640

ACCUMULATION AND MOVEMENT OF AVAILABLE POTASSIUM IN SEWAGE TREATED DELHI SOIL

Dissertation submitted to the Jawaharlal Nehru University
in partial fulfilment of the requirments for the
award of the degree of

MASTER OF PHILOSOPHY

MUKESH KUMAR

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067
1986

CERTIFICATE

This dissertation entitled "Accumulation and Movement of Available Potassium 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.

Mukesh Kumar

MUKESH KUMAR
(Student)

DR. A.K. BHATTACHARYYA
(Supervisor)
24/X/86

24.10.86
PROF. V. ASTHANA
(Dean)

OCTOBER, 1986

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI - 110 067.

ACKNOWLEDGEMENT

I express my deep sense of gratitude to Dr. A.K. Bhattacharyya, Associate Professor for having suggested me this problem, his valuable guidance and supervision throughout the course of this work. His constructive suggestions at the time of preparing this dissertation helped me in bringing it to the final shape.

I am thankful to Prof. V. Asthana, Dean and Prof. Mrs. Anjali Mookerjee, the former Dean, School of Environmental Sciences, for providing me with necessary facilities and help.

I am grateful to the authorities of Delhi Water Supply and Sewage Disposal Undertaking for their kind permission to collect the effluents from Okhla Sewage Treatment Plant, New Delhi for my research work. I am thankful to Mr. S.K. Sharma, Water Analyst and Mr. R.K. Vig, Chemist, Okhla Sewage Treatment Plant for their active co-operation and necessary help given to me.

I am thankful to Prof. J.M. Dave for his valuable suggestions during this study. Thanks are due to Prof. H.K. Das for his keen interest, inspiration and constant encouragement.

My appreciations are also due to my seniors, especially Dr. S.P. Mohapatra and friends, especially Supriyo and Laxmi for their various kinds of help to complete this work.

I am grately indebted to my parents and elder brother, Mr. V.K. Agarwal for their encouragement and inspiration during this period.

Finally, I acknowledge the financial assistance in the form of JRF offered to me by Jawaharlal Nehru University to carry out this research work.

Mukesh Kumar
24.10.86
(MUKESH KUMAR)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX

A. Tolerance limits for inland surface waters for irrigation, industrial cooling or controlled waste disposal.

B. Indian Standards Institute Standard No. IS 3307 of 1965 "Tolerance limits for industrial effluents discharged on land for irrigation".

C. Concentration of metals in the sewage effluents from Okhla Sewage Treatment Plant, New Delhi.

D. Chemical characteristics of sewage effluents from Okhla Sewage Treatment Plant, New Delhi.

E. Water Quality of reuse water from Sewage Treatment (1964) in Japan.

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
BOD	Biochemical Oyxgen Demand
cm	Centimeter(s)
COD	Chemical Oxygen Demand
Conc.	Concentration
DO	Dissolved Oxygen
EC	Electrical conductivity
FP	Flame photometer
gm	gram (s)
kg/ha/year	Kilograms per hectare per year
km	Kilometer(s)
meq	Milli-equivalents
MGD	Million gallons per day
mg/1	Milligrams per litre.
ml	Millilitre
$m.m^3/d$	Million cubic meters per day
ppm	Parts per million

INTRODUCTION

Proper management of municipal and industrial wastes is necessary not only for our welfare, but also for the well-being of future generations. Land disposal remains one of the viable methods of waste management practices. An important task in waste disposl is adequate evaluation of the confinement and the rate of movement of pollutants from the source of contamination in the soil. Also precise information on the fate and attenuation of pollutants is needed to establish a base for evaluating waste-disposal system (Amoozegar et al., 1984).

Increasing volumes of municipal waste water are usually correlated with increasing demands on the local water supply which, in turn, is related to increasing population, urbanisation and industrialisation.

Waste water renovation and reuse technology has today become a major area of interest to engineers, biologists, chemists, agronomists, public health officers and water resources authorities. Their concern may vary from the need to prevent surface water pollution, the desire to conserve and recycle soil nutrients and the development of additional water resources for agriculture, industry, or urban uses as well as the protection of public health.

As the water resources are limited and are being rapidly despoiling and exhausting, it is very essential to pay attention to rational conservation, renovation and reuse of water to protect our precious water resources and recycle them for the better use of man. The driving force to resue waste-water has mainly been the urgent need to conserve and reuse water in arid areas and to reduce river and lake pollution (Shuval, 1977).

The conventional waste water treatment plants are not fully efficient to remove all the potentially harmful organic and inorganic pollutants. They are also incapable to remove or inactivate all harmful micro-organisms of sewage origin. There must be some alternative method to remove these harmful elements upto some extent. The application of municipal wastewater on the agricultural land could be one of the best alternative ways for disposal of the wastewater.

The pollution control approach is exemplified by the report of the first Royal Commission on Sewage Disposal in England in 1865. The Commission recommended that "the right way to dispose off town sewage is to apply it continuously to land, and it is by such application that the pollution of rivers can be avoided". At the end of the last century, the concept of land treatment of sewage by grass filtration and broad irrigation was initiated in the United Kingdom, Germany and the United States primarily as a method of sewage treatment to reduce river pollution rather than as a rational method of conserving water or returning nutrients to the soil.

Discharge of raw or only partially treated wastewater into natural water resources has in many cases, resulted in eutrophication of lakes, rivers, estuaries and other natural waters. In 1972, the U.S. Water Pollution Control Act Amendment (PL 92-500) established a national goal of eliminating the discharge of pollutants to the natural waters by 1985. It was apparent that reclamation of waste water by conventional sewage treatment would not be adequate to achieve this goal and the need for alternatives arose. This coincides with the world shortage of food, fertilizer, and energy supplies (Iskandar, 1978). The alternative methods also could reduce pollution of surface waters (Lance et al., 1982).

Thus with shortages and subsequent increased costs of fertilizer materials due to energy crisis, greater interest is being manifested in the use of waste materials such as sewage effluents and sludge for fertility of agricultural lands (Boswell, 1975).

In Egypt, the simplest and most logical way to get rid of liquid effluents might seem to be to redistribute them by irrigation of orchards and farms (not garden crops), particularly in regions with sandy soils. These soils have no available means of irrigation and are very poor in organic matter and plant nutrients. The liquid effluents are usually rich in soluble salts that furnish plant nutrients. In addition to nitrogen, the most important plant nutrients are the non-metals, viz. phosphorus and sulphur, and the metals, viz. Potassium, calcium, and magnesium with smaller amounts of micronutrients particularly iron, manganese, and boron (El-Nennah and El-Kobbia, 1983).

The application of industrial wastes and sewage sludges on agricultural soils is receiving greater emphasis because of the increasing energy requirements and costs associated with alternative disposal methods and because of the benefits gained from recycling plant nutrients present in wastes. After application to soils, the various components in wastes are subjected to a diversity to chemical and biochemical processes. For most wastes, the main processes of interest are decomposition of organic compounds, transformation of N, P, and K and alteration of metal solubility. These processes, either directly or indirectly, influence the availability of metals and nutrients to plants, the mobility of N, P, K, Ca, and Mg, and the potential environmental impact (e.g. ground water contamination) resulting from waste application on soil (Sommers et al., 1979).

The water and soil pollution due to industrialisation and urbanisation is a co~~n~~smopolitan problem, creating accute insanitation as well as affecting the soil and crops (Ajmal and

Khan, 1983). But according to Day et al. (1972), irrigation with waste water over extended periods did not decrease field crop yields or result in any major deleterious effects on agricultural soils in southern Arizona.

The advantages in the use of treated waste water for irrigation are (a) low-cost source of water, (b) an economical way to dispose off waste water to prevent pollution and sanitary problems, (c) an effective use of plant nutrients contained in waste water, and (d) providing additional treatment before being recharged to the ground water reservoir.

The factors affecting waste water utilization, its composition, and possible application undoubtedly vary from place to place. Untreated waste water is considered a health and aesthetic nuisance. Waste water, even after some degree of treatment, can cause the pollution of waterways, rivers, and ground water reservoir. Waste water is usually the cheapest water in the arid areas. In some cases, it is the only water available for irrigation (Noy and Feinmesser, 1977).

The application of waste water in irrigation brings about the renovation of the percolating water through the soil profile, especially in the presence of growing plants. The root zone is considered a 'living filter' and the 'effective renovation' has been defined as:

$$\frac{\text{Kg of nutrients used by plants}}{\text{Kg of nutrients added in irrigation water}} \times 100$$

The soil does act as a physicochemical 'filter' by removing colloidal and larger particles from the waste water. The 'living filter' theory is based partially on the biodegradation and, to some extent, chemical degradation that occur in soil based systems. Further, soil may have a significant capacity to sorb dissolved solutes present in waste water. In addition, certain types of chemical transformation, such as reactions would tend to remove chemicals from the waste water and prevent their entering the aquifer. Finally, it is known that during certain periods of the year, terrestrial plants remove some chemical constituents by uptake of these constituents through their root system (Lee, 1976).

Direct resue of municipal and industrial waste water for irrigation purposes is extensively practiced in India. The warm climate, the practically negligible flow in most of the streams during the summer months, and the need to grow more food for its teeming millions make irrigation the favoured mode of disposal of waste waters. The first sewage farm in India was established as far back as 1895. In 1976 there were over 132 farms covering more than 12,000 hectares and utilizing over 1 million m^3 of sewage per day (Arceivala, 1977).

OKHLA SEWAGE TREATMENT PLANT

Okhla sewage treatment plant is situated in South Delhi about 6 km far from Lajpat Nagar. Besides this Okhla treatment plant, there are two more sewage treatment plants in Delhi. One is Keshopur sewage treatment plant in West Delhi and another is Coronation Pillar in North Delhi.

The first stage of Okhla treatment plant started in 1936 and since then it has undergone development in five stages. The present capacity of the plant is 88 MGD. However, it can withstand an overload of 25%. The treatment process is fully biochemical. No chemical is added from outside here. A part of the final treated effluents is sent to the Minor Irrigation Division and the rest of the effluents is by-passed to the Agra Canal (Vig and Sharma, 1986). The treated effluents are continuously available for irrigation (Swamy et al., 1986).

The long term land application of domestic waste water may be hazardous due to (i) pathogenic contamination, (ii) accumulation of toxic and trace metals, (iii) clogging of soil pores with the organic solids normally present in waste waters. At high concentrations, all trace metals either essential or non-essential become toxic to plants and animals. Trace metals from the soil could be translocated to plant tissues directly through absorption. Immediate toxicity may not occur but excessive accumulation of certain metals like cadmium, molybdenum, selenium, etc. could be potentially hazardous (Page and Chang, 1981).

Data present average of duplicate samples

The present investigation was undertaken to assess the characteristics of raw sewage, primary treated and secondary treated effluents from Okhla treatment plant and to evaluate potassium movement and accumulation in soil system.

OBJECTIVES

The main objectives of this piece of research work are summarised below :

(i) To study the physico-chemical properties of sewage effluents received from Okhla Sewage Treatment Plant, before and after the treatment processes.

(ii) To analyse some physico-chemical characteristics of the soil under experiment with emphasis on the available potassium in the soil.

(iii) To observe the accumulation and movement of available potassium in soil columns when treated with raw, primary treated and secondary treated effluents.

(iv) To evaluate the correlation, if any, between the available potassium and other parameters, specially (a) organic carbon, (b) available nitrogen, and (c) pH.

(v) To compare the atomic absorption spectrophotometer and flame photometer results for potassium to evaluate the methodology for available potassium.

REVIEW OF LITERATURE

In this chapter, an attempt has been made to bring a review of the published work related to the present investigation. As the aims and objectives of the present work are limited, emphasis on certain aspects of potassium requirement in soil system and effects of sewage effluent on potassium availability has been given.

Potassium as a nutrient

Potassium (K) is an important element regulating plant growth (Palazzo and Jenkins, 1979). It is one of the essential macronutrients. The function of K is primarily regulatory (Bear, 1965). Most plants remove more K from soil than any other element except N. Typical plant content of K is about 90% of plant N for forage grasses. Intensive cropping and removel of K in the humid region, and on sandy soils generally, results in the development of stunted growth of plants exhibiting K deficiency symptoms (Bear, 1965; Russell, 1973). Thus application of water soluble forms of fertilizer such as KCl and K_2SO_4 is necessary for intensive agriculture in such areas (Sekhon, 1980). Sewage waste water also contains large quantities of water soluble potassium, therefore it can be used for K fertilization.

Potassium plays an essential role in the soil-plant system. It is an activator of dozens of enzymes responsible for such plant process as energy metabolism, starch synthesis, nitrate reduction, and sugar degradation. Because of its ease of transport across plant membranes, it is extremely mobile within the plant (Brady, 1984). ATP production is directly responsible for K ion absorption (Datta, 1985; Bunderson et al., 1985).

Some plant tissues accumulate more potassium. Tobacco leaves, for example, may contain as much as 8% potassium on the dry weight basis and may show symptoms of potassium deficiency if the content falls much below 3% (Black, 1973). In a study, plant accumulation of K was most rapid during the first harvest period. This was apparently related to the luxury consumption of K by plants. The rate of K accumulation was most affected by the rate of dry matter production (Palazzo, 1981).

Potassium in Plant Metabolism

The role of potassium in metabolism, growth and crop yield can be characterised by two major functions :

a) Potassium activates a number of enzymes (Beringer, 1978; Brady, 1984).

b) K^+ ions are very mobile within the plant as well as within a cell. K^+ is transported through biological membranes with high rate and specificity.

The high mobility of K^+ through membranes explains the participation of K^+ in stomatal regulation and osmoregulation in plants (Beringer, 1978; Brady, 1984).

More than 60 enzymes are known to need K^+ as an activator, interalia starch synthetase, acetyle-Co A synthetase and nitrate-reductase. In addition, the synthesis of functional poly-ribosomes and their binding with amino acids and the formation of peptide bonds require K^+. The stimulating effect of K^+ on photosynthesis, phloem-loading and phloem-transport as well as on the synthesis of high molecular substances within the storage organs is based on the association of K^+ with the energy status of the plant (Beringer, 1976; Sinha and Singh, 1984; Brady, 1984).

Influence of K nutrition on protein formation

Potassium is important in the synthesis of amino acids and protein from ammonium ions, because plants growing in solutions high in NH_4^+ and low in K^+ can have their tissues killed by the high concentration of ammonium ions that accumulate in them under these conditions (Russell, 1973).

The omission of K from the culture medium resulted in wide variation in nitrogen metabolism of Japanese mint (Mentha arvensis L.Var. piperascens). It was observed that potassium difficiency led to an accumulation of soluble N fractions mainly nitrate, amide and ammonical-N and fall in insoluble-N (protein N) during both the seasons. Thus it clearly shows that when K is lacking, nitrogen metabolism is hampered at ammonical and amide stages which in turn leads to the retardation of protein synthesis (Sinha and Singh, 1984).

K nutrition and yield

The application of basic plant physiology and chemistry in a study of mineral nutrition of the corn plant shows effectively the important function of K in translocation of carbohydrates (Bear, 1965).

Potassium nutrition stimulates yield of cereals primarily by increasing grain size. The better K-supply not only increased grain yield and grain size, but resulted also in grains with higher protein content. Thus, potassium stimulates quantity and quality of grains (Beringer, 1978). Also tuber development necessiates abundant supply of available potassium (Brady, 1984).

Influence of potassium on tolerance to stress

An adequate supply of potassium has an important role in resistance or tolerance to moisture and temperature abnormalities, diseases and other stresses (Nelson, 1978; Sekhon, 1980). At lower temperature K uptake is reduced. Cells are likely to be ruptured and plants lifted out of the ground by alternate freezing and thawing. Adequate K helps to decrease winter kill through a more extensive root system and higher concentrations of sugars, starch, proteins and K in the cell sap (Black, 1973; Nelson, 1978).

Soil moisture is a major factor influencing the crop yield. Of the major and secondary nutrients, excess moisture greatly reduces K uptake. Drought reduces K uptake by the plant, but added K increases uptake. Adequate K helps regulate stomates and thus helps control water loss under severe transpirational stress (Nelson, 1978; Sekhon, 1980).

Sorghum varieties which accumulated large amounts of potassium were more tolerant to salinity. Increase in potassium application to water deficient soil enhanced the yield of sorghum but had no effect on cotton. However, the length of cotton fibre has been observed to depend on the accumulation of K^+ and malate in the developing fibre (Sinha, 1978). A cultivar is able to withstand saline conditions if it can maintain a high K/Na ratio. The sodium exclusion and maintenance of higher K/Na ratio rendered a cotton variety more tolerent to salinity (Sekhon, 1980).

K and tolerance to disease

Many reports suggested that the crops fertilized with potassium have greater tolerance to certain disease (Black, 1973; Russell, 1973; Nelson, 1978; Sinha, 1978; Brady, 1984 and Baskaran, 1985).

Potassium is not a direct agent of disease control but by eliminating disorders caused by low K levels, natural resistance mechanisms in the plant are strengthened (Nelson, 1978; Baskaran, 1985). It is also reported that potassium helps in controlling diseases by enabling plants develop leaves with thickened cuticle and strong epidermal while preventing entry of the germinating spores from the leaf surface (Sekhon, 1980).

One of the most pronounced recorded effects of potassium supply on plant disease is on wilt of cotton caused by the fungus Fusarium oxysporum f. vasinfectum, (Black, 1973). Potassium is known to reduce effectively a number of diseases and pests such as bacterial leaf blight, brown plant hopper, stem rot, Sesamum leaf spot, Sheath blight and Bronzing of rice, Black rust of wheat; Sugary disease of sorghum; Shoot bores and Eye spot disease of sugarcane; Carcospora leaf spot disease of tapioca; pest incidence and root rot of sunflower; Thkha leaf spot disease of peanut; Phytophthora blight of pigeon pea; Fruit rot, Mosaic disease and Xanthomonas Vesicatoria infection of chillies; and wilt in melon (Nelson, 1978; Sekhon, 1980; Baskaran, 1985).

Movement of K

Repeated applications of fertilizer K produced a downward movement of K. Compared to the control, there was an increase in the level of soil K at the 90 to 120 cm depth (Rehm et al, 1984). The movement of K observed in this study was consistent with the results reported by Kraus~~u~~e (1965) which showed that in a lysimeter situation, K would move through a sandy soil. Movement of K applied to sandy soils has also been reported by Sparks et al. (1980 b). Other researchers have also reported the movement of K from repeated application of both fertilizer and manures (Patterson and Richer, 1966; Pratt and Laag, 1977).

Potassium can only be absorbed by roots after it has been transported to the root surface. These processes can conveniently be considered in terms of transport within the profile on a macroscopic scale, and transport within the rhizosphere upto the root or root hair surface (Tinker, 1980).

Potassium in soil

The distribution of potassium in soils on a world-wide basis follows a definite geomorphologic pattern, and is related more to the condition of weathering of the potash feldspars and micas than to the composition of the parent rocks themselves. Sandy soils, such as those derived from coarse-textured sediments in the costal plain of south-eastern United States, the Cambrian sandstone-derived soils of Central Wiscosin, and the Oxisols and Ultisols of humid tropic areas, are examples of soils low in potassium. On the other hand, soils containing large quantities of micas and feldspars are having large percentages of potassium (Bear, 1965).

Alluvial soils of India are generally rich in available potassium. The distribution of potassium in different soils is a function of the degree of weathering and nature of parent material (Goswami and Bandyopadhyay, 1980). Quantitative mineralogy of potassium in three agriculturally important and widely occurring benchmark soils of Pubjab, viz. Gurdaspur, Jalalbad, and Fajewal was determined by petrographic and X-ray diffraction techniques. Muscovite, biotite, microcline and orthoclase were found to be the potassic minerals present in the sand fractions. Micas, microcline and orthoclase occurred in the silt, while illite was the only K mineral identified in the clay fractions. Bulk of the potassium in these soils resides in micas (Sidhu and Dhillon, 1985).

Potassium cycling

The original sources of potassium are the primary minerals such as the micas and potash feldspare (microcline). As these minerals are subjected to weathering, their rigid lattice structures become more pliable. Potassium held between their 2:1 type layers is slowly made more available, first through nonexchangeable, and finally through the readily exchangeable and the soil solution forms from which plant roots take up this potassium. Potassium is eventually recycled through plant residues and wastes from animals to the soil. At a particular time most of the potassium is in primary minerals or in the nonexchangeable or fixed form, thus chemical fertilizers are increasingly important sources of available potassium for the proper growth of plants (Brady, 1984).

The major forms in which potassium is held in soils and the changes it undergoes as it is cycled through the soil and plant systems, are shown in figure 1.

Forms of K

It is generally recognized that soil potassium occurs in four phases (Goswami and Bandyopadhyay, 1978; Barber, 1984; Jensen, 1984) : water soluble phase; the exchangeable (or adsorbed) phase, containing the readily available potassium; the nonexchangeable (or fixed) phase, containing slowly available potassium in interlayer space in 2:1 aluminosilicates; and the primary mineral phase, including potassium mainly in micas and feldspars (Jensen, 1984).

