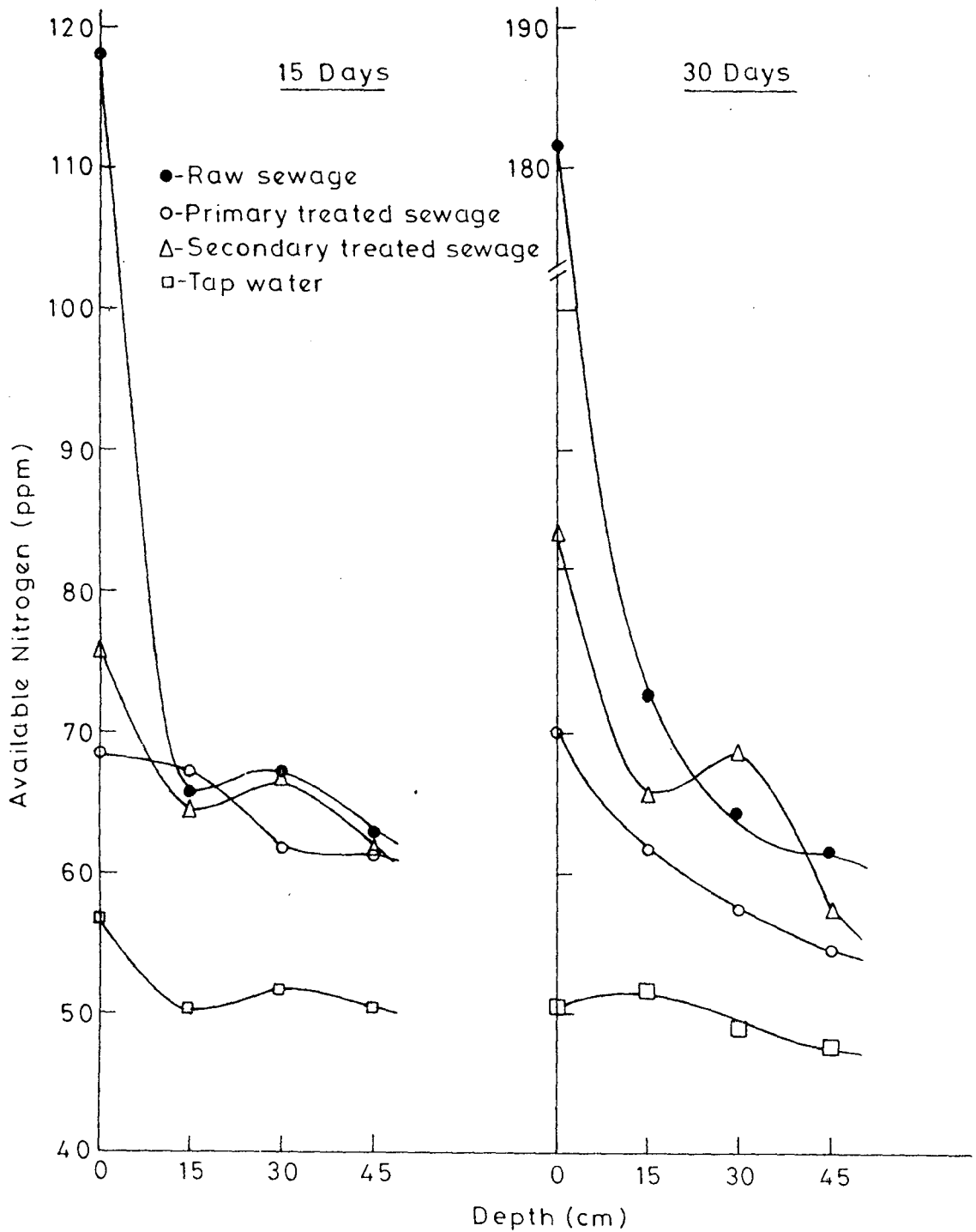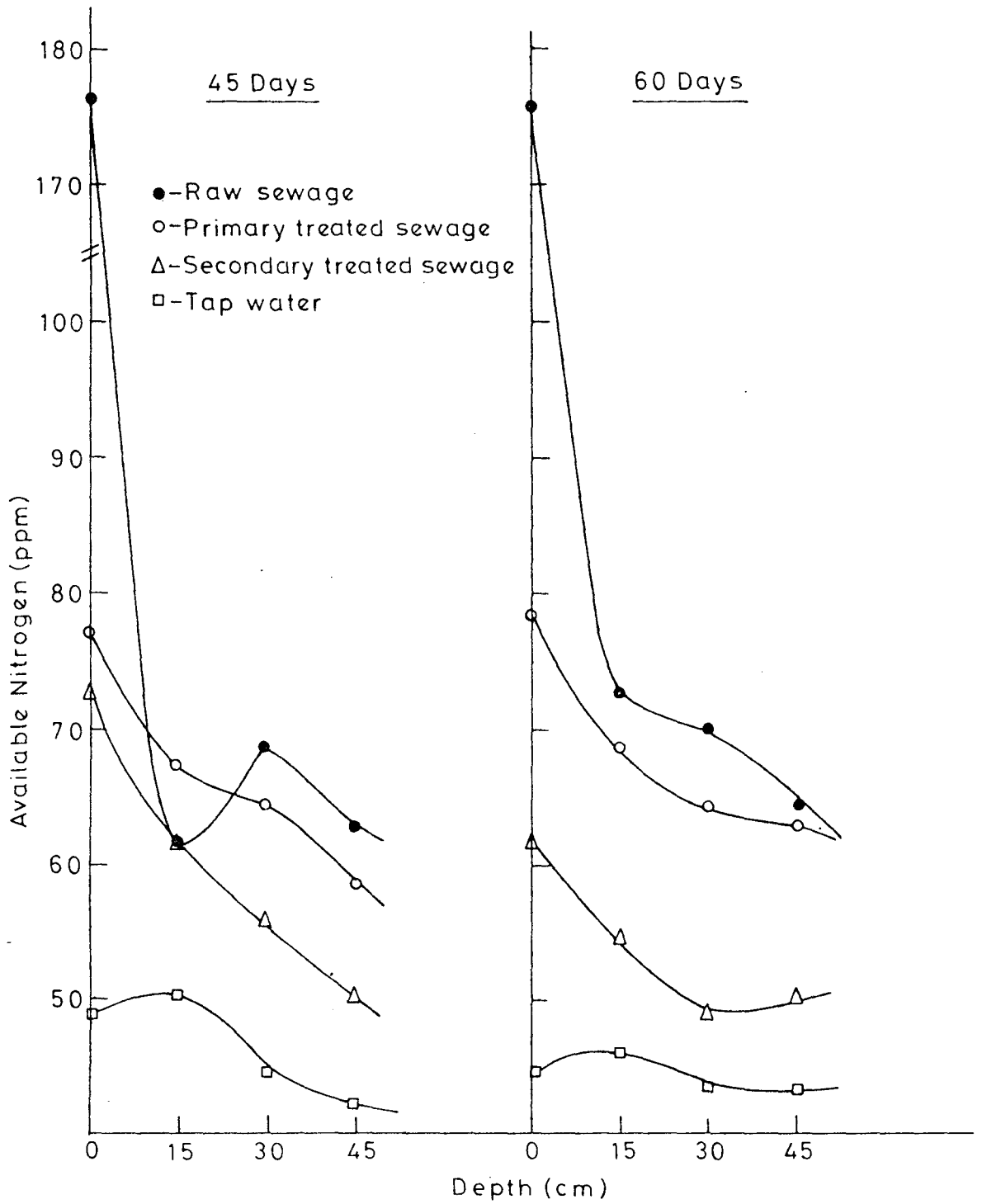