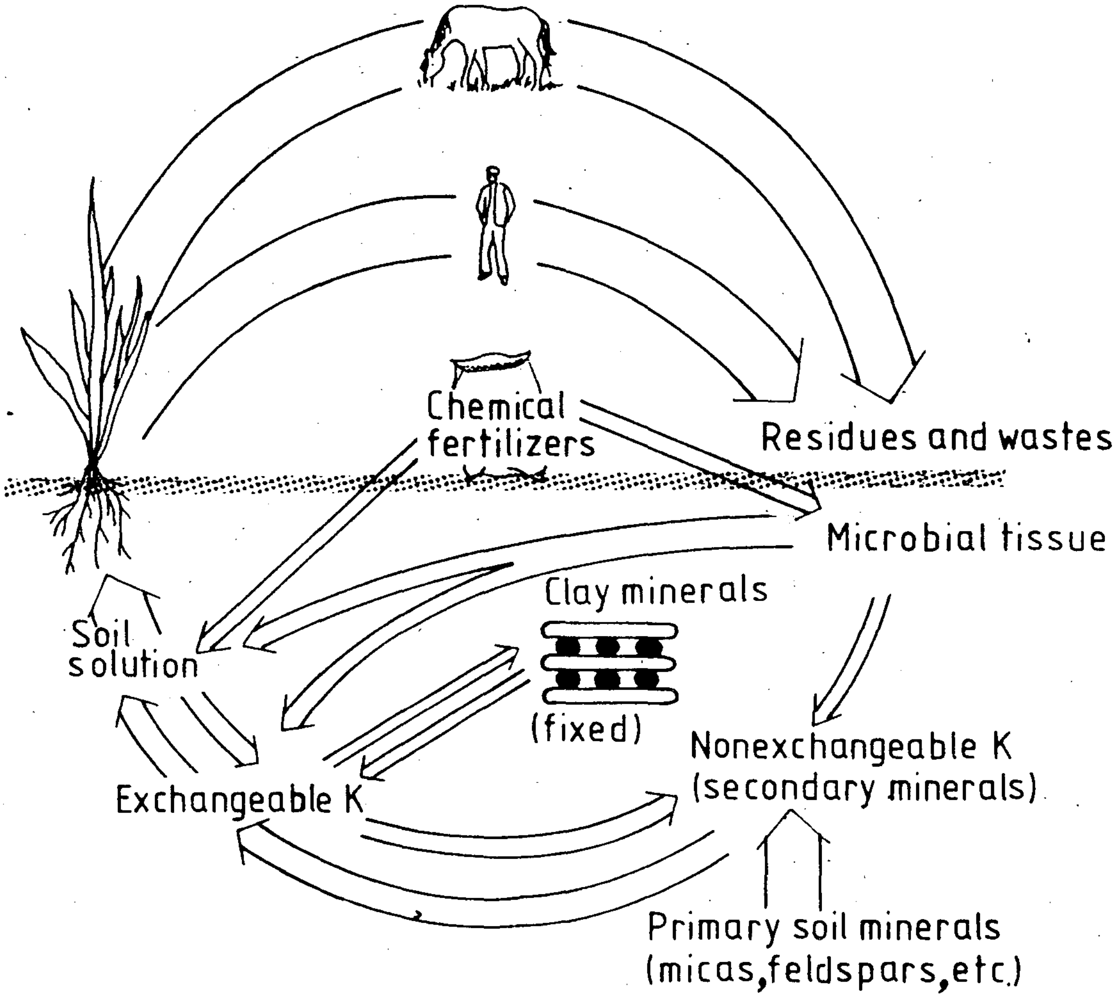
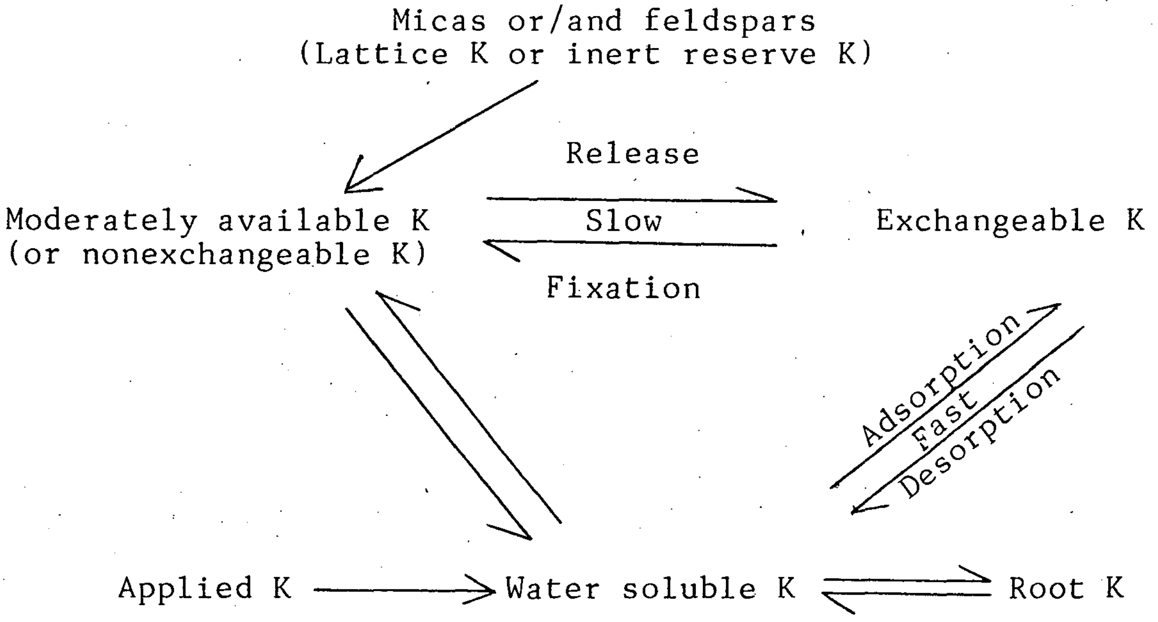


Fig.1. The major components of the potassium cycle.

The different forms of K in the soil system exist in dynamic equilibrium with each other (Goswami and Bandyopadhyay, 1980; Barber, 1984; Dhillon et al., 1985; Unamba-Oparah, 1985). Soil-solution phase and exchangeable phase are regarded as readily available forms of potassium in soils (Selim et al., 1976).

Chemical relationships between the various forms of K

The chemical relationship between the various forms of potassium can be expressed by the dynamic equation as below :



Ghosh and Ghosh (1976) also observed that water soluble, exchangeable and plant utilizable non-exchangeable K fraction (fixed K fraction) in Nagaland soils were in dynamic equilibrium with one another. For the soils of Ambala and Gurgaon (Haryana) Chahal et al. (1976) found a significant correlation between water soluble, exchangeable and fixed K. This is probably due to the slow release of K from the minerals (Goswami and Bandyopadhyay, 1978). The above equation also indicates that addition of potassium fertilizer affects the equilibrium.

Selim et al. (1976) propounded the following model for the chemical relationship between different forms of potassium :

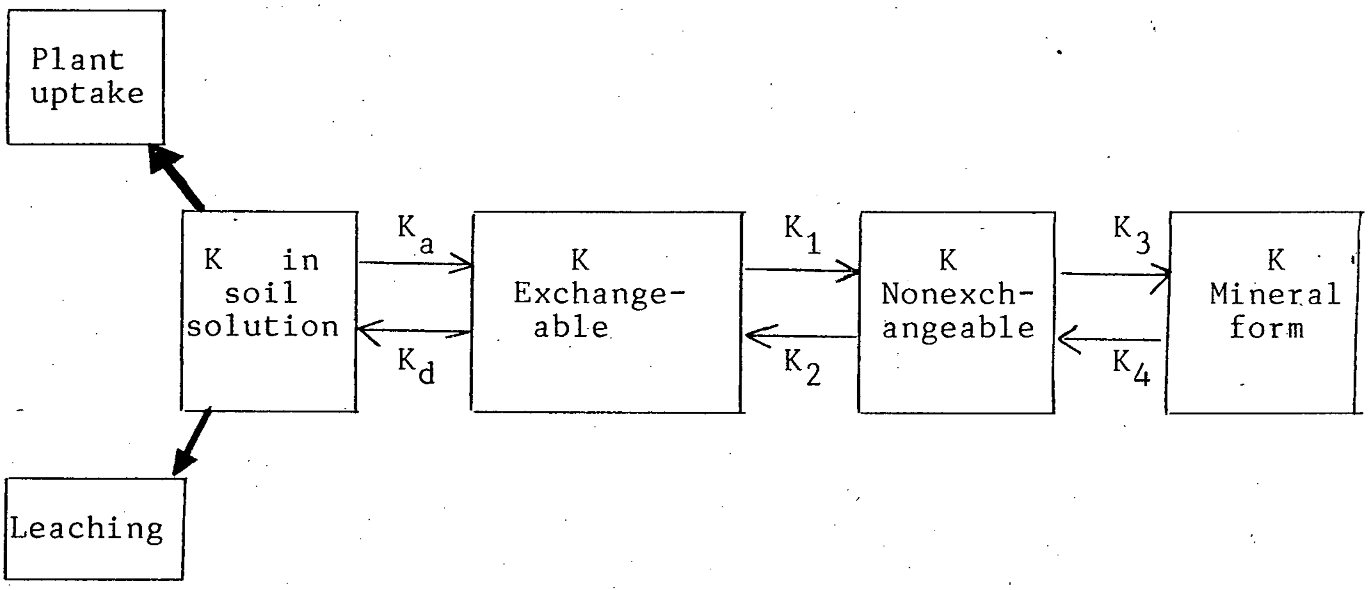


Fig. 2: Schematic representation of the reactions of potassium (K) in solution, exchangeable, nonexchangeable, and primary mineral phases in soil.

where, K_a = The adsorption rate coefficient

K_d = The desorption rate coefficient

K_1 = Non-exchangeable fixation rate coefficient

K_2 = Nonexchangeable release rate coefficient

K_3 = Immobilization rate coefficient

K_4 = Mineralization rate coefficient.

Thus, because of the equilibrium between primary minerals forms and exchangeable and water soluble potassium, plants can, sometimes, survive on soils having primary minerals in fine particle size as the sole source of potassium (Bear, 1965).

The dynamic equilibrium among the various forms of potassium in soil is time-dependent reaction. Potassium ions move from one form to another, whenever equilibrium is disturbed by removing or adding potassium. However, the rates of equilibrium can vary. Equilibration between solution and exchangeable potassium is rapid and usually complete within a few minutes (Malcom and Kennedy, 1969; Barber, 1984). This suggests that the reaction between the soluble and exchangeable potassium occurs instantaneously, while as long as 24 hours may be required for some vermiculitic clays to reach equilibrium (Sparks et al., 1980a). In contrast, the transformation between exchangeable and nonexchangeable phases is slow, requiring days or even months to reach equilibrium and is strongly affected by prevailing soil condition.

It is thus established that the removal of soluble K by leaching or cropping causes exchangeable K to go into solution to replenish the former. Also as exchangeable K is exhausted, the nonexchangeable K that is released may be an insufficient supplement of crop needs due to limitation both in quantity and in rate (McLean, 1980; Dhillon et al., 1985).

Water soluble potassium

Potassium in soil solution is usually considered the primary source of potassium absorbed by the plant root. Potassium concentrations in soil solution vary with soil weathering, past cropping, and potassium fertilization practices. Potassium in the soil solution is assumed to exist as K^+, since potassium forms few ion pairs or soluble organic coordination complexes. There could be potassium in some soil solutions attached to soluble organic compounds (Barber, 1984). Application of soluble potassium fertilizer results in marked increases of potassium in the soil solution phase. However, very little potassium remains in the solution phase for extended periods of time because potassium in the soluble phase will transfer to exchangeable as well as other phases of potassium (Selim et al., 1976). The water-soluble potassium usually constitutes only a small part of the sum of the water-soluble and exchangeable phases (Black, 1973).

Exchangeable Potassium

Amount of exchangeable potassium in soils usually ranges from 40 to 500 mg/kg. A value of 150 mg/kg is frequently considered high enough to ensure that plants growing on the soil receive sufficient potassium.

The total potassium in soils was very high but exchangeable K was very low, because only 0.3 to 4.4% of total K was in exchangeable form according to the studies done by Fagbami et al. (1985) in Nigeria.

Exchangeable potassium is held by the negative charge on soil clay and organic matter exchange sites. the strength of the bond of exchangeable potassium to the soil varies with the type of exchange site and the nature of other cations present. There are both permanent charge and pH-dependent charge cation-exchange sites. Potassium is usually the dominant monovalent exchangeable cation (except for hydrogen in acid soils); however, there are normally much larger amounts of exchangeable calcium and magnesium ions present. When many of the exchange sites are filled with calcium and magnesium, potassium moves to the more weakly bonded sites (Barber, 1984).

Nonexchangeable Potassium

The nonexchangeable phase generally represents slowly available form of potassium and accounts for illite clay minerals and other 2:1 type of intergrade minerals (Selim et al., 1976). In most soils, the great bulk of the K is in the nonexchangeable form. Nonexchangeable K is held between clay plates in positions that are not readily accessible for exchange with other cations in solution. When exchangeable and soluble potassium are removed from the soil by plant uptake, potassium that was initially nonexchangeable moves into the exchangeable form. Conversely, when K fertilizer is added to a soil, potassium moves from exchangeable to nonexchangeable form.

The nonexchangeable K is of much importance in view of practical agriculture. It helps in the conservation of added potassium. For example, when K fertilizers are added to the soil, a large proportion of the soluble potassium becomes attached to the colloids and as a result, some exchangeable ions are converted to the nonexchangeable form. This potassium being temporarily unavailable, is not subject to leaching and thus a significant amount is conserved. Also, the fixed potassium being slowly reconverted to the soluble forms later, is available to the growing plants (Brady, 1984).

Mineral Potassium

The mineral phase is often considered to be relatively unavailable and accounts for primary potassium minerals (Selim et al., 1976). The majority of it resides in potassium bearing feldspars and micas. The primary silicate minerals rich in potassium are muscovite, biotite, orthoclase, and microcline (Bear, 1965).

Minerals release potassium very slowly and the rate varies with the mineral. Studies of the relative rate of release from particles of similar size show that their order of release is biotite > muscovite > orthoclase > microcline. Biotite is seldom present in soil, because it has a high rate of release and is removed rapidly by weathering (Barber, 1984).

K Fixation in Soil

Potassium fixation is a term appied to indicate a decrease in extractability of potassium as a result of interaction of originally soluble or extractable potassium with a soil or mineral. This foregoing definition of the concept of fixation should be made more specific to the extent that potassium is not to be considered fixed as long as it remains readily exchangeable by cations of neutral salts (Black, 1973). The phenomenon of potassium fixation, i.e., conversion of exchangeable K and water soluble K into slowly available nonexchangeable K is a part of the potassium dynamics in soil; but unlike the equilibrium between 'Exchangeable K $\rightleftharpoons$ water soluble K' it is a slow process. This equilibrium plays an important role in potassium nutrition of plants. It has been reported that with the passage of time the applied K-fertilizer in the alluvial soils changes into nonexchangeable form (Ghosh and Hasan, 1976). When potassium fertilizers are applied to soil, the existing equilibrium among the different forms of potassium is disturbed and potassium is slowly transformed into fixed K to set new equilibrium (Russell, 1973; Singh and Ram, 1976). Movement of water soluble K to exchangeable K is the first step in K-fixation and there exists a significant correlation ($r = 0.91$) between adsorbed and fixed K (Goswami and Bandyopadhyay, 1978).

Martini and Suarez (1977) calculated the amount of the exchangeable K fixed (-) or nonexchangeable K released (+) by using the equation:

$$K = K_2 - (K_0 + K_1)$$

where,

K = Exchangeable K fixed

K_0 = Native exchangeable K

K_1 = Fertilizer K

K_2 = Exchangeable K after incubation.

The fixation of K is usually accompanied by reduction in CEC and there is a limiting value for the amount of K that can be fixed. Illite is considered to be responsible for fixation of K in alluvial soils of India, although doubts have been expressed with regard to the K fixing ability of illite. Vermiculite is also known to fix potassium but not much work seems to have been done pertaining to the alluvial soils. Besides clay, silt also fixes potassium (Mehrotra et al., 1972). In alluvial soils of Tamil

Nadu, Andhra Pradesh and Karnatak, K fixation has been found to be positively correlated with both clay and silt (Ramanathan and Krishnamoorthy, 1976).

It is also well established that the amorphous or poorly organized aluminum silicates in the Andosols are able to fix exchangeable K and release nonexchangeable K more easily than the Kaolinite and the more crystalline hydrous Fe and Al Oxide in the Latosols (Martini and Suarez, 1977). The highest K fixation occurs in the B horizon of the Andosol, a Hydrandept, high in allophane and exchangeable Al and with a very low base saturation (Martini and Suarez, 1977). The formation of some illites may have been due to fixation of K by vermiculite and montmorillonite (Ahmad and Davis, 1970).

Nature of Potassium Fixation

Potassium is fixed in various minerals which may be classified into three groups: (1) those that fix potassium in the unweathered mineral (examples are vermiculites and surface-weathered potassium feldspars), (2) those that fix potassium by ion-exchange in sites that do not necessarily hold potassium in the unweathered mineral (examples are certain zeolites); and (3) those that are newly synthesized (examples are complex phosphates of iron, aluminium, or both, containing also potassium, ammonium, or both).

Vermiculites and zeolites fix more potassium per 100 gm of mineral. Zeolites are hydrous aluminosilicates with small channels in which the potassium presumably may be trapped (Black, 1973).

Factors Affecting Potassium Fixation in Soil

Several soil conditions have marked influence on the amount of potassium fixed.

1. Effect of the Type of Clay

The ability of the various soil colloids to fix potassium varies widely. For example, 1:1 type clays such as Kaolinite and the soils in which these clay minerals are dominant fix very little potassium (Bear, 1965; Brady, 1984). According to Barber (1984), the soils whose clays are primarily Kaolinitic do not fix potassium. On the other hand, clays of the 2:1 type, such as vermiculite, smectite, and fine-grained mica (illite), fix potassium very readily and in large amounts. The vermiculite has a greater fixing capacity than montmorillonite (Brady, 1984).

The extent of K fixation differs in the alluvial soils of different regions. This is to be expected because of the differences in the nature and content of the clay besides other factors. It has been reported to be about 57% in the soils of Uttar Pradesh, 42% in Madhya Pradesh, 33% in Bihar, 16-21% in Punjab and 15-24% in Delhi (Goswami and Bandyopadhyay, 1978).

2. Wetting and Drying

Alternate wetting and drying influences considerably the 'Fixed K $\rightleftharpoons$ exchangeable + soluble K' reaction in soil. If the exchangeable K is more there is fixation and if it is less there is release. Drying at higher temperature results in an increase in K-fixation. This is because higher temperatures favours dehydration and contraction of crystal lattice (Goswami and Bandyopadhyay, 1978).

Fixation of exchangeable K is lower when soils are incubated under wet-dry cycles than under continuously wet conditions for all soils horizons, levels of K fertilization, and times of incubation. The high K fixation in the Andosols points to the fact that allophane may be quite active in fixing fetilizer K, particularly under continuously wet conditions. Presumably, wetting and drying increases the degree of crystallinity in allophane and reduces K fixation (Martini and Suarez, 1977).

But, according to Russell (1973) the portion of potassium ions added to a soil that is converted to the fixed form is increased by drying the soil, so that alternate wetting and drying in the root zone of a crop will tend to increase the amount of fertilizer potassium that is converted to the fixed form (Russell, 1973).

3. Effect of Moistures

The studies indicate that the favourable soil moisture conditions for K fixation may vary with clay mineralogy and degree of K fertilization (Martini and Suarez, 1977). Both K and NH_4^+ fixation under moist conditions are reported in seveal calcareous Iowa soils. These studies indicated that the mechanism of fixation of these two ions appeared to be similar. Under moist conditions, illite fixed K whereas montmorillonite did not; when dried, both clays fixed K (Bear, 1965). But Ahmad and Davis (1970) suggested that soil moisture variations do not significantly affect the amount of potassium fixed.

4. Effect of Soil pH

The effect of soil pH on potassium fixation has been investigated mainly in connection with experiments on application of calcium carbonate. A significant increase in fixation with an increase in soil pH was observed by a large number of soil samples from Finland.

The fixation of potassium under moist conditions by soils containing vermiculite-type minerals was little influenced by pH in the range from 3 to 7 as long as the concentration of aluminum remained low. High concentrations of nonexchangeable interlayer aluminum resulting from leaching the soils with dilute acid prevented fixation of potassium at pH 3. Fixation occurred again when the acid-treated soils were adjusted to pH 7. Fixation of ammonia at pH 7 was reduced if the vermiculite was treated with alkali before fixation. Treatment of acid washed vermiculite with alkali restored the fixation capacity (Black, 1973).

The association of fixation with pH seems to vary with the circumstances, even then Goswamy and Bandyopadhyay (1978) reported that a decrease in pH was associated with the reduction in potassium fixation in the alluvial soils of India. Ramnathan and Krishnamoorty (1976) had similar observations. Both the moist and the dry fixation of K by illite were greatly enhanced by increasing the pH with either NaOH or $Ca(OH)_2$. The power of the montmorillonite to fix K, on the other hand, decreased with increasing pH upto 6.6 and then remained constant (Bear, 1965).

5. Effect of Exchange Capacity of Soil

The fixation of K is associated to the exchange capacity of the soil. It was found that maximum potassium fixation resulted if more than 4 per cent of the exchange capacity was occupied by potassium (Bear, 1965). In an experiment on twenty soil samples of France, the percentage saturation of the cation exchange capacity with potassium was found to be better index of potassium fixation under moist conditions than was the content of exchangeable potassium or the cation exchange capacity. Similarly the fixation of potassium under moist conditions by marsh soils of Germany decreased with an increase in percentage saturation of the cation-exchange capacity with potassium (Black, 1973).

According to Ahmad and Davis (1970), the soil began to fix K at a concentration equivalent of 3 per cent of the exchange capacity. It was also reported that the fixation in the dry state occured in the soils when the exchange complex was about 1.11 per cent saturated with K.

6. Influence of Lime

The fixation of fertilizer potassium takes place more readily in natural, than in acid soils, and liming an acid soil increases its ability to fix potassium (Russell, 1973). Under normal liming conditions, this may be beneficial than detrimental because of the conservation of the potassium so affected. Thus, potassium in well-limed soils is not likely to be leached out as drastically as in acid soils (Brady, 1984).

The negative charge on acid clays is neutralised in part by aluminum ions which will bond the sheets together as in vermiculite if the sheets carry a sufficiently high negative charge. Potassium ions will only be able to diffuse very slowly into these interlamellar spaces to displace the aluminum, unless their concentration in the external solution is high. But if the soil is limed, the aluminum ions will lose their charge, the interlamellar spacing will increase and calcium ions will be able to enter slowly. Potassium ions will then be able to enter these wider spaces more easily, displace the calcium and form islands which will pull the sheets together into a spacing approaching that of mica (Russell, 1973).

7. Effect of Addition of K Fertilizers

Fixation of exchangeable K generally increases with increasing K-fertilization and time of incubation (Martini and Suarez, 1977; Goswami and Bandyopadhyay, 1978). The greater the amount of potassium added, the greater was the amount of K fixed upon drying but smaller was the percentage fixed (Bear, 1965). The recovery of K by pangola grass (Digitaria decumbens) and determination of exchangeable K in the soil showed that fixation started at a K-level of 200 kg/ha (90 ppm) (Ahmad and Davis, 1970).

Time does not significantly affect the ratios of water soluble to exchangeable K for various treatments. The effect of concentration of applied K is, however, highly significant. The K salt added to the soil influences the water soluble to exchangeable K ratio (Ahmad and Davis, 1970). The long continued K fertilization resulted in decreasing the muscovite and muscovite-like component of the clay size fraction (Bear, 1965).

K-Release

The other part of the dynamic equilibrium is the release of K from non-exchangeable or fixed fraction. Plants are able to take more K from the soil than is present in water-soluble and exchangeable forms, indicating that K is released from non-exchangeable sources for use by the crop plant (Wentworth and Rossi, 1972; Goswami and Bandyopadhyay, 1978). This phenomenon plays an important role in the fertility of soil. A wide difference exists among different soils in K releasing capacity (Krishnakumari et al., 1984).

In mica-weathering of soils, potassium and other interlayer cations slowly diffuse out of the interlayer spaces formed by cleavage between the mica layer into the soil solution, which results in cleavage at the weathering edges of mica. The K release from micas is hastened by removal of the resulting exchangeable and/or soluble K^+ ions by intensive cropping for a long time, through leaching, or by chemical precipitation in the laboratory (Bear, 1965; Krishnakumari et al., 1984). Drying or freezing the mica of soils hastens K release if the exchangeable K level is low (Barber, 1984).

In laboratory studies it was observed that an untreated 'goradu' soil liberated about 20% of the amount of K fixed earlier. Thus here the rate of release of K from nonexchangeable sources was fairly rapid to meet the crop requirement (Goswami and Bandyopadhyay, 1978).

Release of nonexchangeable potassium from layer silicates occurs only when the potassium concentration of the mineral environment is below a minimal level characteristic of each layer silicate. This release is conditioned by the ability of the growing plant to maintain the potassium concentration in the soil solution below this minimal level. The release of potassium was very low for muscovite and phlogopite, intermediate for biotite and illite, and high for vermiculite (Wentworth and Rossi, 1972).

The presence of soil organic matter, especially humic and fulvic acids may contribute to accelerate the weathering processes and thus releasing the elements. The humic and fulvic acids are expected to react with most of the elements released and are also capable of attacking the primary minerals, liberating elements from the mineral structure by chelation or the formation of complexes. The dissolution of K-feldspars and micas by humic acid is influenced by pH (Tan, 1980).

Rate of Release of Native K

Under intensive cropping, it has been reported that by the fifth or sixth harvest the readily exchangeable K contents of most soils approach their lowest values. After this stage the K source is mainly the non-exchangeable phase supplemented probably by the transfer of K from the roots. Most of the soils showed a definite drop in K-uptake after the 5th harvest but seven out of the eighteen soils continued to indicate a near linear rate of release of K from the non-exchangeable source by the 8th harvest. Assuming that this near linear rates of release of this source of K is not exceeded at the last cropping or any state of the cropping period, then the amount of K that has been obtained from other sources may be estimated by extrapolating to zero time. From such estimation it was found that the final slow release rate of the 'native' K in few soils was less than 40 Kg/ha/year even under intensive cropping. Among the good releases of K from soil, the rate exceeded 900 Kg K/ha/year. For some other soils, the rate of release was between 140-500 Kg K/ha/year (Ahenkorah, 1970).

Removal of K by Crops

The removal of nutrients from soil depends upon the absolute and relative concentration of ions in the external medium and in plant tissues, the cation exchange capacity of roots and relative mobility of hydrated ions (Reddy and Bhardwaj, 1983).

The wheat and maize crop grown in succession, remove about 150-200 Kg K/ha/year (Goswami and Bandyopadhyay, 1978). On the soils with low levels of exchangeable K, legume and other plant roots characterized by high CEC may adsorb relatively large amounts of divalent cations (Ca, Mg) but may be unable to obtain sufficient monovalent K to maintain normal growth. Conversely, those plant species with relatively low CEC roots, such as the grasses, absorb relatively small amounts of divalent Ca and Mg but relatively large amount of monovalent K, even from soils law in exchangeable K (Bear, 1965).

Under ordinary field conditions and with an adequate nutrient supply, potassium removal by crops is high, often being three to four times that of phosphorus and equals to that of nitrogen. Moreover, this situation is made even more critical by the fact that plants tend to take up soluble potassium far in excess of their needs if sufficiently large quantities are present. This tendency is termed luxury consumption, because the excess potassium absorbed apparently does not increase crop yields to any extent (Russell, 1973).

Effect of N Addition, NH_4 and P on Uptake

Addtion of nitrogen increased the N and K contents of grain and straw. It was also observed that when phosphorus is added, the N, P and K content of grain and straw was enhanced (Reddy and Bhardwaj, 1983). But the presence of NH_4^+ may retard recovery of K uptake (Rosen and Carlson, 1984).

Loss of K by Leaching

The loss of K by leaching beyond the root zone is negligible in soils containing 2:1 type of clay minerals. Potassium must be present in solution form to get lost through leaching. But K moving downward through soil solution equilibrates continuously with the exchangeable cations in the soil. A given potassium ion will spend most of the time in exchangeable form and less time in solution as a freely diffusible cation associated with a freely diffusible anion. Accordingly, the downward passage of potassium is much delayed. The extent of the delay may be perceived to increase with the cation-exchange capacity of the soil and with the ease of replacement of the exchangeable cations.

The leaching of K by rainfall as high as 250 cm/year is usually a significant factor in the management and fertilization of humid tropical soils because most of the soils contain little or none of the layer-silicate clay minerals that retain K by interlayer fixation (Bower, 1975).

Liming of acid soils may significantly decrease the loss of potassium by leaching. It was found that leaching of potassium from a loam soil in Tennessee was decreased from 58 Kg/hectare in the untreated control soil (pH 4.5) to 9 Kg/hectare from the same soil after a heavy application of dolomitic limestone (Black, 1973).

The Availability of Soil Potassium to Crops

In the context of plant availability, potassium is considered as an elusive element; most of its elusiveness is a consequence of the amount and type of clay in the soil and the low hydration energy of K^+ which favours its entrapment in the inter layer space of micaceous mineral (McLean, 1980; Dhillon et al., 1985).

The studies made by Gensheimer and Stout (1982) showed that the mudstones are a possible source of plant available K in newly constructed mine soils. It also revealed that the plant available K in the mudstone is largely associated with either exchangeable or nonexchangeable solid-phase K. In fact, a high level of potash fertilizers is one of the surest indications of intensive cropping systems. Potassium in the soil solution is the immediate source of K for crops. The availability of potassium by a crop is dependent on: (i) the potassium ion concentration close to the root surface; (ii) the rate at which K^+ ions can diffuse from the exchange site on the soil surfaces to the root surface, and (iii) the intimacy with which the root ramify through the soil, which in turn, affects the length of the diffusion paths of potassium in the soil solution (Russell, 1973).

Potassium Ion Activity Ratio (KAR)

There are marked differences between the compounds in which the K is found in soils and in the rate at which it is made available to plants. But the concept of 'Intensity' and 'Quantity' is useful in describing and measuring potassium supplying power (Brady, 1984). The potassium ion activity ratio (KAR) is usually defined as the ratio of the potassium ion activity to the square root of the activities of the calcium plus magnesium ions.

$$\text{KAR} = \frac{K^{+}}{\sqrt{[\text{Ca}^{2+}] + [\text{Mg}^{2+}]}}$$

Thus, potassium release from the exchangeable to the soluble state depends on the potassium activity ratio in the solution, and it is for this reason that so many soil studies have been concerned with the effect of the activity ratio on the availability and uptake of potassium by a crop (Russell, 1973).

Good correlations have been obtained between the activity ratio and availability or uptake of K by plants. However, in many cases activity ratios have been observed to be inadequate to describe availability of K to plants. The most serious objections in using KAR as an index of K-availability are (i) two soils exhibiting the same value of KAR may differ in absolute K concentration and (ii) the assumed negative effect of (Ca + Mg) on K-uptake has not been fully established. Prediction of availability of K is successful only when factor like Q/I relationship (buffering capacity), K-binding energy (a clay mineral character), diffusion coefficient (a complex parameter depending upon factors like soil water status and relatively stable characters of soil like texture and structure), and plant characters are taken into consideration (Goswami and Bandyopadhyay, 1978).

K Mobilization by Micro-Organisms

Potassium is a major cation in the nutrition of plants and its mobilization in soils is of considerable importance. In many instances, the availability of potassium and other elements is also affected to varying extents by microbial action. Microorganisms affect the availability of this element through the mineralization of organically bound potassium by decomposition processes as well as by the solubilization of insoluble forms present in soil minerals. In the later instance, potassium is made available as a result of acid production by soil microorganisms. Immobilization of potassium during active proliferation of the soil flora may also shift the equilibrium between available and bound potassium resulting in the release of the bound form (Bear, 1965).

Potassium Manuring of Soils

When the soils are exposed to intensive cultivation for years without adequate potassium manuring, they lose their K content, mainly in the form of structural exchangeable K. Hence they need large quantities of K fertilizers. Furthermore, to avoid leaching losses, K fertilizers should be applied in small doses but frequently depending on the circumstances (Unamba-Oparah, 1985).

Out of the several effective measures such as increase in gross cultivated area, multiple cropping involving high yielding and improved varieties, higher nutrient inputs, better irrigation facilities, soil conservation and plant protection contributing to the growth rate in agricultural output in the country, the use of fertilizers continues to be the king-pin in substantially raising the level of crop production (Bhargava, 1985). It has been observed that for some of the high intensity cropping systems, the total removal of nutrients from the soil ranges from 500 to 900 Kg NPK/ha/year of which potassium alone accounts for about 50 per cent. To maintain the productivity of the soil, it is therefore necessary to include potassium while propagating the use of balanced fertilizers (Sekhon, 1980).

Appreciation of potassium supplying capacity of Indian soils has been changing with time. Thirty seven years ago potassium status of the country's soils was considered adequate and its application was not generally profitable. With the introduction of high yielding varieties (HYV) of crops and progressive intensification of agriculture, potassium deficiency has become fairly widespread (Kanwar et al., 1972, 1973; Goswami et al., 1976) and is tending to create greater needs for external supply of this nutrient.

Current interest in the potassium fertility of soils has switched over from measurements of the amount of exchangeable K, which are often greatly in excess of that needed by crops, to measurements of the rate at which potassium can be supplied (Heming and Rowell, 1985). Three processes have been identified to decide the use of K-fertilizer: (i) movement of exchangeable and soluble potassium; (ii) release of K from initially non-exchangeable forms; (iii) K removal by plants and leaching etc.

A single dressing of a potassium fertilizer can not, in practice, always supply all the potassium needed for maximum yield of the crop if the soil is initially low in potassium. It is difficult to distribute a single dressing of fertilizer K evenly through the depth of cultivation. A single heavy dressing of potassium fertilizer can, however, have the undesirable effect of increasing the osmotic pressure of the soil solution, due to the high concentration of the associated anion usually chloride, which can harm the growth of young plants during spell of dry weather. It is for this reason that heavy dreassing of farm yard manure is more valuable than fertilizers for building up the relatively high concentration of potassium ions in the solution needed by many young crops (Russell, 1973).

Inorganic Sources of Potassium

All potash salts used as fertilizers are water soluble and are, therefore, rated as readily available. Unlike nitrogen salts, most potassium fertilizers, even if employed in large amounts, have little or no effect on the soil pH. Some discrimination is made, however, against potassium chloride (muriate) with respect to potatoes and especially tobacco, since large doses are considered to lower the quality of crop. Hence, when large amounts of potash are to be applied for tobacco, the sulphate form is preferred (Brady, 1984).

Non-Conventional Sources of Potassium Fertilization

The annual consumption of potash (K_2O) in the world has exceeded 18 million tonnes and with more intensive agricultural practices, appreciable demands are forthcoming even from traditionally non-responsive areas. No doubt, the conventional forms of potassic fertilizers are available in unlimited quantities in certain parts of the world but for most other countries it amounts to a near total dependence on external supply. During 1972-73, India had to import the entire 0.49

million tonnes of potassic fertilizers (mainly as muriate) at a huge cost of 165 million rupees (FAI, 1974). Thus attempts have been going on to exploit alternative sources of fetilizer potassium to save foreign exchange.

Plant Ash

Since ages, inadvertant addition of potash through ash of plant residues has been practised. The ash should contain at least 5 per cent K_2O as carbonate and the soil pH would invariably go up with its use. The ash of deciduous trees is richer in potassium than of conifers. Olive residues after ashing are quite effective as they contain 16% K_2O. In coconut, banana and coffee plantations, ash of the unutilized residues has a place of its own as a supplier of potassium and partly of calcium.

The ash of distillery, specially from beetroot molasses, has 10 to 12 per cent K_2O and was reported to be as efficient as the conventional sources (Ghosh, 1976).

Furnace Dust

Quite a good amount of potassium which is volatilized off from the furnace settles on the flue duct. Blast furnace dust may contain more than 14 per cent of K_2O with 60 to 70 per cent of water solubility. In greenhouse tests with rice and beans, it proved as good as KCl and K_2SO_4. Flue dusts are alkaline in nature and have compared quite well with muriate and sulphate of potash in field and pot tests with several crops (Ghosh, 1976).

Potassium Metaphosphate

Potassium metaphosphate containing 35% K_2O and 55% of P_2O_5 is quite a good source of K as well as of P. Being mostly water insoluble, the leaching loss of K is less. The K is slowly released after hydrolysis but in field test this did not inhibit the luxury consumption by maize at high rates of application.

Natural Replenishment of K Losses

While potassium in the straw of cereal crops and aerial parts of tuber crops may be available for recycling at the site of its production, there are less chances for a turnover of the potassium in cereal grains, storage organs of tuber crops and fruits of horticultural plants (Sekhon, 1980).

It has been estimated that cattle and buffaloes in India excrete annually through their dung and urine, plant nutrient equivalent of 5.7 million tonnes NPK, including 1.8 million tonnes K_2O. Contribution of urban solid compost and sewage to this potential resource is of the order of 0.66 million tonnes NPK, including 0.25 million tonnes of K_2O (Gaur, 1979; Sekhon, 1980).

Organic Resources and Potential

India has vast potential of manurial resources. Gaur (1979) has listed the major resources as :

Animal Wastes

(i) Cattle shed wastes such as cattle and buffalo dung, urine, litters and spoiled fodder; (ii) Sheep and goat droppings and (iii) By-products of slaughter houses and animal caracases: Blood and meat wastes, bones, horns and hooves, leather and hair wastes.

Crop residues and aquatic weeds

(i) Crop wastes of cereals, pulses and oilseeds; (ii) Stalks of corn, cotton, jute, tobacco, sugarcane trash, (iii) leaves; (iv) water hyacinth; (v) forest litter.

Green manure

Sunnhemp (Crotalaria juncea), Dhaincha (Sesbania aculeata), Clusterbeans (Cyamposis tetragonoloba), Sanji (Melilotus parvitlora) Cowpea (Vigna catjang), horse gram (Dolichos bifloras), Pillipesara (Paseolus trilobus), Berseen (Trifloium alexandrinum), etc.

Agroindustries by-products

Oil cakes, fruit and vegetable waste, tea, tobacco, cotton, wool and silk wastes, paddy husk and bran, by-products of sugar industry, saw mill wastes.

Marine wastes

Fish meal and seaweeds.

Urban and rural wastes

(i) Urban compost: urban solid wastes, viz., city garbage/wastes; (ii) urban liquid wastes - sewage and sludge; and (iii) rural compost (urine and litters) etc.

Organic manuring for K

The importance of organic matter in plant nutrition was realised later by soil microbiologists and chemists who showed that the decay of organic matter released nitrogen, phosphorus, potassium and other nutrients in forms available to plants. Decomposition products of organic matter had a beneficial effect on soil aggregation, increased water-holding capacity, cation exchange capacity and availability of nutrients. Carbon dioxide liberated by organic matter decomposition, when diffused into the atmosphere, served as a source of carbon for the plant (Bear 1965).

The humus content of aerable soils is increased if they receive regular dressings of farmyard manure, compost (Russell, 1973) or other organic wastes such as sewage water and sewage-sludge.

Waste Water as a Source of Potassium Fertilization

Waste water is a good source of plant nutrients such as N, P, K for crop plants (Dye, 1958; Bole and Bell, 1978). In addition to providing irrigation water for crops, the waste water also nourishes the soil. It was observed that potassium ion concentration increased in the soil solution after treated effluents were applied to the soil and so did the exchangeable potassium percentage (EPP). This contributed to the fertilizer value of waste water (Noy and Feinmesser, 1977).

Disposal of waste water and sludge on land is not new, dating back at least to the sixteenth century. Irrigation systems, using waste water, were reported as early as 1881 in Cheyenne, Wyoming, and in 1891 in Fresno, California (Day et al., 1979a). Noer (1926) suggested the application of sewage to agricultural land as a source of nutrients such as N, P and K as early as 1926. The municipal waste water in Israel contains about 50 gm N, 15 gm P_2O_5, 30 gm K_2O and 150 gm organic matter per cubic meter. In addition there are small amounts of micronutrients present (Noy and Feinmesser, 1977).

It is also estimated that the N, P and K present in 10.3 ha-cm of Madison, Wisconsin waste water were the equivalent of 125 Kg of a 20-20-10 fertilizer (Bole and Bell, 1978; Day et al., 1979a). According to Palazzo and Jenkins (1979), the waste water annually supplied from 231 to 433 Kg/ha of nitrogen and 36 to 153 Kg/ha of potassium when forage grasses received waste water at a rate of 5.0 cm/week.

Dugan et al. (1975) noted that waste water was used for irrigation of grass land and sugarcane (Saccharum officinarum L.) in Hawaii. In Muskegon County, Michigan, 4050 ha of lands were used to grow corn (Zea mays L.), beans (Phaseolus vulgaris L.), wheat (Triticum aestivum L.) and sudangrass with waste water irrigation (Chaiken et al., 1973).

Effect of Effluents on Plants

Waste water is useful primarily as a source of water for irrigation and other purposes. Sewage has important components, water, plant nutrients and organic matter which are badly required in Indian agricultural soil. The average NPK content of Indian city sewage is 50 ppm N, 15 ppm P_2O_5 and 30 ppm K_2O (Gaur, 1979). This is especially felt in arid areas where water is scarce and its cost is high.

1. Plant Nutrients in Effluents

The amount of nutrients contained in treated domestic wastewater in Israel are about 50 gm N, 15 gm P_2O_5, and 30 gm K_2O/m^3. There must be assumed to save fertilizers when these treated waste water are applied for irrigation. A number of trials have shown an increase in yield due to the fertilizer effect of the effluents used in irrigation (Noy and Feinmesser, 1977).

Day et al. (1975) found that wheat (Triticum aestivum L.) grain grown with waste water contained more protein than wheat grain produced with well water and fertilized with equivalent amounts of N, P and K. Higher yields from wheat grains irrigated with the mixture of municipal waste water and pump water were obtained than with the pump water alone (Day et al., 1979a).