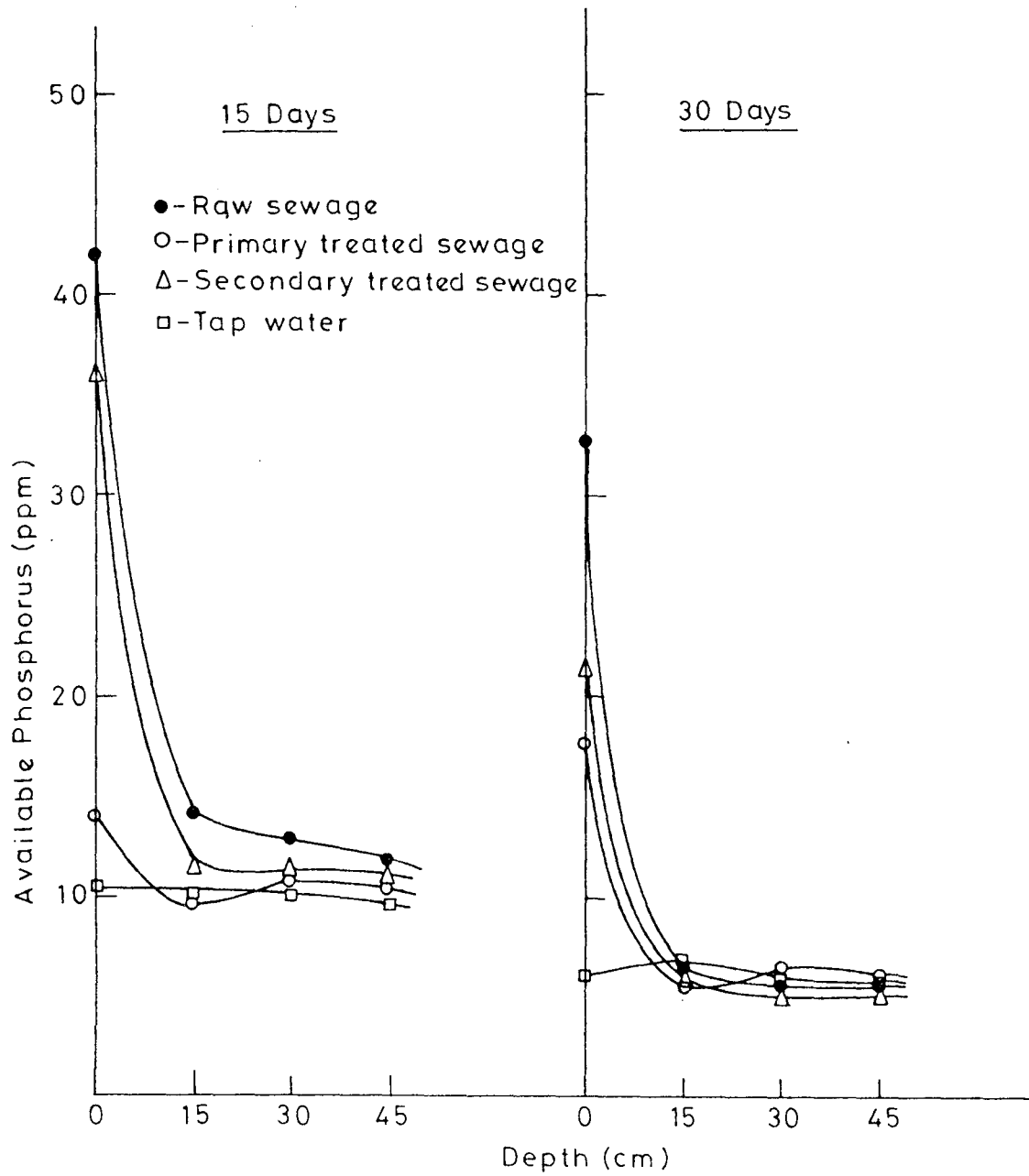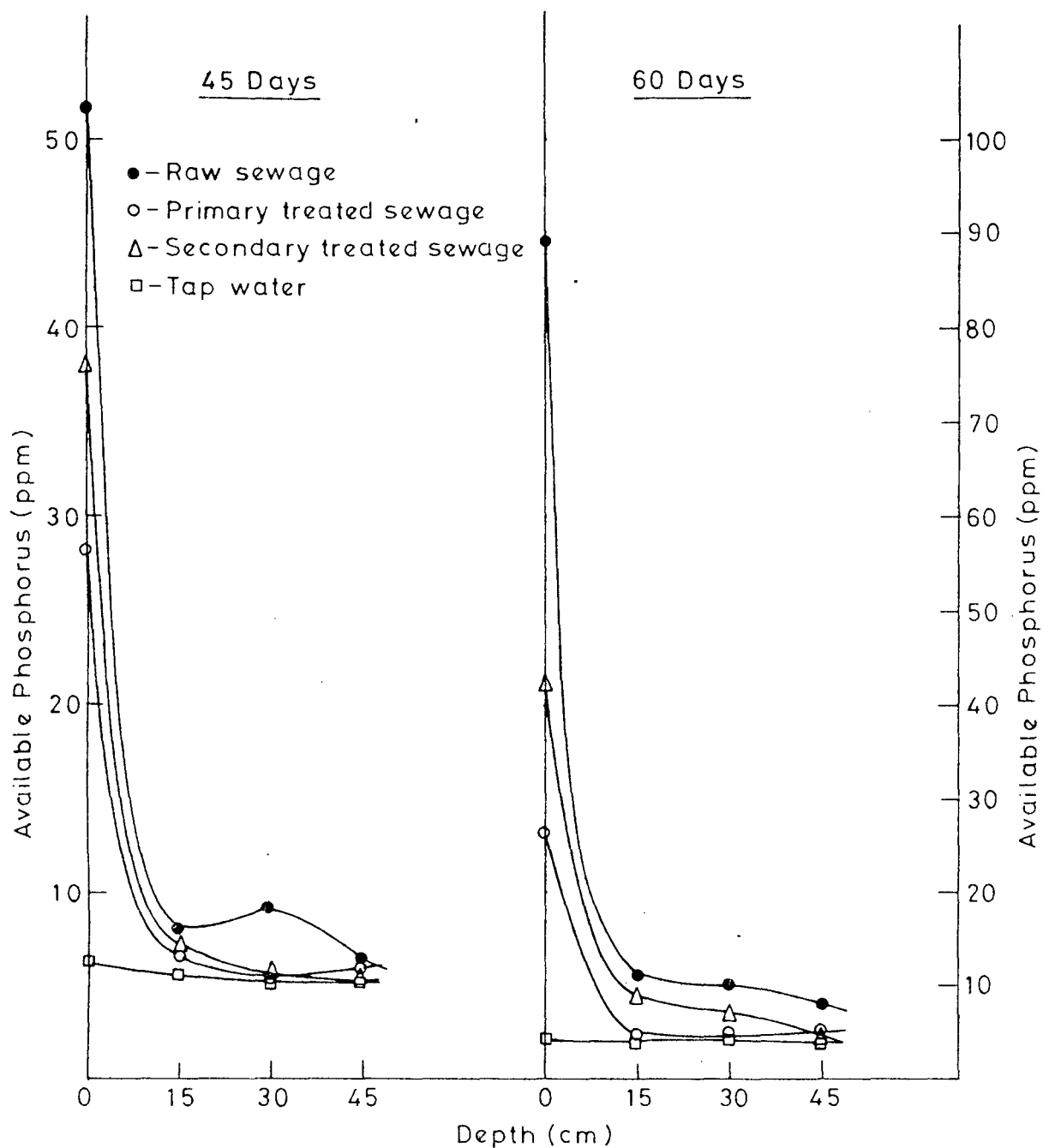