In the town of Toocle, Utah, the waste water used for irrigation of corn, alfalfa and wheat was having significantly higher amount of potassium and sodium. The corn growing on the effluent-irrigated site was significantly taller than those on the control-irrigated site. The dry weights of sweetcorn plants grown on the effluent site were significantly higher than those on the control site. With alfalfa, plants on the waste water site were taller and recovered more rapidly. Dry weights for the first and second harvests of alfalfa were significantly greater on the effluent-irrigated site than on the control-irrigated site (Crites, 1975; Day et al., 1982; Campbell et al., 1983).

Barley had more vegetative growth when it was irrigated with a mixture of waste water and pump water than when it was irrigated with pump water alone (Day et al., 1979b). The yields of forage grasses and the removal of nutrients are highly dependent on cutting management. At the high rate application of 10 cm/week, reed canarygrass, orchard grass (Dactylis glomerata L.), and tull fescue (Festuca arndinacea Schreb.) were usually the best yielders and had maximum persistence (Palazzo, 1981).

Day and Tucker (1977) reported higher grain yields from sorghum (Sorghum bicolor L.) grown with waste water than from sorghum irrigated with well water plus N, P and K in amounts equal to those present in waste water. It has been estimated that a ton of alfalfa removes approximately 35 pounds of potassium from soil (Kresge and Younts, 1962).

A field study was conducted to evaluate the effects of applying 25, 50, 100 and 200 cm of simulated municipal sewage effluents to corn (Zea mays L.) grown on a tile-drained loam soil. The effects of these annual loading rates were determined by measuring corn silage and grain yields. Silage yields were maximized at the 50 cm loading rate, however, the grain yields were maximized at the 200 and 100 cm rates in 1973 and 1974 respectively. The potassium losses from the sewage effluents ranged from 0.2 to 8.5 Kg per hactare per year. The K uptake exceeded 90% when the corn was harvested as silage, but was less than 40% if only the grain was removed (Karlen et al., 1976).

The period of effective control of N leaching was lengthened by harvesting either once or twice annually. The removal of N by the harvest assured that most N applied in the waste water irrigation would not leach from the site (Hook and Burton, 1979).

Municipal waste water-N and fertilizer-N were found to be equally effective in stimulating forage production (Bole and Bell, 1978). Thus when waste water is being utilized in a slow infiltration land treatment system, the application rate is usually based on a quantity of N which will result in an acceptable NO_3^--N concentration in downward percolating water after treatment (Clapp et al., 1978). Forage grasses are generally considered to be the most efficient crop for N removal. The forage grasses can remove over 400 Kg/ha of N annually (Palazzo, 1981). Municipal wastewater has been effectively used as a source of irrigation water and plant nutrients in the commercial production of cotton in Arizona. Waste water had no significant detrimental effect on the quality of fibers (Day et al., 1981).

The waste water annually supplied from 231 to 433 Kg/ha of K and 36 to 153 Kg/ha of K, when the waste water was applied at a rate of 5.0 cm/week. Waste water contained more than twice as much N as K (Palazzo and Jenkins, 1979). King and Morris (1973) working with bermudagrass and rye at various application rates of liquid sewage sludge, found that annual plant uptake of K range upto 475 Kg/ha.

Reduction in K in soils to low levels may result in a lower N uptake, thereby reducing the treatment efficiency of a land treatment system. On the other hand, excessive applications of K have been found to alter the uptake of other elements by plants and reduce the quality of the forage as a feed of ruminant animals (Kresge and Younts, 1962). Therefore, K applications should approximate plant needs to maximize plant performance and quality of the forage grass produced in a land treatment system.

K/N ratio

In a study, the inadequate plant availability of K at the land treatment site was related to the K/N ratio of the waste applied. the studies showed that the K/N ratio of the waste water is an important factor in determining whether K fertilization is needed at specific land treatment sites. It appears that a waste water K/N ratio of 0.9 or greater will satisfy the K nutrient requirements of a forage grass. In waste water with the K/N values lower than this may require supplemental applications of fertilizer K (Palazzo and Jenkins, 1979). It was also observed that when sewage wastes applied to the land were having a K/N ratio between 0.13 and 0.55, potassium uptake by plants is limited (King and Morris, 1973; Karlen et al., 1976; Palazzo, 1976).

Posible disadvantages in the use of waste water for irrigation

It is imperative that soils on which the effluents are applied, must be studied periodically from the view point of physico-chemical characteristics to ensure that they are not damaged and the ground waters are not polluted (Indian standard, 1965). When waste water is used for irrigation, a number of possible disadvantages have to be considered:

a. The supply of waste water is continuous throughout the year, while irrigation is seasoned and dependent on crop demands.

b. Treated wastewater may plug nozzles in irrigation systems and clog capillary pores of heavy soils.

c. Some of the soluble constituents in waste-water may be present in concentrations toxic to plants.

d. Health regulations restrict the application of waste water to edible crops.

e. When waste water is not properly treated, it may prove a nuisance to the environment (Noy and Feinmesser, 1977).

Thus waste water must be properly treated before the use for irrigation.

Adverse effects on crop due to waste water:

The solutes contained in waste water may restrict crop development either by the increase in osmotic pressure of the soil solution in the root zone due to the accumulation of soluble salts, or by the specific effect of soluble constituents toxic to plants (Noy and Feinmesser, 1977). However, Day et al. (1972) reported that irrigation with waste water over extended periods neither decreased field crop yields nor resulted in any major deleterious effects on agricultural soils. Municipal waste water was reported to have no detrimental effect on the quality of forage grasses (Palazzo, 1981).

The critical concentrations detrimental to plant development depend on a number of parameters such as soil permeability, precipitation, quantities of water applied, conc. and nature of elements present in waste water, methods of irrigation and crop tolerance (Noy and Feinmesser, 1977).

It is also known that pathogens are present in sewage in great quantity and variety and can survive for periods in the soil and on crops and thus it is apparent that irrigation of health sensitive crops including fruits and vegetables eaten uncooked, with raw or partially treated waste water can present real health risks. For these reasons, health authorities in many countries have established regulations restricting the types of crops that can be grown on soils irrigated with effluents (Shuval, 1977).

Waste water irrigation in India

At present about 36 million urban population is served by drainage systems producing about 292000 million gallons sewage per annum. The total nutrient potential is worked out as 36.5 thousand tonnes of N, 7.3 thousand tonnes P_2O_5 and 21.9 thousand tonnes of K_2O. Out of this, about 91250 million gallons is being utilized on organised sewage farms (Gaur, 1979).

The amount of sewage produced in India is of the order of 3.6 $m.m^3/d$ or 800 MGD. About 30% of this amount (1.9 $m.m^3/d$) is produced at urban centres which number over 220. Only about 1.3 $m.m^3/d$ (i.e., 20.4% of India's one-day total) is treated at these centres. In other words, nearly 80% of sewage produced in the country still remains to be treated and utilised. The amount of manure obtained from one-day production of sewage in India would be about 0.126 m.tons. This amounts to 46 m.tons per year. The manure from one-day sewage is enough for cultivating 0.2

m.hectare of biennial or 0.1 m.hectae of annual crop (Gouder and Hooli, 1986).

The first sewage farm in India was established as far back as 1895. Today there are over 132 farms covering more than 120000 hectares and utilizing over 1 million m^3 per day. There are several more farms that receive industrial effluents, particularly from sugar, distillary, food-processing, fertilizer and other industries (Arceivala, 1977).

Okhla Sewage Treatment Plant situated at New Delhi, receives more than 80 MGD sewage water. The Minor Irrigation Department (Effluents Irrigation Division), New Delhi, is following the standards for the use of primary and secondary effluents, as given below (Vig and Sharma, 1986; Swamy et al., 1986) :

Characteristic	Primary effluent	Secondary effluent
BOD (mg/l)	100	30
Suspended solid (mg/l)	100	30

A very high and good yield of crops irrigated with treated sewage effluents is reported by the Minor Irrigation Department, Okhla (Swamy et al., 1986).

Soil Amendment and Law with Sewage and Environmental Implications

Due to increasing awareness about environmental pollution, different methods for waste disposal are being practised. One of the best method for the disposal of municipal waste as well as industrial waste water is land treatment. Indian Standard Institute has laid down tolerance limits for inland surface water used for irrigation (Indian Standard, 1982) and for industrial effluents discharged on land (Indian Standard, 1965). In 1965, Israel's Ministry of Health issued regulations that allowed the reuse of secondary effluent (including oxidation ponds effluent) in irrigation of crops with the exclusion of vegetables and fruits that were consumed without cooking (Shelef, 1977).

The existing and proposed laws and regulatory standards can aid us in achieving a higher goal in waste water treatment.

MATERIALS AND METHODS

I. COLLECTION AND PREPARATION OF SOIL SAMPLES

Soil samples used in this study were collected from the fallow land adjacent to the J.N.U. nursery. It was an 'undisturbed' soil and presumed to be free of contamination. Shrubs and grasses were the main vegetation. Samples were randomly collected from different points in the same field at 0 to 15 cm depth. All samples were mixed and brought to laboratory.

Then the soil was air dried, powdered and sieved through a 2 mm perforated sieve (Indian Standard, 1983). A portion of soil sample was stored in plastic bottle for physico-chemical analysis and remaining sieved soil was filled in eight PVC columns.

II. SOIL COLUMN

For the purpose of studying accumulation and movement of potassium in soil columns, eight PVC columns of the following specification were designed (Figure 3).

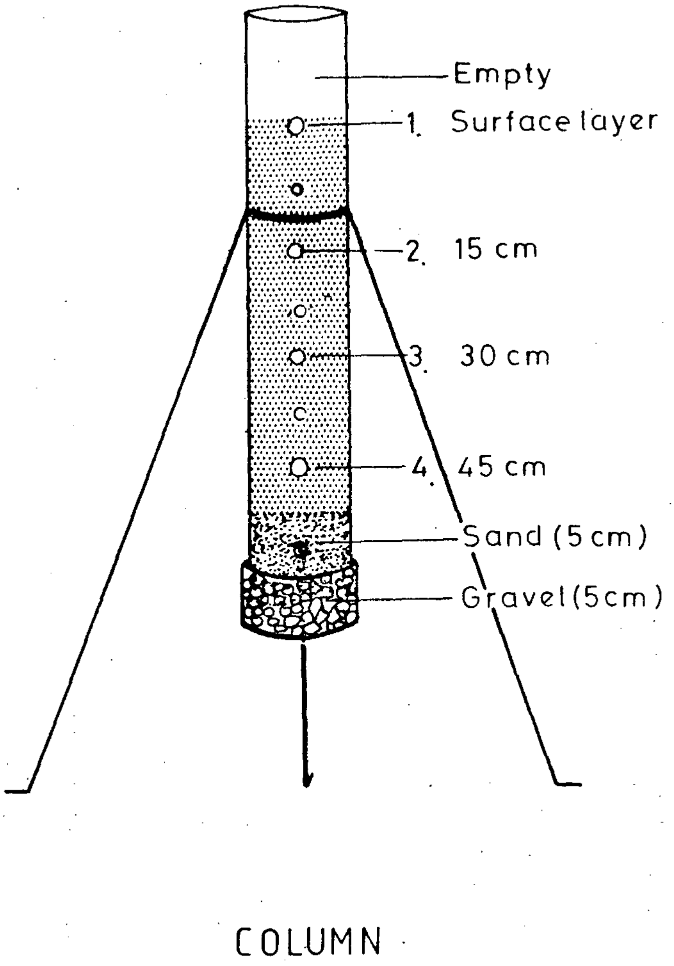


FIGURE 3. Schematic diagram of column showing depths from where soil samples were drawn for analysis.

SPECIFICATIONS

(a) Material used - PVC
(b) Height of the column - 60 cm
(c) Inner diameter - 15 cm
(d) Distance between two holes - 7.5 cm
(e) Bottom of the columns - Iron screen fitted.

Columns were having side holes at the regular interval of 7.5 cm for easy sample collection at different depths. The columns were fixed vertically on iron stands (Figure 4).

III. COLUMN FILLING

The bottom of the columns was packed with gravels thoroughly washed with dilute HCl and distilled water, upto a height of 5 cm followed by fine sand upto 5 cm more. Then air dried and sieved soil was filled in all the columns upto the height of 45 cm. The weight of this soil column was about 11 kg.

IV. COLLECTION AND PRESERVATION OF SEWAGE EFFLUENTS

The raw sewage and effluent samples were collected at three different occassions at an interval of 20 days from the same specific points as shown in figure 5. The samples were collected in polythylene jerry cans with a thoroughly cleaned bucket. A

FIGURE 4. Experimental set-up as used during the course of study.

(i) For Raw sewage

(ii) For Primary treated effluents

(iii) For Final treated effluents

(iv) For Tap water (control)

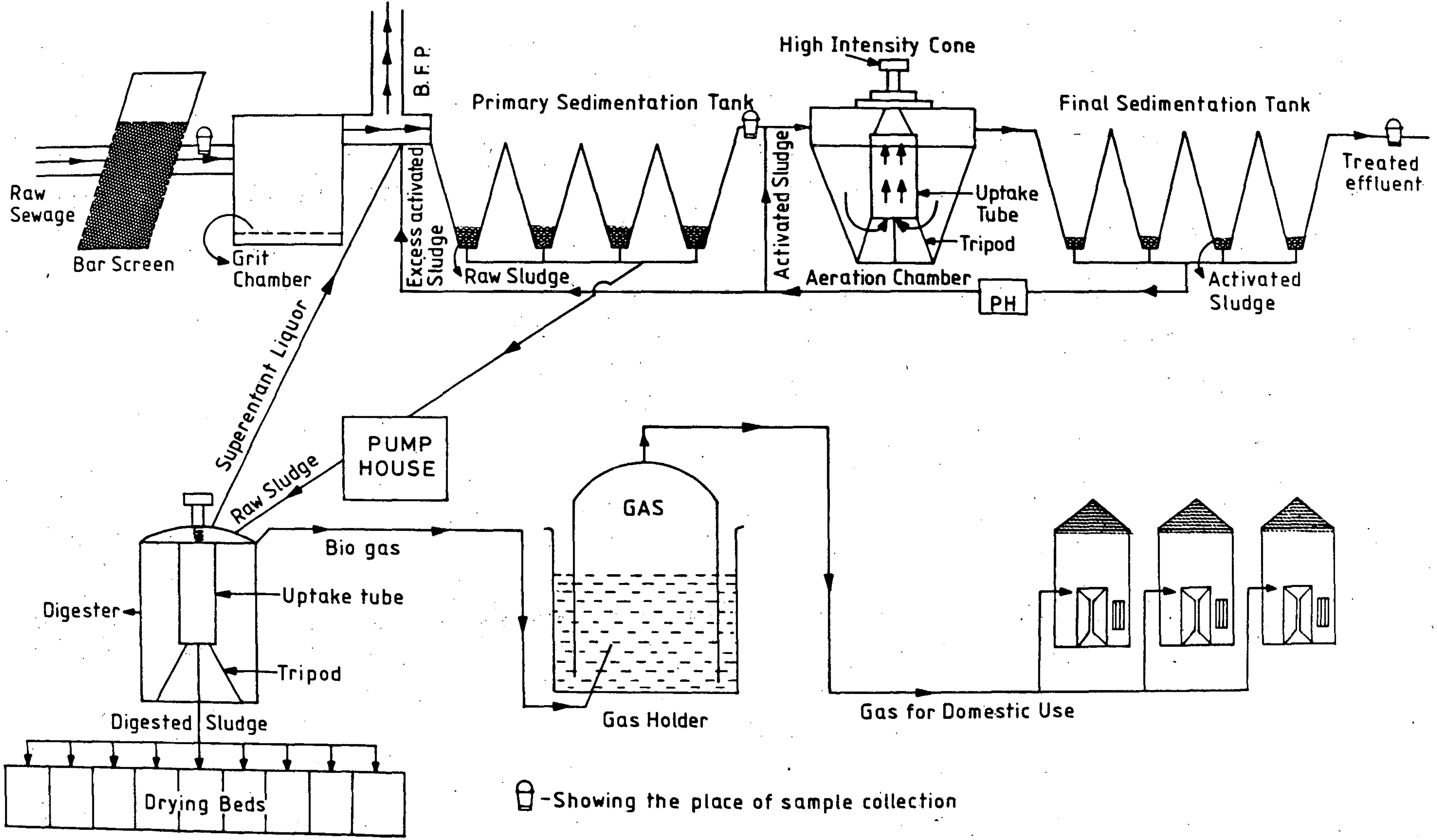


FIGURE 5: Lay out diagram of Okhla Treatment Plant Showing the points for collecting the sewage effluents.

portion of these samples was preserved at $4^{o}C$ refrigeration for analysis as suggested by Indian Standard (1980) and the rest was utilised for application to the soil columns.

V. ANALYSIS OF SOIL SAMPLES

1. pH of Soil

pH of the soil was measured with the help of pH meter (Elico, model LI-12) using 1:5 soil-water suspension as suggested by Jackson (1973).

2. Electrical Conductivity (E.C.)

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

3. Soil mechanical analysis

Mechanical analysis was done by hydrometer method as described by Piper (1966).

4. Cation exchange capacity (CEC)

The soil was dried at $105\text{-}110^{o}C$ for 24 hours to measure CEC (Indian Standard, 1983) and the cation exchange capacity of the soil was determined by neutral 1N ammonium acetate extraction method (Jackson, 1973).

Reagents

(a) 1N Ammonium acetate

57.5 ml glacial acetic acid and 60.0 ml conc. ammonium solution were added in 30 ml of water and mixed well. The solution was diluted to 1 litre and mixed thoroughly. The pH of the solution was adjusted to 7.00 ± 0.05 with drops of acetic acid or ammonia as necessary (Allen, 1974).

(b) Ethyl alcohol (95%)

(c) Potassium chloride (10%)

100 gm KCl was dissolved in 1000 ml of distilled water and pH was adjusted to 2.5.

(d) Sodium hydroxide solution (40%)

40 gm NaOH was dissolved in distilled water and volume was made upto 100 ml.

(e) Boric acid solution (2%)

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

(f) Mixed indicator

0.1 gm of methylene blue was dissolved in 50 ml of ethanol and 0.2 gm of methyl red was dissolved in 100 ml of ethanol and the two solutions were mixed.

(g) Indicator boric acid solution

10 ml of mixed indicator was added to 1000 ml of 2% boric acid solution.

(h) Standard sulphuric acid (0.01N)

Procedure

5 gm of soil and 33 ml ammonium acetate (1N) were taken in a 50 ml plastic centifuge tube. It was shaken for 5 minutes and centrifuged for about 10 minutes. The supernatant liquid was rejected. The process was repeated three times. Next, the soil was treated exactly in the same manner with ethanol.

Finally 33 ml 10% KCl was added to the soil residue and subjected to the same treatment three times. In this case the decanted extract was collected in a 100 ml volumetric flask. The volume was made upto 100 ml with KCl solution.

The extract collected was transfered to a Kjeldahl flask and diluted to about 200 ml with distilled water. 25 ml of 40% NaOH solution was added and ammonia distilled was collected in 50 ml boric acid-indicator solution. Finally the solution was back titrated against standard H_2SO_4. An equal portion of KCl solution as a blank was run simultaneously.

Calculation

$$\text{CEC (meq/100 gm soil)} = \frac{100/v \times a \times N \times 100}{W}$$

where, v = volume of extract taken out from total of 100 ml for distillation

a = ml of H_2SO_4 required for titration

N = normality of H_2SO_4 used

W = Weight of the soil in grams.

5. Availabile potassium

The neutral 1N ammonium acetate extraction method has been widely used for assessing the available potassium pool in soils by many workers (Black, 1965; Ahmad and Davis, 1970; Ahenkorah, 1970; Nemeth and Grimme, 1972; Unamba-Oparah, 1972; Jackson, 1973; Papanicolaou, 1976; Martini and Suarez, 1977; Gensheimer and Stout, 1982; Moorhead and McLean, 1985; Unamba-Oparah, 1985).

Principle

The available postassium is generally in solution and exchangeable form. When soil is extracted with neutral ammonium acetate, the potassium ions are exchanged with ammonium ions and come in solution. Then the potassium can be measured by flame photometry or by atomic absorption spectroscopy using the appropriate standards.

Method employed

The method selected for the determination of potassium was proposed by Jackson (1973) for soil and by APHA (1980) for effluent samples.

Most of the researchers have applied flame photometer for the determination of potassium in the extracts (Ahmad and Davis, 1970; Ahenkorah, 1970; Ekpete, 1972; Unamba-Oparah, 1972; Martini and Suarez, 1977; El-Nennah and El-Kobbia, 1983; Moorhead and McLean, 1985). While only few workers suggested atomic absorption spectrophotometer (AAS) for the measurement of K in the extracts (Black, 1965; Heinrichs and Mayer, 1977; Palazzo and Jenkins, 1979).

For the present study the neutral 1N ammonium acetate extraction method was used and K was measured by flame photometer (FP) as well as by atomic absorption spectrophotometer (AAS).

Interference

Burner-clogging particulate matter was removed from the samples by filtration through a quantitative filter paper of medium retentiveness. The interference due to other cations was overcome by addition of a standard calcium solution.

Instruments used (FP)

1. Flame Photometer

Model - Corning
Make - England
Filter used - Potassium filter

This flame emission spectrophotometer was used to determine the potassium concentration of unknown samples with the help of standard potassium curve.

2. Atomic Absorption Spectrophotometer (AAS)

Model - GBC 902
Make - Australia
Wave length used - 766.5 nm

Reagents

To minimize potassium pick up, all the solutions were stored in plastic bottles.

(a) Deionized distilled water

This water was used for the preparation of all reagents and calibration standards, and as dilution water.

(b) Stock potassium solution

1.907 gm KCl dried at 110°C was dissolved and diluted to 1000 ml with deionized distilled water to give 1000 ppm of K.

(c) Preparation of working standards

10.0 ml stock potassium solution was diluted with deionzed distilled water to 100 ml.

This intermediate potassium solution (100 ppm) was used to prepare the calibration curve in K range of 1 to 10 mg/l.

(d) Standard potassium solution

10.0 ml intermediate potassium solution was diluted with deionized distilled water to 100 ml.

This standard potassium solution (10 ppm) was used to prepare the calibration curve in K range of 0.1 to 1 mg/l.

(e) 1N Ammonium acetate (pH 7.0)

57.5 ml glacial acetic acid and 60.0 ml conc. Ammonium solution were added in 30 ml of water and mixed well. The solution was diluted to 1 litre and mixed thoroughly. The pH of the solution was adjusted to 7.00 ± 0.05 with drops of acetic acid or ammonia as necessary (Allen, 1974).

Procedure

Extraction of soil with neutral ammonium acetate

4 gm of air-dry sieved soil was taken in a 500 ml conical flask and 100 ml of 1N ammonium acetate solution was added to it. The mixture was shaken for one hour on a rotary shaker. The mixture was filtered through No. 41 filter into polythene bottles and the first 20 to 25 ml filtrate was rejected.

Dilution of samples and standards

5 ml of original solution was pipetted out and the calcium solution was added to all the samples and standards to minimize interference. The volume was made up to 50 ml with deionized distilled water. Two blanks were also prepared in the same way.

Measurement of K concentration

By Flame Photometer: The potassium filter was selected. The gas pressure, slit width and other settings were adjusted as recommended for the instrument employed.

A calibration curve was drawn from the standard range by setting the top standard to a suitable scale deflection and the zero ppm standard to zero. The operation was repeated with both the calibration standards a sufficient number of times to secure a reliable average reading for each solution.

The sample solutions and blanks were aspirated into the flame under the same condition as the standards. The top, zero and an intermediate standards were frequently checked. The calibration curve was used to determine the exact concentration of K in the sample solutions (Allen, 1974).

By Atomic absorption spectrophotometer: The wave length was selected at 766.5 nm. Then the K-lamp, gas pressure, slit width and other settings were adjusted as recommended for the instrument. The instrument was calibrated and the sample solutions and blank were direcly aspirated into the flame under the same conditions. The readings were recorded on a printer.

Calculation

K (mg/1 or ppm) = (ppm K in portion) x D

where, D = Dilution ratio.

6. Organic Carbon

Organic carbon was determined by the method of Walkley and Black as modifed by Smith and Weldon (1940), in which the reducing material in soil is oxidized by chromic acid formed by addition of conc. H_2SO_4 to potassium dichromate solution as described by Allison (1965), Piper (1966) and, Chopra and Kanwar (1976).

Principle

Organic matter is oxidized 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)

49.0 gm of $K_2Cr_2O_7$ was dissolved in distilled water and the volume made upto 1000 ml.

(b) Ferrous ammonium sulphate (N/2)

196.0 gm of $FeSO_4(NH_4)_2 SO_4.6H_2O$ was dissolved in distilled water, 15 ml of conc. H_2SO_4 was added and made up to 1000 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 was added and mixed slowly.

(d) 85% Orthophosphoric acid

Analytical grade 85% H_3PO_4.

(e) Solid sodium flouride (NaF).

Procedure

2 gm of soil 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, 0.2 gm of NaF and about 1.0 ml of diphenylamine indicator were added and the solution was back titrated with N/2 ferrous ammonium sulphate solution. The colour was dull green at the beginning, then shifted to a turbid blue and at the end point, this colour changed sharply to brilliant green. A standardisation blank without soil was run in the same way.

Calculation

$$\% \text{ of Organic carbon in soil} = \frac{(a-b) \times 0.003 \times N \times 100}{W}$$

where

a = Blank titration value

b = Sample titration value

N = Strength of ferrous ammonium sulphate

W = Weight of soil.

7. Available Nitrogen

The modified alkaline permanganate digestion method as suggested by Subbiah and Asija (1956) was employed to assess the available nitrogen content of effluents as well as soil samples. The method was evaluated by Hussain and Malik (1985) as an index of soil nitrogen availability.

Principle

Soil, when digested with alkaline permanganate solution releases:

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

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

Reagents

(a) Potassium permanganate (0.32%)

3.2 gm of $KMnO_4$ was dissolved in distilled water and volume was made upto 1000 ml.

(b) Sodium hydroxide solution (2.5%)

25 gm of NaOH was dissolved in distilled water and volume was made upto 1000 ml.

(c) Standard sodium hydroxide (0.02N)

The solution was standardised by titrating against standard oxalic acid.

(d) Standard sulphuric acid (0.02N)

It was prepared by titrating against standard sodium hydroxide.

(e) Methyl red indicator

0.1 gm reagent was dissolved in a mixture of 60 ml ethyl alcohol and 40 ml water and mixed well.

Procedure

20 gm of soil was taken in a Kjeldahl flask. It was moistened with 20 ml of distilled water, and then 100 ml of 0.32% $KMnO_4$ solution and 100 ml of 2.5% NaOH solution were added. The contents of the flask were distilled and about 75 ml of the distillate was collected in 20 ml standard sulphuric acid (0.02N).

Ammonia released during the reaction, reacted with standard H_2SO_4 which was back titrated against standard 0.02N NaOH using methyl red indicator which turned from red to pale yellow colour at the end point. A blank was also run simultaneously.

Calculation

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

$$\therefore \text{ ppm of nitrogen} = \frac{(a-b) \times 0.28 \times 1000}{W}$$

where

a = Blank titration value with N/50 NaOH.

b = Sample titration value with N/50 NaOH.

W = Weight of soil in gm.

VI. ANALYSIS OF SEWAGE SAMPLES

1. pH of the effluents

pH of the raw sewage and other effluents was measured by Elico pH-meter, model LI-12.

2. Electrical conductivity (E.C.)

Electrical conductivity of samples were determined by using Systronics direct reading conductivity meter. The instrument was previously standardized with 0.1 M KCl solution.

3. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) test determines the oxygen required for the chemical oxidation of organic matter with the help of strong chemical oxidant.

COD determination has an advantage over BOD determination in that the results can be obtained in about 4 to 5 hours as compared to 5 days required for BOD test. Further, the test is relatively easy, gives reproducible results and is not affected by interference as the BOD test (Sundaresan, 1979).

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

Principle

The organic matter gets oxidised completely by $K_2Cr_2O_7$ in the presence of H_2SO_4 to produce CO_2 and H_2O. The excess of $K_2Cr_2O_7$ remaining after the reaction is titrated with ferrous ammonium sulphate (FAS). The dichromate consumed gives the O_2 required for oxidation of the organic matter.

Apparatus

a. Reflux apparatus consisting of a flat botton 500 ml capacity flask with ground glass joint and a condensor with 24/29 joint.

b. Hot plate.

Reagents

i. Standard potassium dichromate (0.25N)

12.259 gm of $K_2Cr_2O_7$ dried at 105°C for 24 hours was dissolved in distilled water and the volume was made upto 1 litre.

ii. Ferrous ammonium sulphate (0.25N)

98 gm of $Fe(NH_4)_2(SO_4)_2.6H_2O$ was dissolved in distilled water, 20 ml of conc. H_2SO_4 was added and the volume diluted to

1 litre. This solution was standardised against standard $K_2Cr_2O_7$ solution.

iii. Silver sulphate solution

2.5 gm of Ag_2SO_4 was dissolved in 250 ml of conc. H_2SO_4 and kept overnight for complete dissolution.

iv. Ferroin indicator

1.485 gm of 1,10-Phenanthroline and 0.695 gm of $FeSO_4 \cdot 7H_2O$ were dissolved in 100 ml of distilled water.

v. $HgSO_4$

Solid analytical grade.

Procedure

0.5 gm $HgSO_4$ was placed in a reflux flask and 20 ml of the sample was added and mixed well. Three effluent samples each in duplicate were taken in the same manner. Then 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 each flask was cooled and washed with 80 ml distilled water. The excess of dichromate was titrated against standard FAS solution using ferroin indicator. Sharp colour change from blue green to wine red indicated the end point.

Two blanks were also refluxed in the same manner using distilled water instead of sample simultaneously.

Calculation

$$\text{COD (mg/l)} = \frac{(a-b) \times N \times 8000}{\text{Vol. of sample in ml}}$$

where

a = ml of FAS used for blank (or blank titre value)

b = ml of FAS used for sample (or sample titre value)

N = normality of FAS.

4. Dissolved Oxygen (D.O.)

The determination of dissolved oxygen is based on the modified Winkler procedure having Alsterberg (sodium azide) modification as described by Sundaresan (1979), Indian Standard (1980) and APHA (1980). The reagent $NaOH + KI + NaN_3$ was used in the method to eliminate interference caused by NO_2. This also reduces interference due to higher concentration of ferric ion (Sundaresan, 1979).

Principle

Iodometric test is a precise and reliable titrimetric procedure for D.O. analysis. Oxygen present in sample oxidizes the divalent manganous to its higher valency which precipitates as a brown hydrated oxide after addition of strong alkali and KI. Upon acidification, manganese reverts to divalent state and liberates iodine from KI equivalent to D.O. content in the sample. The liberated iodine is titrated against standard sodium thiosulphate solution using starch as an indicator.

Reagents

a. Manganous sulphate solution

36.4 gm of $MnSO_4H_2O$ was dissolved in distilled water, filtered and the volume was made upto 100 ml.

b. Alkali-Iodide-Azide reagent

50 gm of NaOH and 15 gm of KI were dissolved in distilled water and volume was made upto 100 ml. 1 gm of sodium azide (NaN_3) was dissolved in 40 ml of distilled water and added to NaOH-KI solution and mixed well.

c. Standard sodium thiosulphate solution (0.0125 N)

3.15 gm of $Na_2S_2O_3.5H_2O$ was dissolved in distilled water and diluted to one litre. The solution was standardised against KIO_3.

d. Standard potassium iodate (0.0125 N)

0.446 gm of KIO_3 previously dried at 120°C was dissolved in distilled water and diluted to one litre.

e. Starch indicator

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

Procedure

300 ml capacity BOD bottles were filled with the effluent samples, 2 ml of $MnSO_4$ follwed by 2 ml Alkali-Iodide-Azide reagent was added to it. The tip of the pipette was kept below the liquid level while adding these reagents and the bottles were stoppered immediately. The contents were mixed carefully by inverting the BOD bottles for about 10 times.

Precipitate formed was allowed to settle down and then 2 ml of conc. H_2SO_4 was added immediately after removing the stopper. It was restoppered and mixed gently to dissolve the precipitate. 100 ml solution was taken into a conical flask and immediately the liberated iodine was titrated with standard thiosulphate solution to a pale yellow straw colour. 2 ml of starch solution was added and the titration was continued till the blue colour disappeared.

Standardisation of $Na_2S_2O_3$ solution

10 ml of standard potassium iodate (0.0125 N) 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 using starch as indicator.

Calculation

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

where

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

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

5. Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is the quantity of oxygen required by a definite volume of the liquid effluent for oxidizing the organic matter present in it by micro-organisms under specified conditions. For its determination, the dissolved oxygen content of the sample is measured before and after incubation at 20°C for 5 days. The difference of two D.O. readings gives BOD value (Indian Standard, 1980).

The BOD test is widely used to determine (1) the pollutional load of wastewaters, (2) the degree of pollution in lakes and streams at any time and their self-purification capacity, and (3) efficiency of wastewater treatment methods.

Apparatus

1. BOD bottles of 300 ml capacity.
2. Incubator, to be controlled at 20°C (±1°C).

Reagents

(a) Phosphate buffer

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

(b) Calcium chloride solution

6.875 gm of anhydrous $CaCl_2$ was dissolved in 250 ml of distilled water.

(c) Magnesium sulphate solution

6.25 gm of $MgSO_4.7H_2O$ was dissolved and diluted to 250 ml with distilled water.

(d) Ferric chloride solution.

0.125 gm of $FeCl_3.6H_2O$ was dissolved in distilled water and diluted to 250 ml.

(e) Dilution water

10 litres of distilled water was aerated for 48 hours by bubbling compressed air to attain DO saturation. To this 10 ml each of phosphate buffer, magnesium sulphate, calcium chloride, and ferric chloride was added and mixed well.

Procedure

15 ml, 30 ml, and 60 ml each of the three effluents (raw, primary and secondary effluents) were transferred to 1000 ml volumetric flasks and the remaining volume was made up by addition of the dilution water. This corresponds to 1.5%, 3% and 6% solutions of the effluent samples. From the 1000 ml volumetric flasks containing the diluted samples three 300 ml BOD bottles were filled up, without entrapping air bubbles in the bottles. One bottle was kept for determining initial (zeroth day) dissolved oxygen and the other two bottles were incubated at 20^oC 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 accordingly along with the samples.

Calculation

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

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 blank on 0th day

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

6. Organic carbon

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

Calculation

$$\% \text{ of organic carbon} = \frac{(a-b) \times 0.003 \times N \times 100}{V}$$

where

a = Blank titration value

b = Sample titration value

N = Strength of ferrous ammonium sulphate

V = Volume of the effluent sample.

7. Available Nitrogen

The same modified alkaline permanganate digestion method was followed as described for soil samples.

50 ml of the sewage samples each in duplicate were taken in the Kjeldahl flasks for estimating their available nitrogen content. A blank with 50 ml of distilled water was also run in the same way.

Calculation

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

where

a = Blank titration value with 0.02 N NaOH

b = Sample titration value with 0.02 N NaOH

V = Volume of sewage sample.

8. Available Potassium or Water Soluble Potassium

The soluble potassium in the effluent samples was determined by the neutral ammonium acetate extraction method as described earlier. The procedure given in 'the standard methods for examination of water and wastewater', APHA (1980) was followed.

The effluent samples were filtered through Whatman filter No. 42.

VII. Raw sewage and effluents study using columns

Columns were arranged in two series to render duplicate columns for one treatment. The soil sample in each column was first stabilized by pouring tap water. After stabilizing, the columns were marked for respective samples as follows :

(i) Columns 1 and 2 for raw sewage.
(ii) Columns 3 and 4 for primary treated effluent.
(iii) Columns 5 and 6 for final treated effluent.
(iv) Columns 7 and 8 for tap water (control).

Samples of sewage effluents and tap water were poured into columns continuously at a fixed rate of one litre per day (Tan et al., 1985). The treatment was continuous for 60 days. The samples were drawn at an interval of fifteen days and analysed for pH, EC, organic carbon, available nitrogen and available potassium.

Experimental Soil

The physico-chemical properties of the original soil for the present study have been shown in Table 1. The soil was analysed for different particle size by hydrometer method (Piper, 1966). It was found to have 12.17% of clay, 30.43% of silt and 57.4% of sand. The water holding capacity was 34.5%. The soil was alkaline in nature. pH was 8.45 and electrical conductivity, 0.095 mmhos/cm. Cation exchange capacity as determined by neutral 1N ammonium acetate extraction method, was 8.2 meq/100 gm. Organic carbon content of the soil was 0.26%. The levels of available nitrogen and neutral 1N ammonium acetate extractable potassium (flame photometer value) were 56 ppm and 64.7 ppm respectively.

Sewage effluents

Some of the characteristics of the sewage effluents collected from Okhla Sewage Treatment Plant on three different dates have been presented in Tables 2, 3 and 4. The average pH values for raw, primary and secondary treated sewage were 7.46, 7.48 and 7.76 respectively. The electrical conductivity values were 1.05, 1.086 and 1.14 respectively in the above order. Thus, there was a very minute change in pH and E.C. after treatment.

TABLE - 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 m mhos/cm
5.	Organic Carbon		0.2586%
6.	Available Potassium		64.7 ppm
7.	Available Nitrogen		56.0 ppm
8.	Cation Exchange Capacity		8.2 meq/100 gm

TABLE - 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/1)	247.50	217.80	69.30
4.	BOD (mg/1)	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 potassium (ppm) (soluble potassium ions)	10.30	10.55	10.05

Data represent average of duplicate samples.

TABLE - 3

Physico-Chemical Characteristics of Effluents Collected on 11-3-1986

	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/1)	270.00	160.00	70.00
4.	BOD (mg/1)	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 potassium (ppm) (soluble potassium ions)	11.44	10.60	10.80

Data represent average of duplicate samples.

TABLE - 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)	305.0	140.0	35.0
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 potassium (ppm) (soluble potassium ions)	8.78	9.54	9.29

Data represent average of duplicate samples.

COD values were 274.17, 172.6 and 58.1 mg/l for raw, primary and secondary sewage effluents respectively. The corresponding BOD values were 120.6, 60.88 and 16.79 mg/l and the organic carbon content of the sewage effluents were 0.0146%, 0.0063% and 0.003% respectively. The values of available nitrogen in raw, primary and secondary treated sewage were 26.85, 21.65 and 16.05 ppm respectively. The soluble potassium contents were 10.17, 10.23 and 10.05 ppm respectively (Table 5).

There was no significant variation in pH, electrical conductivity, organic carbon, available nitrogen and soluble potassium ~~potassium~~ of sewage effluents collected at different dates. In other words, the properties of sewage effluents were almost constant during the experimental period. In evaluating the properties of effluents and assessing the efficiency of conventional treatment stages revealed that BOD, COD, organic carbon and inorganic constituents were significantly changed by the different treatment processes. After secondary treatment BOD load decreased about seven fold but there was no change in potassium content.

TABLE - 5

Average Physico-Chemical Characteristics of Sewage Effluents

	Parameters	Raw Sewage	Primary Treated Sewage	Secondary Treated Sewage
1.	pH	7.46	7.48	7.76
2.	Electrical Conductivity (mmhos/cm)	1.05	1.08	1.14
3.	COD (mg/1)	274.17	172.6	58.1
4.	BOD (mg/1)	120.6	60.88	16.79
5.	Organic Carbon (%)	0.014	0.006	0.003
6.	Available Nitrogen (ppm)	26.85	21.65	16.05
7.	Available potassium (ppm) (soluble potassium ions)	10.17	10.23	10.05

Data represent average of duplicate samples.

EXPERIMENTAL RESULTS

Effect of sewage effluents on characteristics of soil in columns

A laboratory experiment under controlled conditions was set up to study the effect of the effluents on the accumulation and movement of potassium in the soil columns at a regular interval of 15 days for a period of two months. The detailed results of this experiment have been incorporated in this dissertation.

pH

Periodic changes in the pH of soil in the different layers of soil columns at a interval of 15 days have been shown in table 6. The application of sewage resulted in the decrease of soil pH. In the surface layer of the soil columns treated with raw sewage, the pH values declined by one unit (8.45 to 7.45) within first 15 days. However, this decrease in pH was comparatively less with other treatments including the control treatment with tap water. Again, while the surface layers experienced considerable change in the pH values, the cahnge in the subsequent layers were negligible.

It was also noticed that the pH values increased with depth in the soil columns irrespective to the type of effluents applied. Subsequent observations showed that the pH values almost invariably increased till the end of the incubation period. However, the final values did not go beyond the original pH of the soil.

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

Electrical conductivity

The periodic variations in electrical conductivity at different layers under the application of sewage effluents on the soil columns have been presented in table 7. 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 after 15 days. However, in the tap water treatment, the E.C. values slightly declined. It was observed that electrical conductivity increased progressively thereafter till the end of the experiment. While the increase in the electrical conductivity in the surface layers was remarkably high, that in the subsequent layers was cmparatively less.

The values of electrical conductivity generally decreased with depth with a few exceptions. After 60 days, the electrical conductivity in all the layers of the colunms treated with secondary treated 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 8 and figure 22. Only the surface layers of the columns treated with raw sewage showed a slight increase in the organic carbon content within 15 days. In almost all the other layers the values remained 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 (more than 100%). A slight increase (about 10%) 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 incubation, the organic carbon increased slightly in the surface layers of the columns amended with treated effluents. 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 control 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 9 and figure 23. 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 (117 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 in available N progressively decreased with depth in all the columns irrespective of the type of treatment.

It was observed 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 the available nitrogen were 184 and 84 ppm respectively. Thereafter the values showed a slight decrease in these columns till the end of the 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 dereased with depth. The control treatment showed a decrease compared to the original value in all the layers and unlike 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 case of other treatment.

Available Potassium

The variations in available potassium at different periods of incubation in the soil columns treated with different types of effluents as determined by flame photometer have been presented in Table 10 and Figure 24.