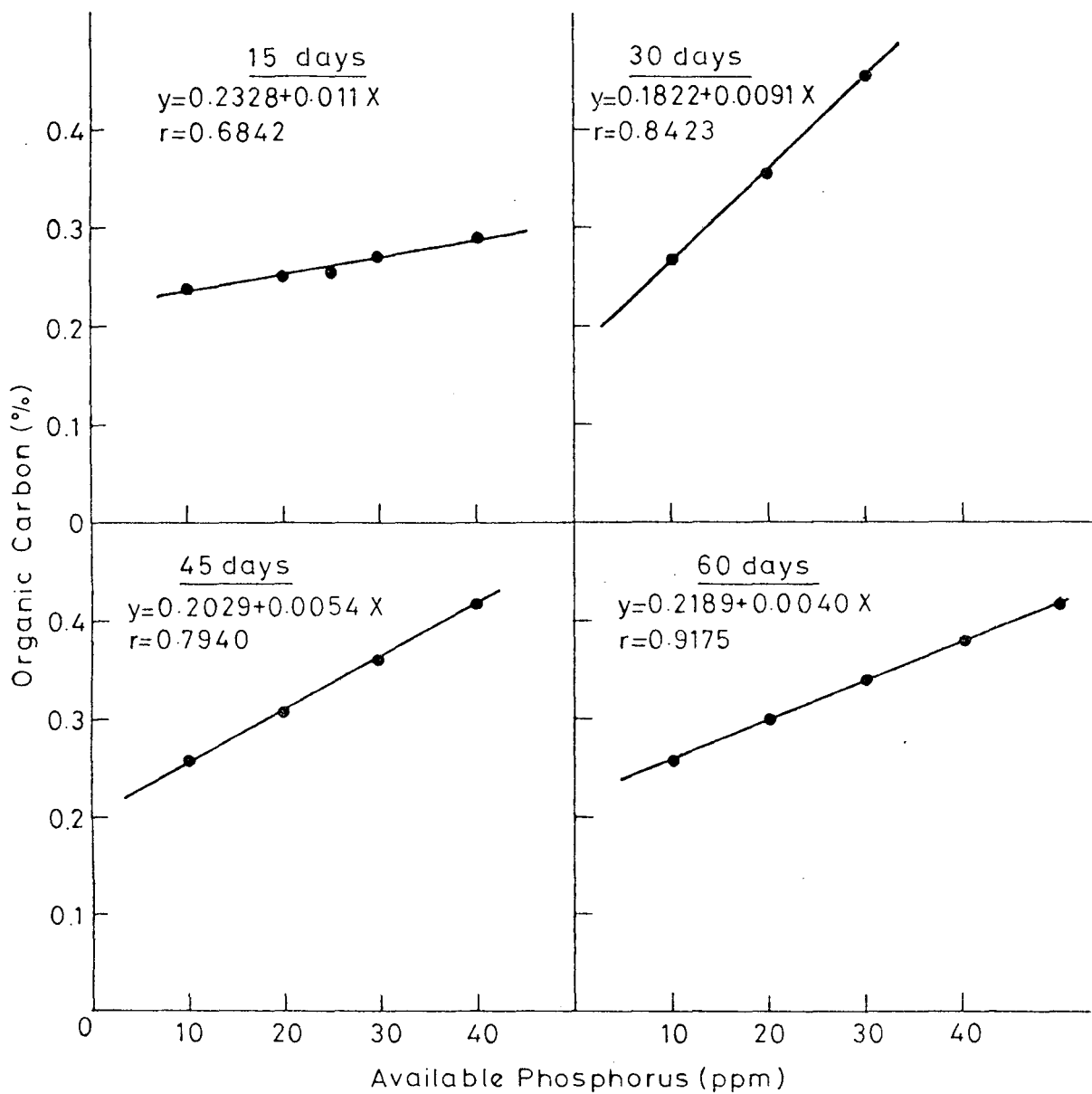
FIG. 16 RELATIONSHIP BETWEEN AVAILABLE PHOSPHORUS
AND ORGANIC CARBON IN SEWAGE TREATED
SOIL COLUMNS.
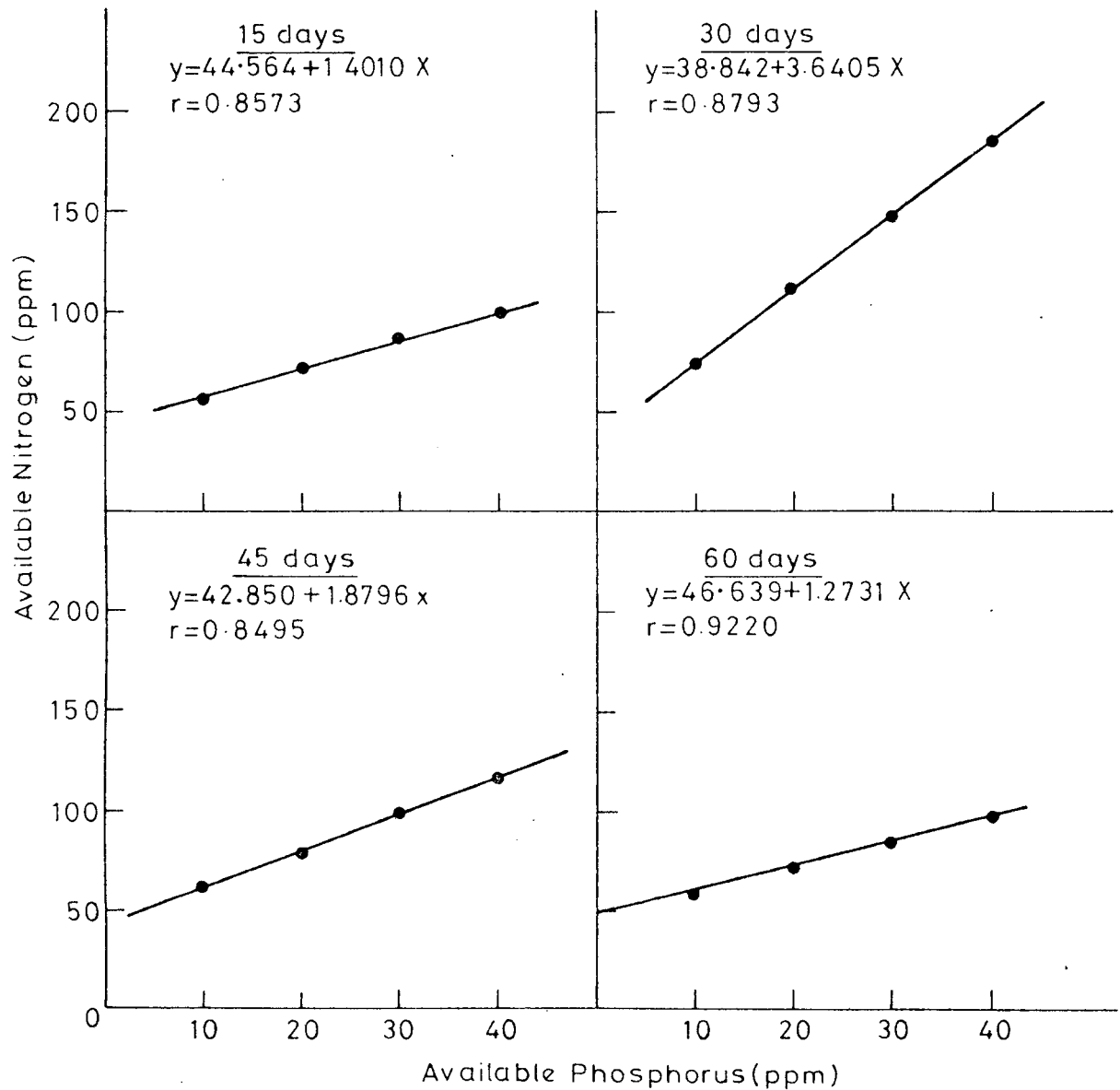
FIG. 17 RELATIONSHIP BETWEEN AVAILABLE PHOSPHORUS