Effect of raw sewage

A remarkable increase in the available potassium over the initial value (64.7 ppm) was observed at all the layers of the soil columns treated with raw sewage. The increase in available potassium at the surface layer was high (174.5 ppm, Table 10) compared to the subsequent layers. After a remarkable increase within first 15 days, the available potassium of the surface layer started declining upto 45 days. It was interesting to note that the available potassium content of the soil at the surface layer again increased to a high value (183 ppm) at the end. At the 15 cm and 30 cm layers the available potassium values initially increased upto 30 days. Then it showed a slight decrease at 45 days, but again increase at the end. At 45 cm layer, the initial increase was upto 15 days only as observed in the surface layer. Thereafter, it decreased till 45th day with a little increase again at the end.

Ordinarily, the available potassium decreased with the increase in depth, but at the 15th day the available potassium values interestingly increased to a high value at the 45 cm layer.

Effect of primary treated sewage

Almost similar trends were observed in the columns amended with primary treated sewage and raw sewage, but the values are less in the former case. After 15 days the surface layer showed an appreciable increase (149.0 ppm) in the available potassium. This increase was more than 125% when compared to the initial value. The value declined to 99.5 ppm after 30 days of incubation and again increased to 123.5 ppm at the end of the experiment. Other layers also showed almost the similar pattern.

Available potassium decreased with the increase in depth throughout the incubation period with exception at 15 days where it increased at the 45 cm layer after a gradual decline in the value upto the 30 cm layer.

Effect of secondary treated sewage

The values of available potassium did not show a definite trend under the application of secondary treated sewage effluent. Initially the available potassium increased in all the layers after 15 days of incubation, although the increase at 30 cm and 45 cm layers was not much pronounced. In the surface layer, the available potassium decreased at the 30th day and again increased at the 45th day. On the 60th day, it again decreased. At the 15 cm layer, the available potassium values started decreasing after 15 days till the 30th day whereafter it increased till the end of the incubation period. At the 30 cm layer, the value of available potassium increased upto 30 days and then gradually decreased till the end. At the 45 cm layer, the value of available potassium, however, decreased till 45 days after an initial increase at the 15th day. After 45th day, it again increased to show a slightly higher value at the end.

Also no definite trend was noticed with regard to the value of available potassium at different depths in the soil column. At the 15th day, it decreased at the 15 cm layer but again increased gradually with depth. At the 30th day, available potassium decreased at the 15 cm layer, showed an increase at the 30 cm layer but again decreased at the 45 cm layer. At the 45th day, the available potassium invariably decreased with depth, while at the 60th day, first it decreased with depth but slightly increased at the 45 cm layer.

Control Treatment

Under the application of tap water in the soil column, which was used as the check treatment, the available potassium had a significant increase from the initial value only at the surface layer, while the increase at the 15 cm layer was not significant, the value of available potassium practically remained the same as the initial value at the 30 cm and 45 cm layers. The value of available K decreased after a depth of 15 cm at the 30th day, while no significant change was observed at the 45th day. At the 60th day, however, the value of available potassium increased slightly after a depth of 15 cm. In the surface layer, the value of available K gradually decreased till the end of the incubation period. At the 15 cm layer, it increased till 30th days whereafter it decreased till the end. On the other hand, the value of available potassium invariably increased till the end of the experiment at the 30 cm and 45 cm layers.

TABLE - 6

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 SEWAGE	Surface Layer	7.45	7.60	7.55	7.50
	15	7.90	8.20	8.15	8.20
	30	8.00	8.15	8.30	8.35
	45	8.10	8.25	8.25	8.40
PRIMARY TREATED SEWAGE	Surface Layer	7.65	7.75	7.60	7.65
	15	8.30	8.25	8.00	8.25
	30	8.20	8.30	8.25	8.45
	45	8.20	8.30	8.30	8.45
SECONDARY TREATED SEWAGE	Surface Layer	8.20	8.00	8.15	8.35
	15	8.10	8.20	8.30	8.45
	30	8.25	8.30	8.40	8.40
	45	8.00	8.35	8.35	8.50
TAP WATER	Surface Layer	8.20	8.30	8.45	8.65
	15	8.35	8.30	8.45	8.50
	30	8.30	8.40	8.50	8.55
	45	8.40	8.50	8.60	8.55

* pH in orginal soil = 8.45
Data present average of duplicate samples.

TABLE - 7

Periodic Changes of EC (mmhos/cm) in the Soil Columns Under the Application of Sewage

Effluent Type	Depth in cm	15 days	30 days	45 days	60 days
RAW SEWAGE	Surface Layer	0.110	0.270	0.450	0.600
	15	0.090	0.120	0.180	0.270
	30	0.095	0.120	0.210	0.240
	45	0.085	0.150	0.180	0.240
PRIMARY TREATED SEWAGE	Surface Layer	0.112	0.240	0.420	0.630
	15	0.097	0.150	0.180	0.300
	30	0.090	0.180	0.210	0.270
	45	0.095	0.120	0.210	0.300
SECONDARY TREATED SEWAGE	Surface Layer	0.120	0.240	0.480	0.750
	15	0.110	0.210	0.450	0.600
	30	0.110	0.270	0.510	0.630
	45	0.120	0.240	0.480	0.570
TAP WATER	Surface Layer	0.075	0.120	0.240	0.300
	15	0.080	0.120	0.210	0.270
	30	0.075	0.125	0.210	0.240
	45	0.075	0.120	0.210	0.240

* EC of original soil = 0.095 mmhos/cm.
Data present average of duplicate samples.

TABLE - 8

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 SEWAGE	Surface Layer	0.2821	0.5818	0.6206	0.6432
	15	0.2697	0.2650	0.2456	0.2830
	30	0.2586	0.2586	0.2650	0.2766
	45	0.2508	0.2508	0.2586	0.2573
PRIMARY TREATED SEWAGE	Surface Layer	0.2586	0.2844	0.2715	0.2830
	15	0.2350	0.2327	0.2327	0.2508
	30	0.2586	0.2508	0.2456	0.2447
	45	0.2350	0.2508	0.2508	0.2701
SECONDARY TREATED SEWAGE	Surface Layer	0.2586	0.2456	0.2586	0.2766
	15	0.2468	0.2327	0.2327	0.2508
	30	0.2350	0.2508	0.2586	0.2508
	45	0.2350	0.2327	0.2508	0.2573
TAP WATER	Surface Layer	0.2355	0.2456	0.2315	0.2315
	15	0.2350	0.2315	0.2350	0.2251
	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 present average of duplicate samples.

TABLE - 9

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 SEWAGE	Surface Layer	117.6	184.8	176.4	173.6
	15	65.8	72.8	61.6	72.8
	30	67.2	64.4	68.6	70.0
	45	63.0	61.6	63.0	64.4
PRIMARY TREATED SEWAGE	Surface Layer	75.6	84.0	77.0	78.4
	15	64.4	65.8	67.2	68.6
	30	67.2	68.6	64.4	64.4
	45	61.6	57.4	58.8	63.0
SECONDARY TREATED SEWAGE	Surface Layer	68.6	70.0	72.8	61.6
	15	67.2	61.6	61.6	54.6
	30	61.6	57.4	56.0	49.0
	45	16.6	54.6	50.4	50.4
TAP WATER	Surface Layer	53.2	50.4	49.0	44.8
	15	50.4	51.8	50.4	46.2
	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 present average of duplicate samples.

TABLE - 10

Periodic Changes in Available Potassium (ppm) of Soil Under the Application of Sewage (Flame Photometer Value)

Effluent Type	Depth in cm	15 days	30 days	45 days	60 days
RAW SEWAGE	Surface Layer	174.50	153.37	134.87	183.00
	15	76.87	98.12	91.00	108.00
	30	76.87	98.00	84.00	92.37
	45	126.37	89.62	69.75	77.75
PRIMARY TREATED SEWAGE	Surface Layer	149.00	99.50	129.25	123.50
	15	83.87	62.75	90.37	101.62
	30	78.37	72.62	73.50	81.87
	45	118.00	65.75	68.75	58.62
SECONDARY TREATED SEWAGE	Surface Layer	125.00	103.75	140.50	127.75
	15	69.75	61.25	78.37	98.00
	30	84.00	89.62	76.25	69.87
	45	112.25	82.62	69.50	74.75
TAP WATER	Surface Layer	100.5	93.87	82.62	74.12
	15	74.0	91.0	82.5	72.0
	30	62.75	72.75	77.0	81.87
	45	65.5	76.25	79.12	81.12

*Initial value of available potassium in soil = 64.7 ppm.
Data present average of duplicate samples.

TABLE - 11

Periodic Changes in Available Potassium (ppm) of Soil
Under the Application of Sewage
(AAS Values)

Effluent Type	Depth in cm	15 days	30 days	45 days	60 days
RAW SEWAGE	Surface Layer	189.00	163.37	147.12	181.25
	15	104.37	96.75	106.75	116.62
	30	99.37	91.50	102.37	104.62
	45	140.00	83.37	90.00	89.37
PRIMARY TREATED SEWAGE	Surface Layer	162.50	120.75	132.87	135.5
	15	104.87	93.37	104.62	111.5
	30	104.75	87.25	87.62	92.5
	45	127.5	81.12	84.62	72.5
SECONDARY TREATED SEWAGE	Surface Layer	142.00	122.50	153.62	117.25
	15	97.00	84.50	94.50	111.12
	30	107.75	98.25	88.37	80.75
	45	133.37	94.25	83.25	86.50
TAP WATER	Surface Layer	95.87	103.25	97.75	90.87
	15	102.62	109.87	93.25	83.87
	30	94.25	88.62	88.0	94.87
	45	97.37	90.62	91.0	96.12

Initial value of Available Potassium in soil = 74.6 ppm.
Data present average of duplicate samples.

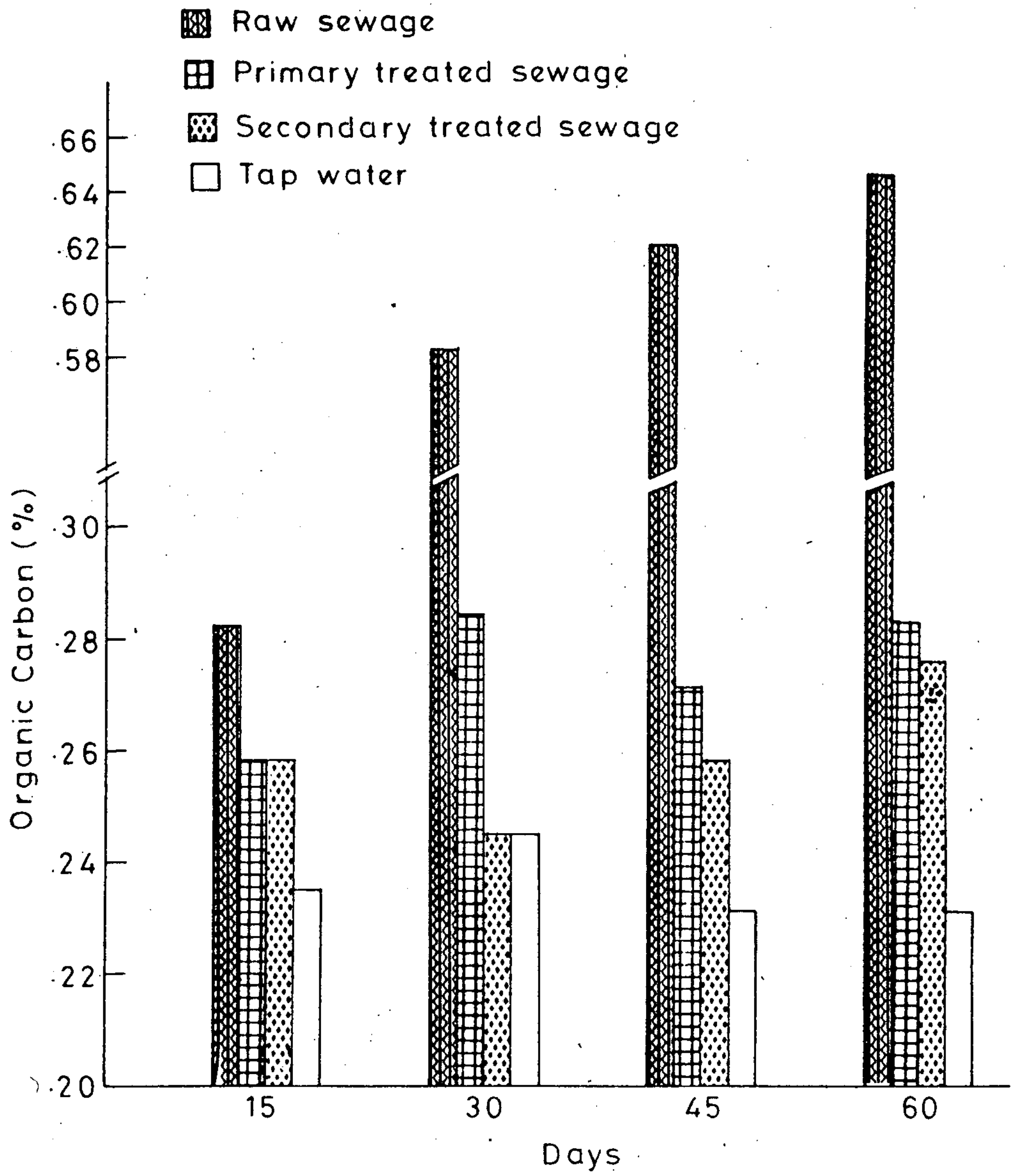


FIGURE 6. Changes of organic carbon in the <u>Surface layer</u> of sewage treated soil columns.

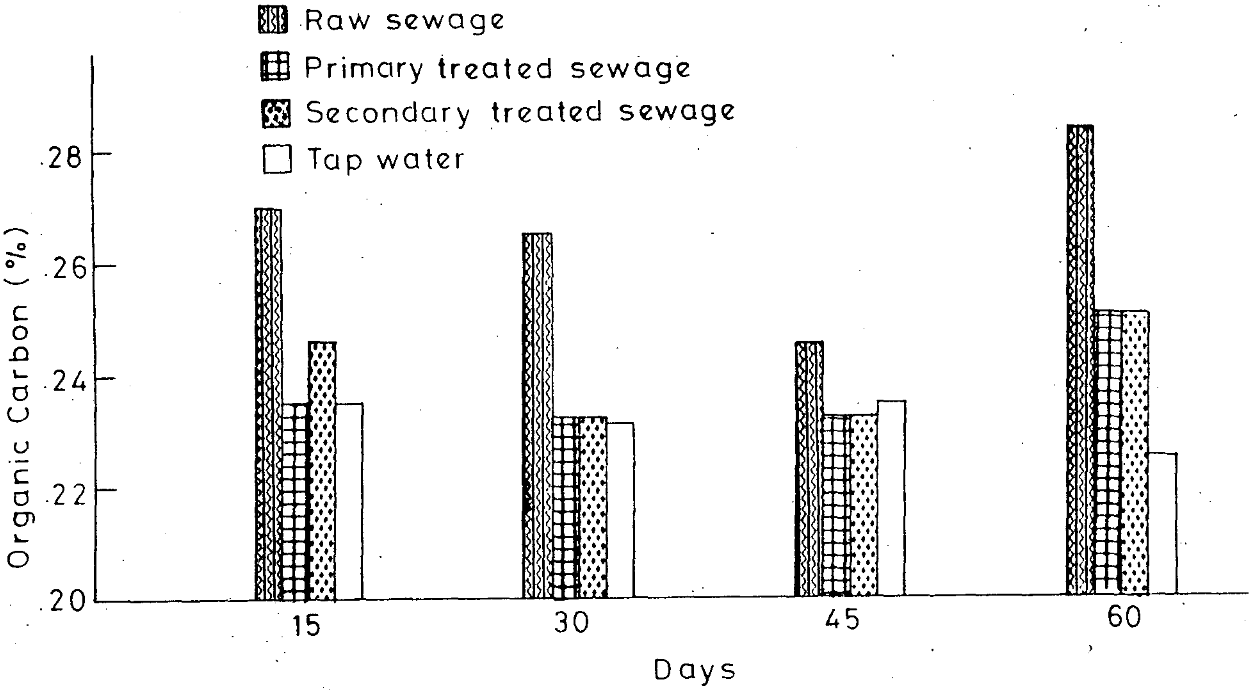


FIGURE 7. Changes in organic carbon at the depth of 15 cm in sewage treated soil columns.

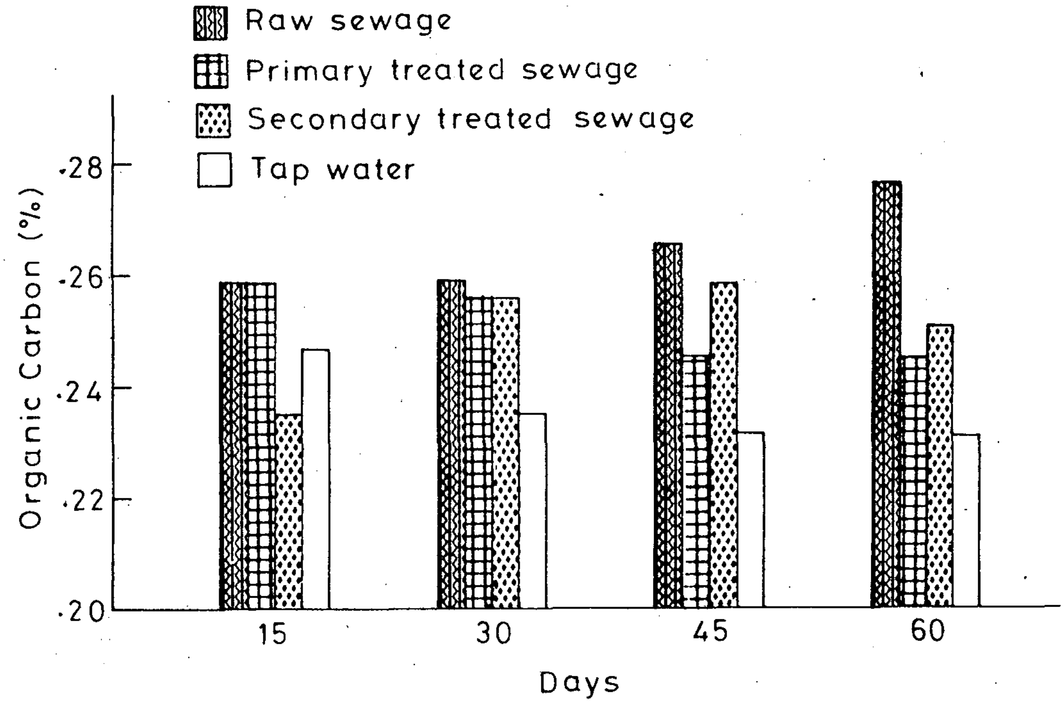


FIGURE 8. Changes in organic carbon at a depth of 30 cm in sewage treated soil columns.

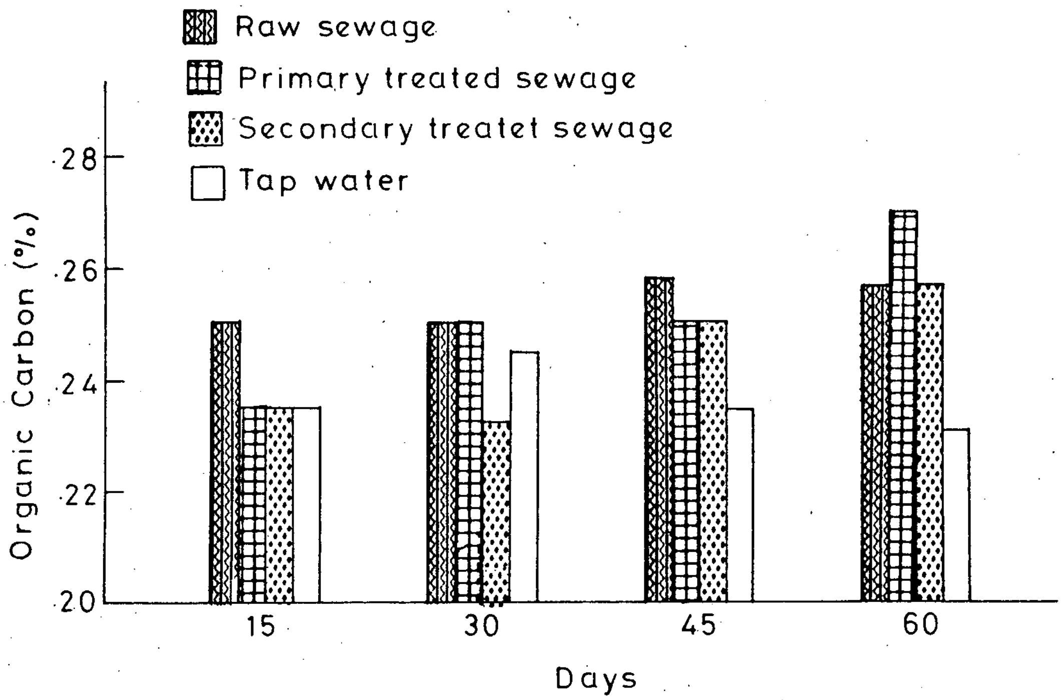


FIGURE 9. Changes in organic carbon at a depth of 45 cm in sewage treated soil columns.