AND AVAILABLE NITROGEN IN SEWAGE TREATED

SOIL COLUMNS.

DISCUSSION AND CONCLUSION

pH: A close observation of table 5 shows that only in the surface layers of soil the pH values have decreased by about one unit within 60 days. This may be attributed to the fact that surface layers were in direct contact with the atmosphere throughout the incubation period and hence they were subjected to aerial oxidation and microbial activity. As a consequence, some organic acid might have been formed during the treatment resulting in the decrease of soil pH in the surface layer. The release of H^+ ion during nitrification of ammonium salts and organic nitrogen added through the sewage effluents might have also lowered the pH (Broadbent et al., 1977).

ELECTRICAL CONDUCTIVITY

The electrical conductivity value is related to the amount of soluble salts and other ions present in the medium. Accumulation of these ions in the soil from the effluents resulted in the increase of electrical conductivity values in the sewage amended soil columns. Bole (1979) reported that the electrical conductivity of surface layer up to 90 cm of soil columns increased appreciably when treated with effluents.

Electrical conductivity values during the present study of the soil columns amended with secondary treated sewage were relatively higher in all the layers than

in the other two treatments. More organic matter accumulation on the surface layers of the soil columns in the other two treatments might have led to ionic complexation and chelation of soluble ions with organic matter accounting for slightly lower electrical conductivity values in these surface layers.

ORGANIC CARBON

Increase of organic carbon content in different layers of the soil columns treated with effluents might be due to the presence of organic carbon in the effluents. Since raw sewage contained more organic carbon compared to the other effluents, the values were higher in all the layers of this column. Again the sharp increase (table 7) of organic carbon within 30 days in the surface layer of the column treated with raw sewage might be due to the higher organic carbon content (0.0168%) in the second effluent sample compared to the first sample (0.0126%). In addition to this the suspended organic matter in the raw sewage which accumulated on the surface layer might have undergone microbial activity resulting in more mineralised organic matter. (Beek, et al., 1977; Quin and Wood, 1978).

The slight decrease in the final values of almost all the other layers showed that organic carbon contributions by the effluents might have been balanced by

the quantity lost due to decomposition during the treatment.

In the case of the control treatment the decrease in organic carbon of the soil throughout the experiment could be due to the fact that it did not receive any organic matter during the period but loss might have occurred through normal microbioal decomposition process (Sekar and Bhattacharyya, 1982).

AVAILABILE NITROGEN

The increase in available nitrogen in the soil columns treated with sewage was due to the presence of available nitrogen in the effluents. Available nitrogen in the surface layer of the soil column treated with raw sewage increased appreciably within 30 days. This increase was obviously due to the fairly high amount of available nitrogen in the raw effluent. Besides this the mineralisation of organic nitrogen from organic matter which accumulated on the surface layer of this column could also account for the high value. The peak values in the surface layers of raw and primary treated sewage were 184.8 and 84 ppm respectively and corresponding average values of available nitrogen in the sewage samples were 26.8 and 21.6 ppm. This shows a proportionately much higher value in the raw sewage treatment which might

be due to contributions from the mineralisation of organic nitrogen.

The slight decrease in available nitrogen towards the end indicated that the rate of loss of nitrogen exceeded the amount entering the soil profile through the effluents. Gilbert et al., (1979), have worked on denitrifying bacteria populations and nitrogen removal in soil columns intermittently flooded with secondary treated sewage. Their studies showed that nitrogen removal processes include (i) denitrification (ii) volatilisation of NH_4^+ (iii) adsorption of NH_4^+ by clay fraction (iv) incorporation into microbial tissues (v) adsorption of NH_3 by organic matter. In addition to this, microbial processes affecting nitrogen removal dominated in the surface 15 cm of the soil profile where carbon, nitrogen sources and environmental conditions necessary for denitrification were concentrated (Gilbert et al., 1979).

A combination of all the above factors might have been responsible for the decrease in the available nitrogen content of the surface layer towards the end. Broadbent and coworkers (1977) observed that the optimum pH for nitrification was neutral to slightly alkaline. This was the pH range of the soil column under the present study.

Variations in available nitrogen similar to the

present study were reported earlier by Sekar and
Bhattacharyya (1982) while working on effects of sewage
on carbon and nitrogen mineralisation of Delhi soil. The
decrease in available nitrogen in the check treatment
throughout the incubation period might be due to the gradual
loss of nitrogen at every stage.

AVAILABLE PHOSPHORUS.

The increase in the levels of available phosphorus
within 15 days in the column treated with sewage effluents
was primarily due to the presence of soluble phosphate
in the effluents. A linear relationship exists between
the soluble phosphorus extracted and the amount added
(Sharpley et al., 1984). This accounts for the compara-
tively high values in the column treated with raw sewage.

The values of available phosphorus in the soil column
have almost invariably decreased in all the layers within
30 days of incubation. This might be due to the fact that
the amount of phosphate fixation in the soil was more than
the amount entering the soil profile. Milne and Graveland
(1972) found that available phosphorus in sludge-amended
soils increased after two weeks of incubation under labo-
ratory experimental conditions, but then decreased only
after four weeks in two of their soil samples. This decr-
ease was attributed to phosphate fixation in the soils.

Significant increase, specially in the surface layers of the soil columns till the end of the experiment was due to the accumulation of phosphorus on the soil surface. There is a lot of evidence regarding the accumulation of phosphorus in the surface layer of the soil profile. This might be due to the less mobility of phosphate ion in soils (Hill et al., 1981 Sleight et al., 1984) Sommers et al. (1979) working on the effects of wastewater irrigation on the status of soil phosphorus showed that majority of the available phosphorus remained in the upper 30 cm of the clay loam soil. Similar observations were also reported by Meek et al., (1979), and Sleight et al, (1984).

The available phosphorus in the surface layer of the columns treated with raw sewage increased appreciably at the end of the treatment (88.6 ppm). This might be due to i) addition of relatively high soluble phosphate present in the raw sewage ii) mineralisation of organic phosphorus iii) and greater rate of phosphorus mineralisation due to increase of temperature (Hooker et al., 1980).

The last factor has been included since the climate was relatively warmer towards the end of the experiment Mineralisation of organic phosphorus and its contribution to the avaialable pool is supported by the following observation.