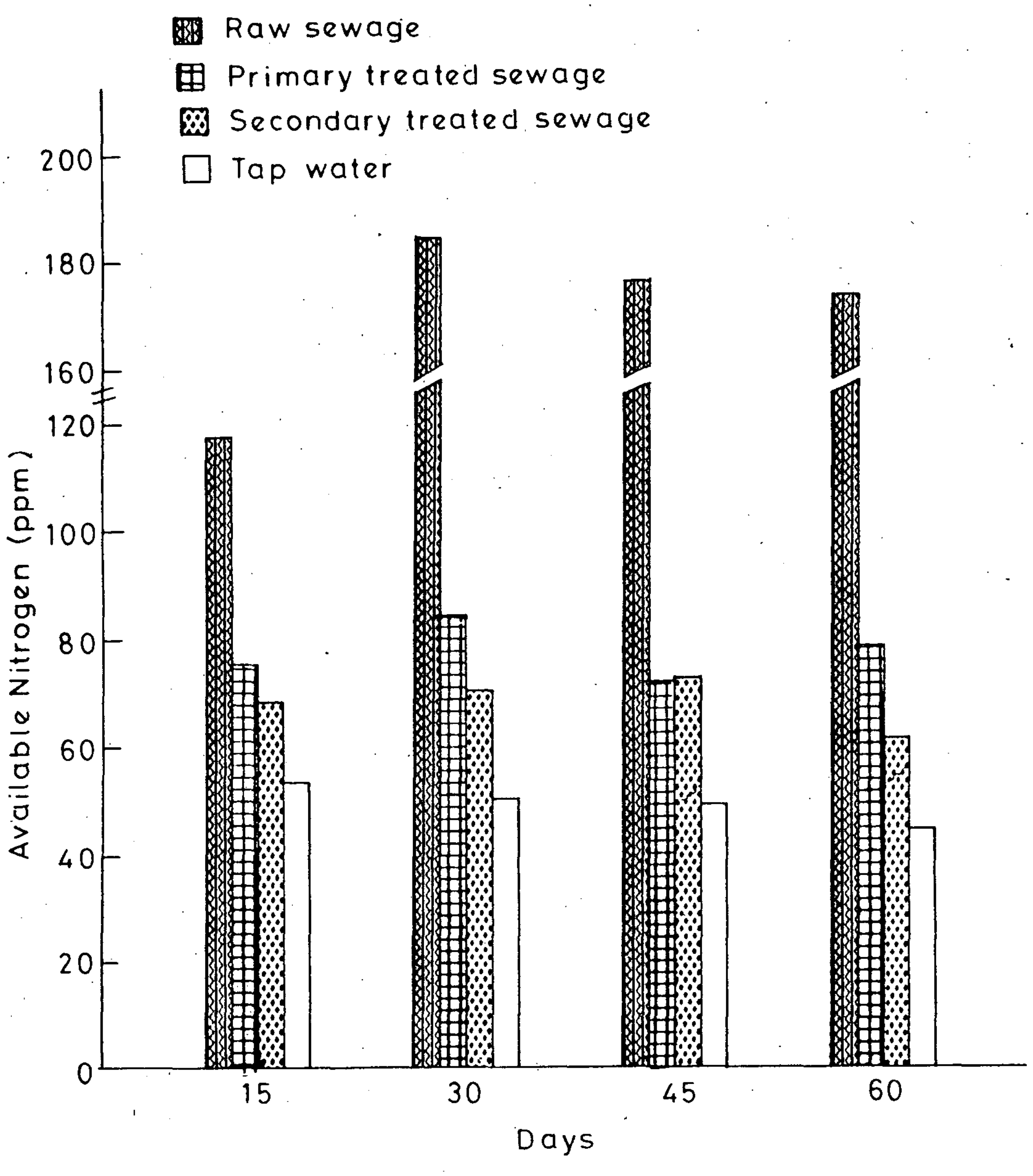


FIGURE 10. Changes of available nitrogen in the <u>surface layer</u> of sewage treated soil columns.

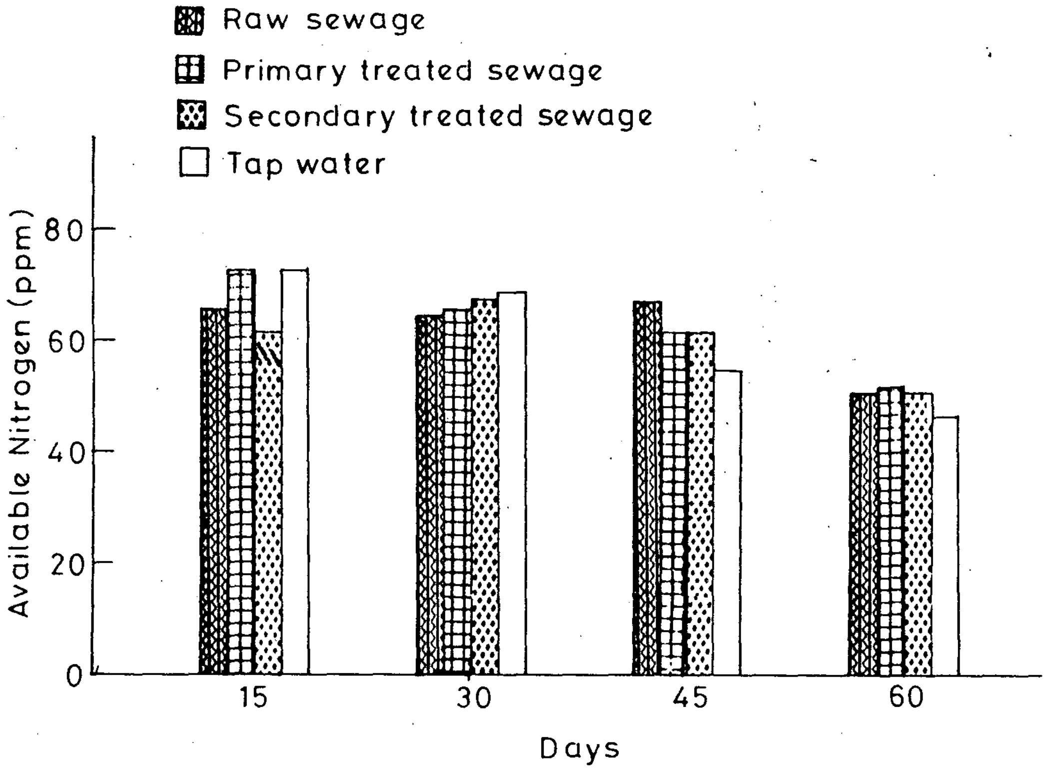


FIGURE 11. Changes in available mitrogen at a depth of 15 cm in sewage treated soil columns.

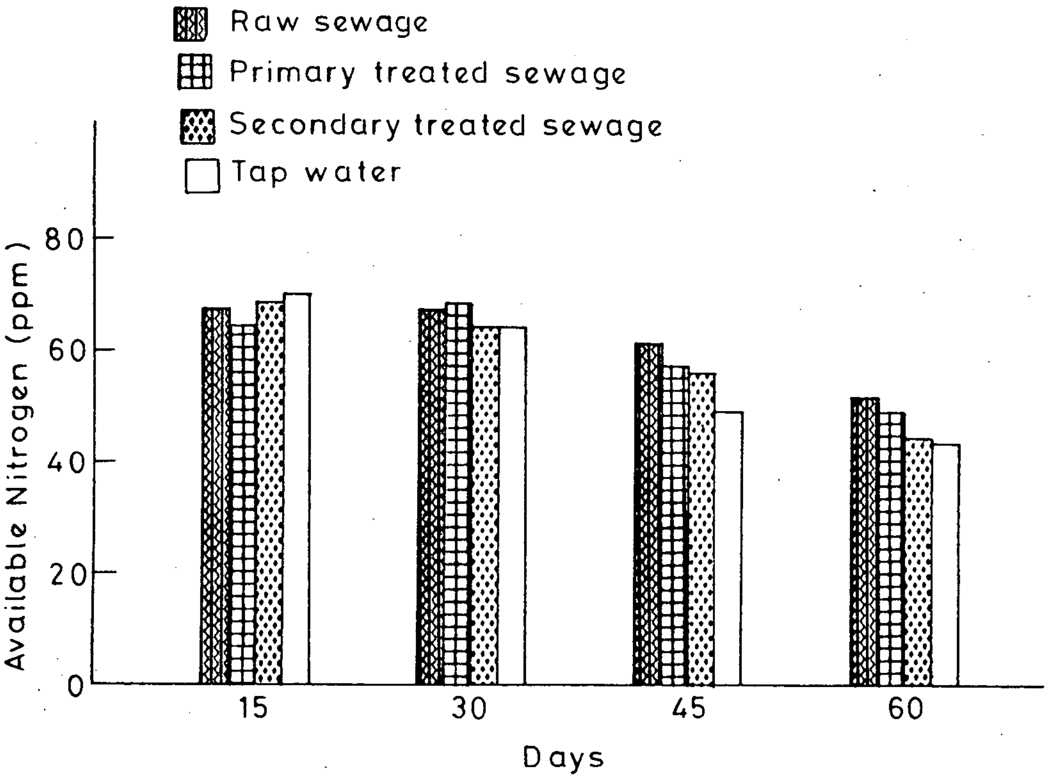


FIGURE 12. Changes in available nitrogen at a depth of <u>30 cm</u> in sewage treated soil columns.

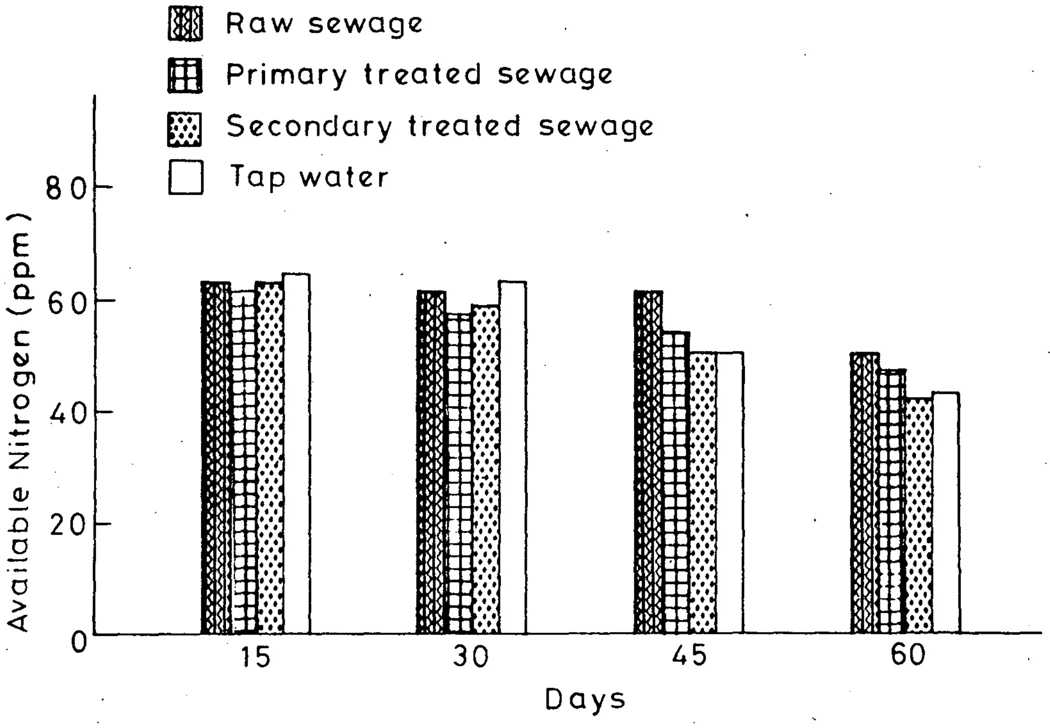


FIGURE 13. Changes in available nitrogen at a depth of 45 cm in sewage treated soil columns.

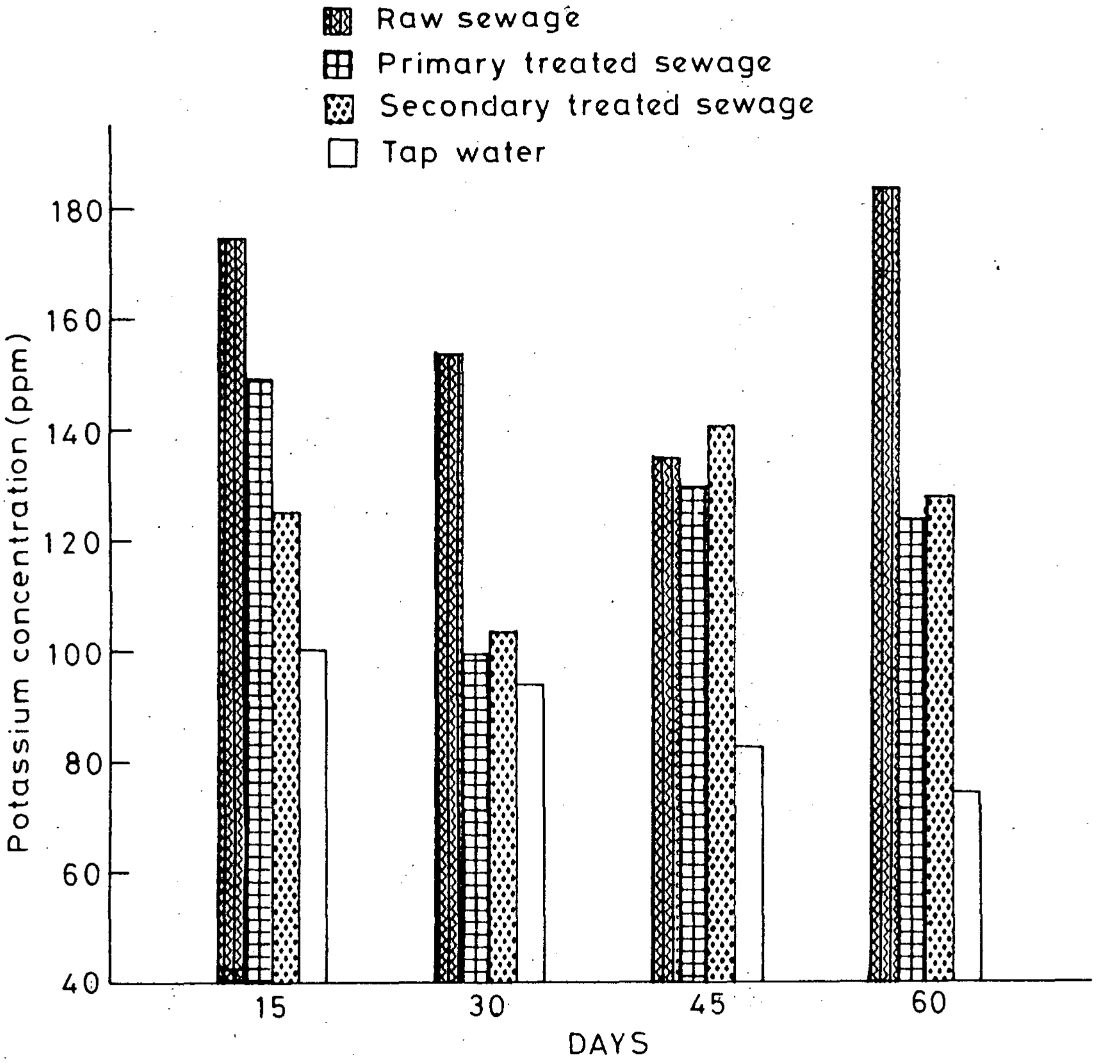


FIGURE 14. Changes in available potassium (Flame photometer values) in the Surface layer of seawage treated soil columns.

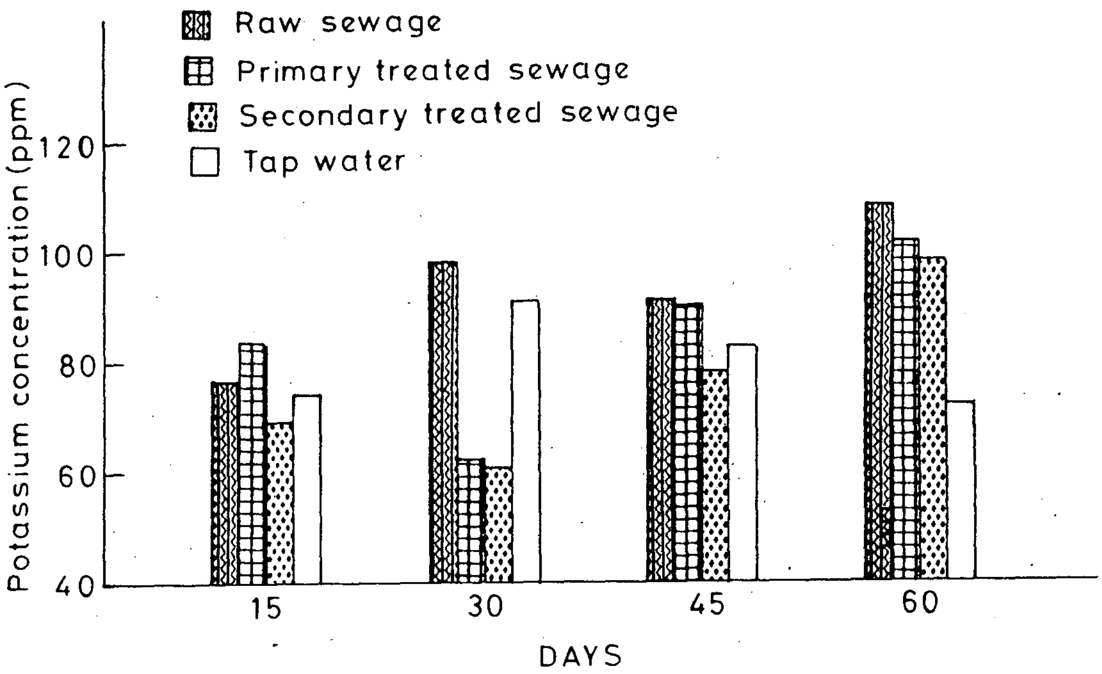


FIGURE 15. Changnes in available potassium (Flame photometer values) at a depth of 15 cm of sewage treated. soil columns.

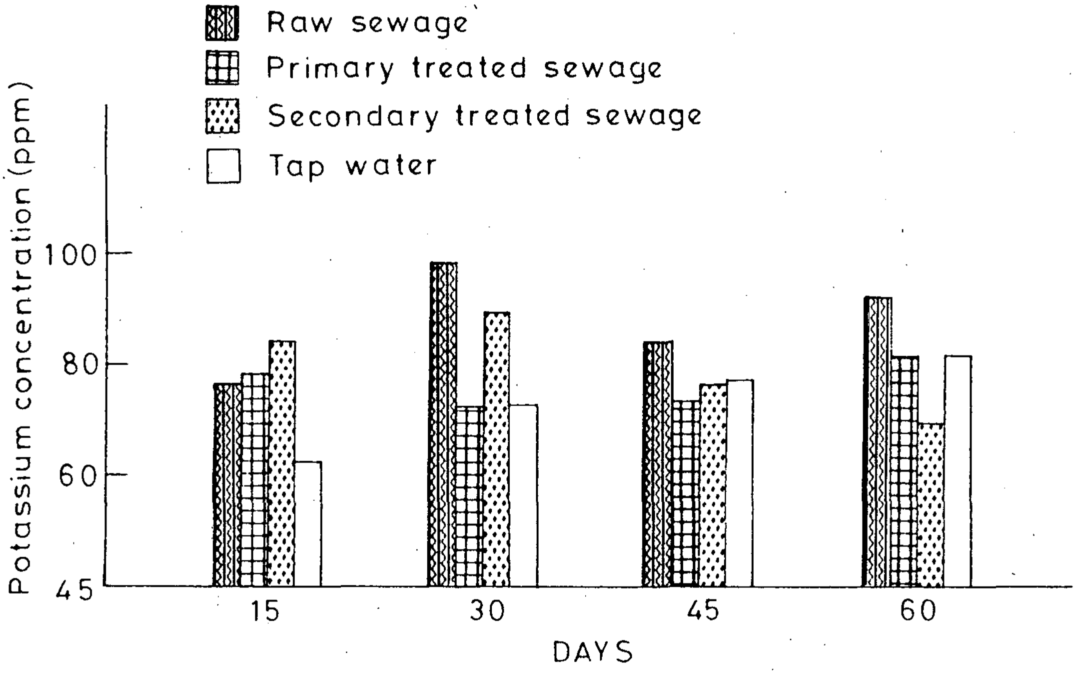


FIGURE 16. Changes in available potassium (Flame photometer values) at a depth of 30 cm of sewage treated soil columns.