The peak values in the surface layer of the soil columns under the application of raw sewage and primary treated sewage were 88.6 and 44.6 ppm (table 9) and the corresponding average values of soluble phosphate in the sewage samples were 5.03 and 4.2 ppm respectively. It was evident from these values that in the former treatment the value was proportionately much hihger indicating that some other source might have contributed to the available pool. This could be due to the mineralisation of organic phosphorus in the surface layers of the column treated with raw sewage. Higher organic carbon content in the same layer of this column supported this assumption. (Adepetu and Corey 1976). The comparatively lower value in the surface layer of columns under the application of secondary treated sewage might be due to i) low soluble phosphate present in the effluent and ii) less mineralisation of organic phosphorus.

Values of available phosphorus in some of the layers of primary and secondary treated soil columns were much lower than that in the original soil. This might be due to phosphate fixation, the chances of phosphate losses due to leaching was ruled out because of the low mobility of phosphate ion (Hill and Sawhney, 1981).

In the control treatment, the increase in available phosphorus after 15 days could be due to the release of

phosphate from some labile source as a result of moist conditions imposed after the treatment. The subsequent decrease at the end of the treatment might be due to the reversion of phosphate (Milne and Graveland, 1972).

The alternate increase and decrease observed in some of the layers of the soil column treated with effluents might be due to microbial activity.

Microbial population regulates the available phosphorus. Increase in microbial population would immobilise a portion of phosphorus. Phosphorus would then become available as the microbial population decreases. Rates of phosphorus mineralisation and release from microbial cell are probably functions of phosphorus added, organic matter, soil temperature, moisture content and other factors. These factors temporarily could cause immobilisation of phosphorus (Goss et al., 1979).

Correlation between available phosphorus and other soil parameters.

The constants of correlation analysis between available phosphorus and other soil parameters have been presented in table 10. Available phosphorus was found to be highly correlated with organic carbon, the maximum being at the end of 60 days ($r = 0.9175$). This shows that organic matter

has a considerable influence on phosphorus mineralisation (Adepetu and Corey, 1976).

It was also observed that available phosphorus had a significant correlation with available nitrogen. Thus it could be inferred that nitrogen mineralisation and phosphorus mineralisation are inter related. As in the previous case maximum correlation was obtained at 60 days (r = 0.9220).

Available phosphorus and pH had a significant negative correlation (r = -0.589). This can be explained by assuming that accumulation of phosphorus is the precursor of OH^- ion removal thus lowering the pH value (LopezHernandez et al., 1979). However, available phosphorus was found to have no significant correlation with electrical conductivity.

SUMMARY

A laboratory experiment was conducted using Delhi Soil in P.V.C. Columns to study the changes in available phosphorus and other soil parameters under the application of municipal wastewater for a period of two months and to examine the movement and accumulation of phosphorus in the soil columns. The salient findings of the experiment are summarised below.

Significant increase in the values of electrical conductivity was observed in the sewage treated soil. This could be due to the accumulation of ions in the soil from the effluents. The pH values suffered a slight decline in the surface layer probably due to i) release of H^+ ion through nitrification processes and ii) displacement of OH^- by the PO_4^{---} ion.

Appreciable increase in organic carbon content was observed only in the surface layer of the column treated with raw sewage. This was due to the i) contribution from the effluent ii) accumulation and mineralisation of suspended organic matter. Significant increase in available nitrogen was observed in the surface layers. This could be attributed to i) contribution from the effluents and ii) mineralisation of organic nitrogen.

In the columns treated with raw sewage and primary treated sewage increase in available nitrogen was also observed to some extent in the lower layers of soil columns.

Available phosphorus content in the surface layers of the soil columns also showed a remarkable increase. The peak value of available phosphorus was 88 ppm in the soil column treated with raw sewage. This could be due to i) input of soluble phosphate from the effluents ii) very low mobility of PO_4^{---} ion and iii) mineralisation of organic phosphorus. In the columns treated with raw sewage there was a little increase in available phosphorus up to a depth of 30 cm.

This indicates that Delhi Soil has the capacity to retain an appreciable amount of available phosphorus. Correlation studies reveal that available phosphorus is highly correlated with organic carbon (r = 0.912) and also with available nitrogen (r = 0.92). The pH has a significant negative correlation with available phosphorus, however no significant correlation has been found with electrical conductivity.

From the environmental point of view the use of

secondary treated sewage for irrigation purpose appears to be quite acceptable for Delhi Soil. However, extensive long term studies regarding the accumulation of nutrients, toxic substances, pathogens, etc are essential before utilising the treated effluent for agricultural purpose.

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