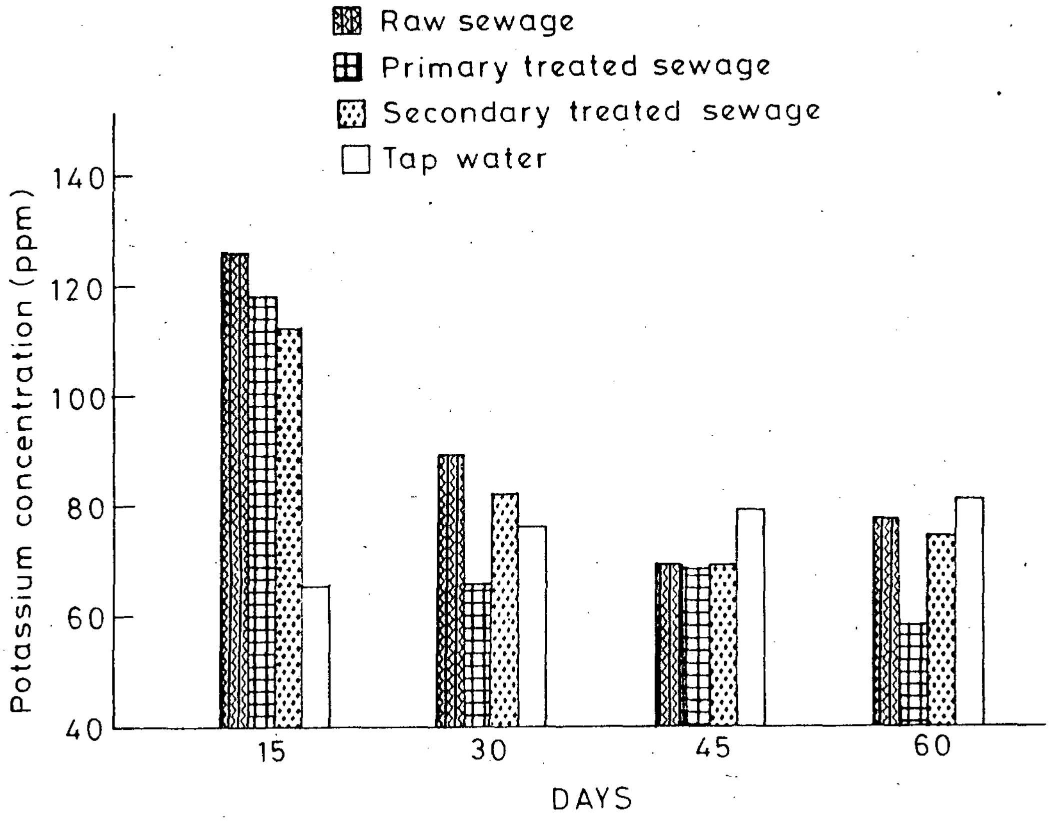


FIGURE 17. Changes in available potassium (Flame photometer values) at a depth of 45 cm of sewage treated soil columns.

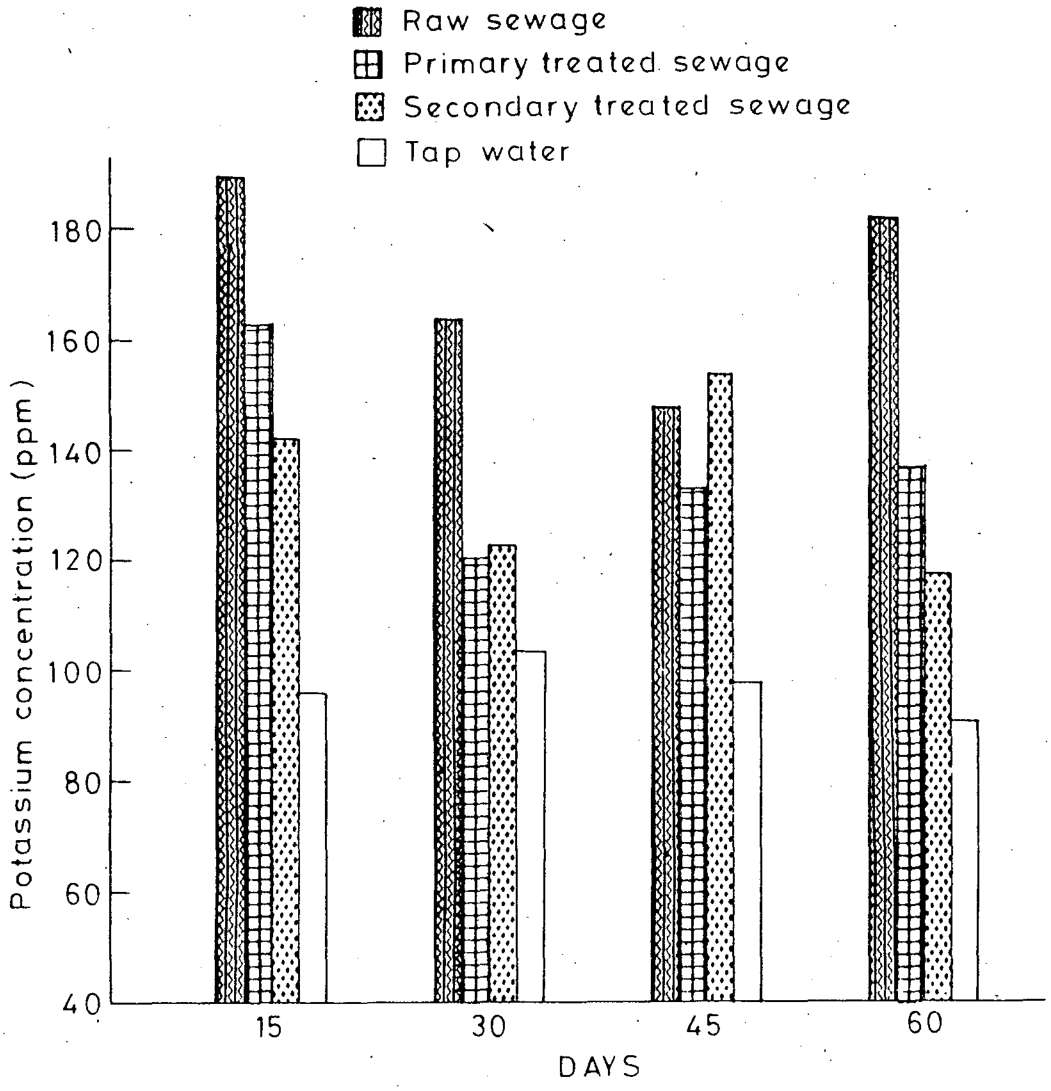


FIGURE 18. Changes in available potassiium (AAS Values) in the <u>Surface layer</u> of sewage treated soil columns.

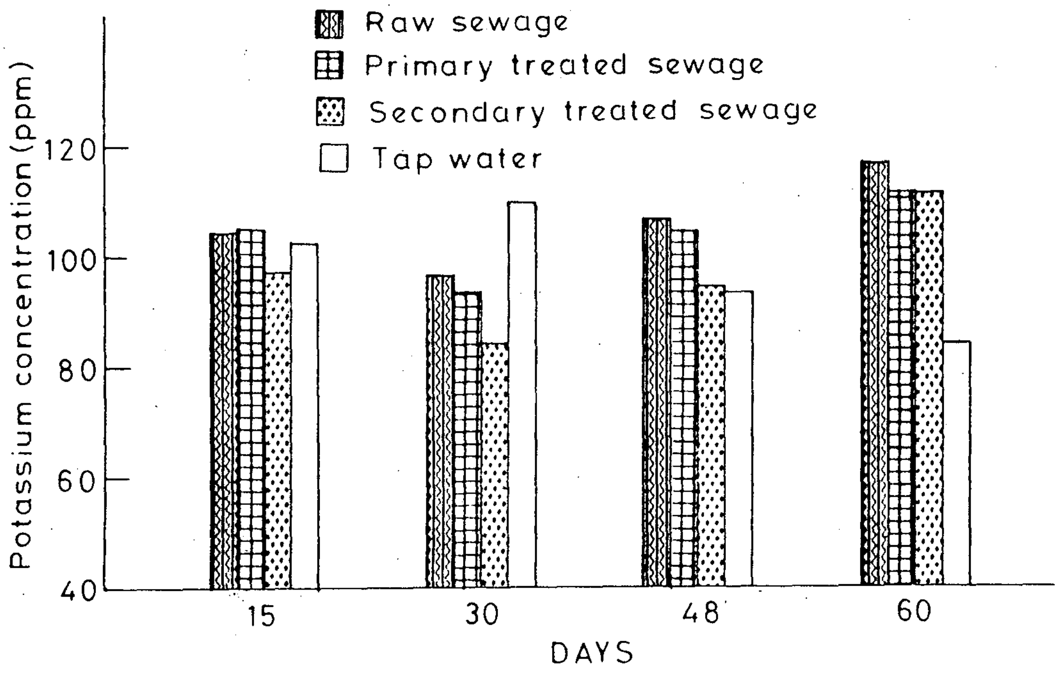


FIGURE 19. Changes in available potassium (AAS values) at a depth of 15 cm in sewage treated soil columns.

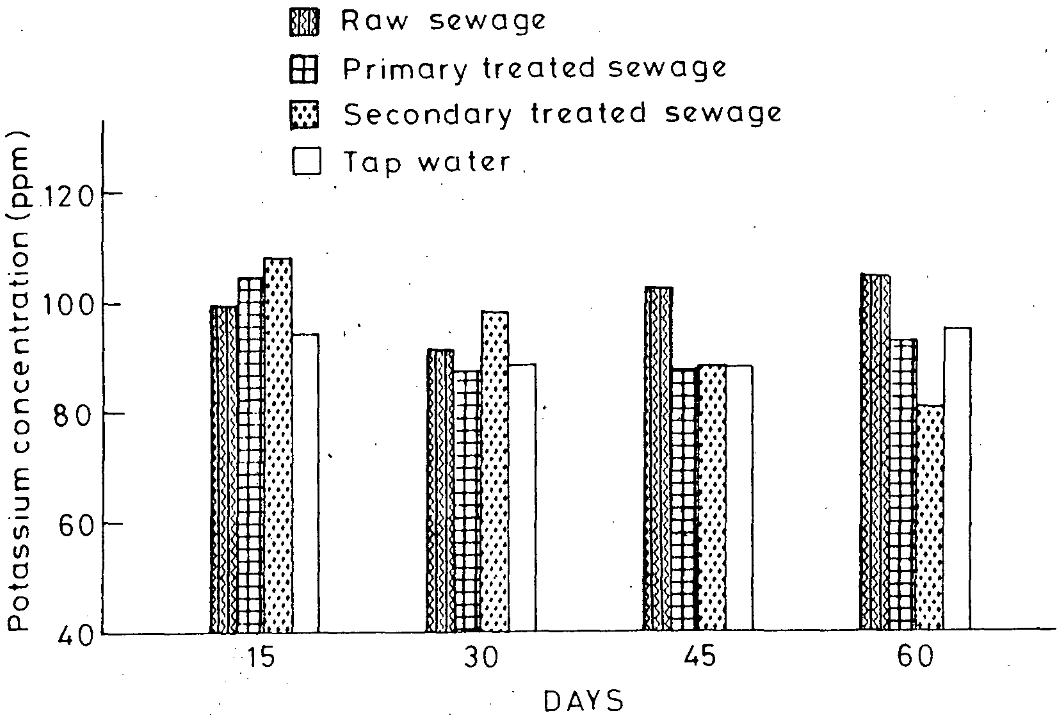


FIGURE 20. Changes in available potassium (AAS values) at a depth of 30 cm in sewage treated soil columns.

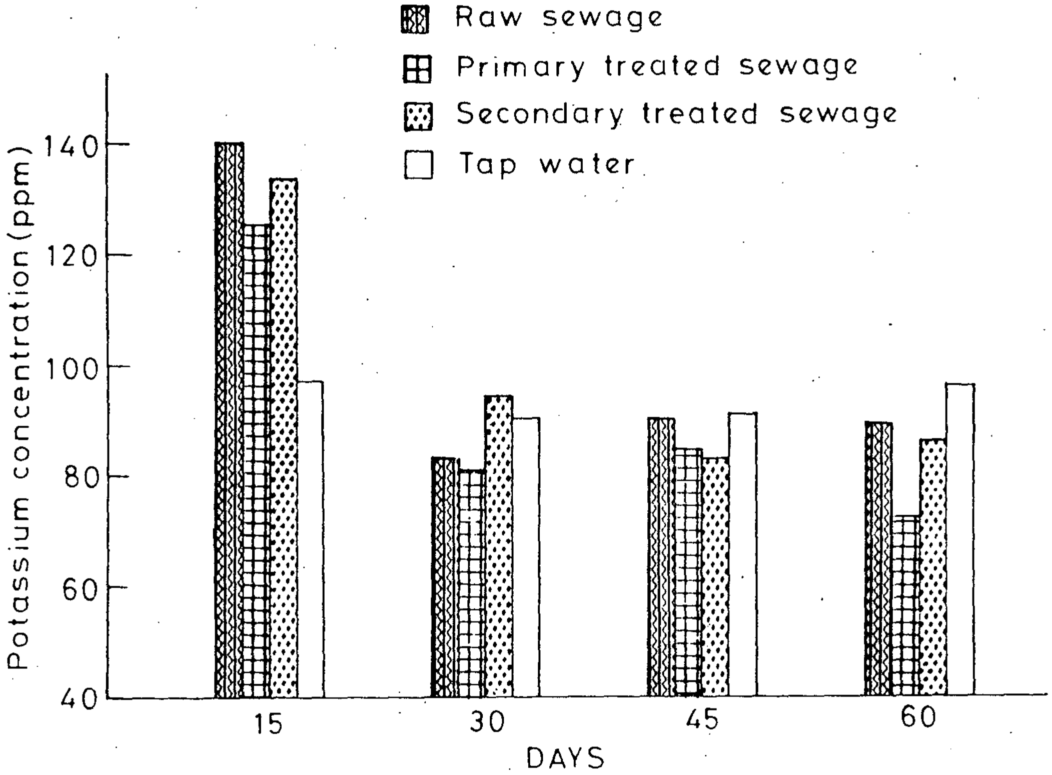


FIGURE 21. Changes in available potassium (AAS values) at a depth of 45 cm in sewage treated soil columns.

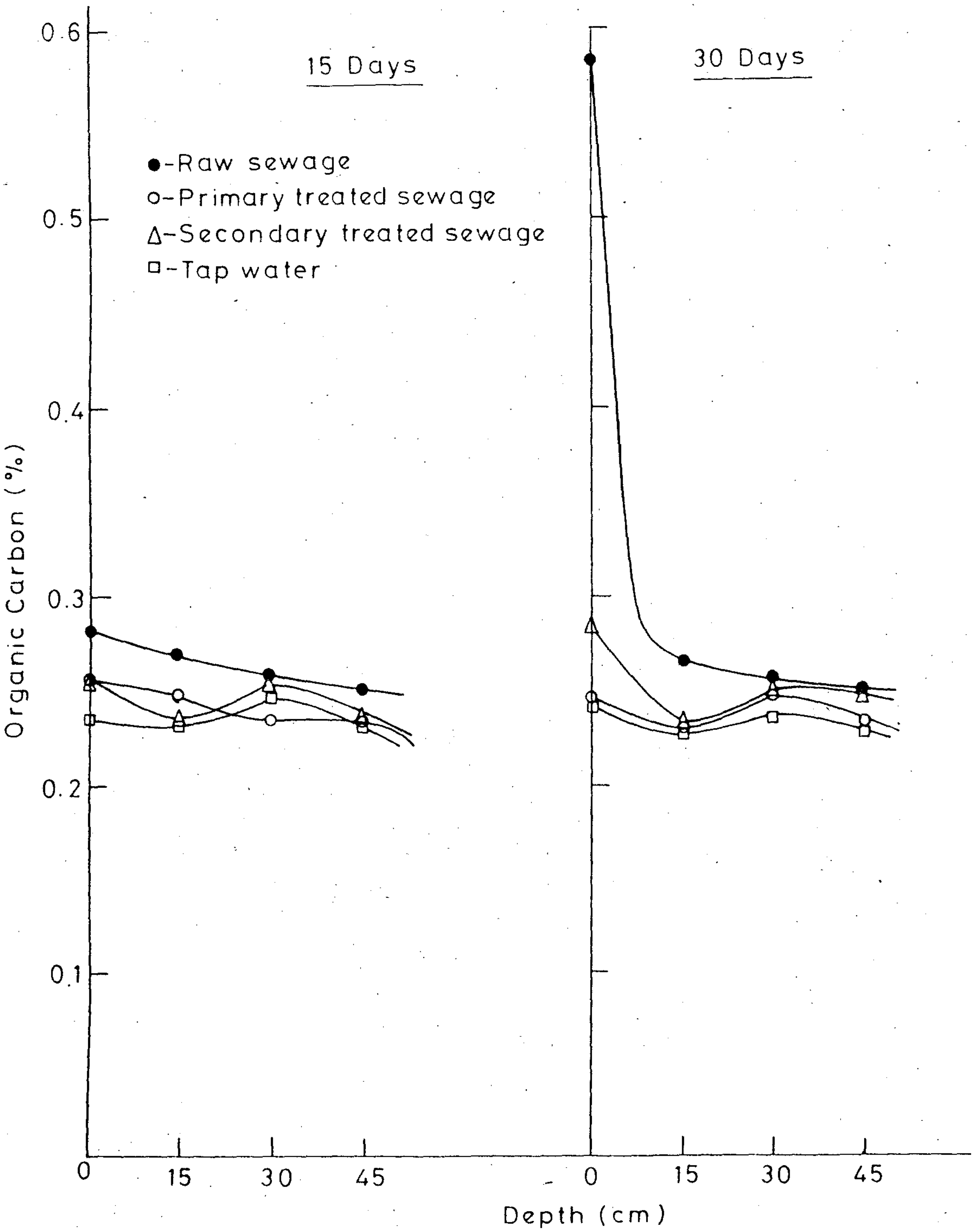


FIGURE 22. (a) Distribution of organic carbon as a function of depth in sewage treated soil columns after 15 and 30 days.

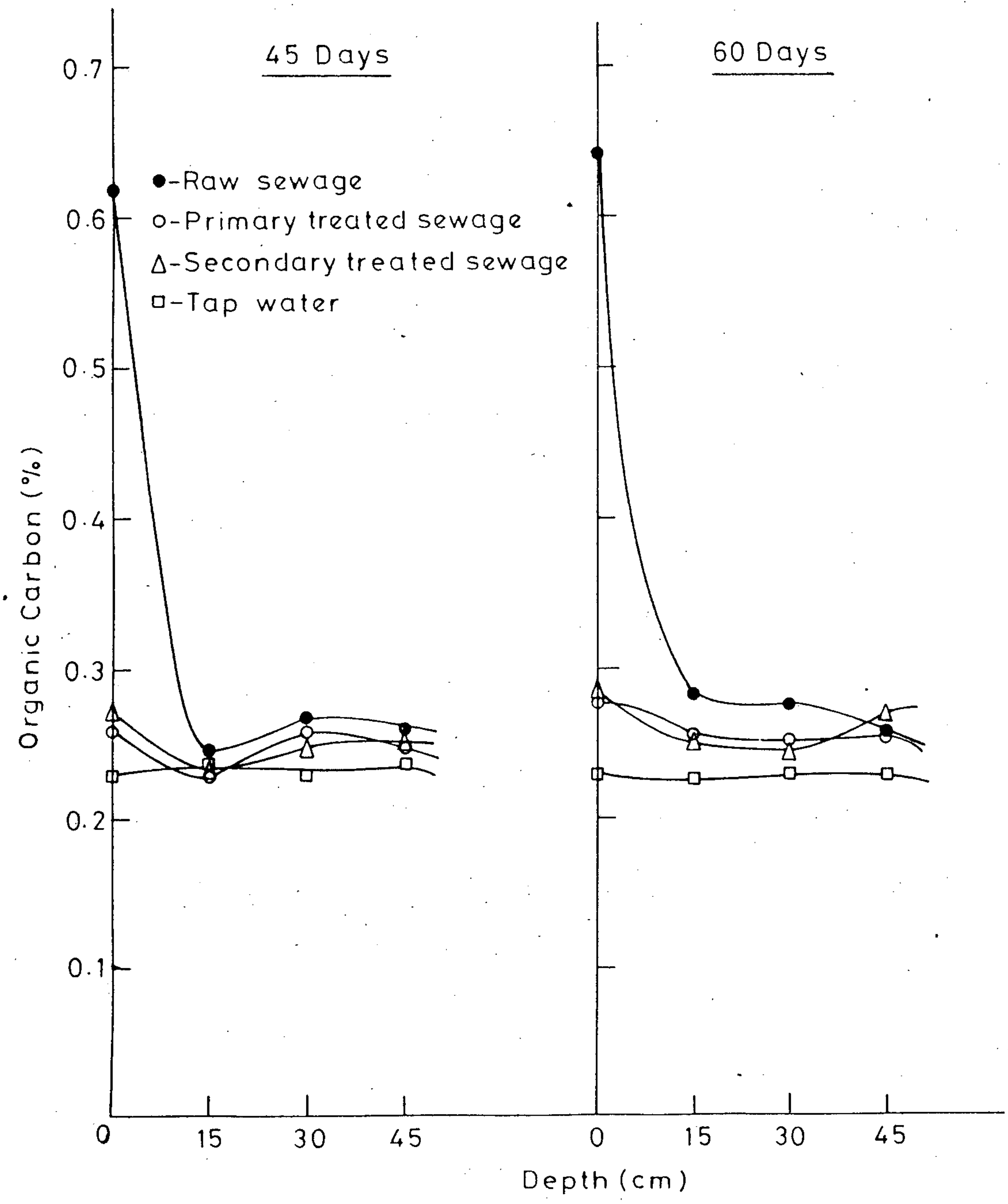


FIGURE 22. (b) Distribution of organic carbon as a function of depth in sewage treated soil columns after 45 and 60 days.

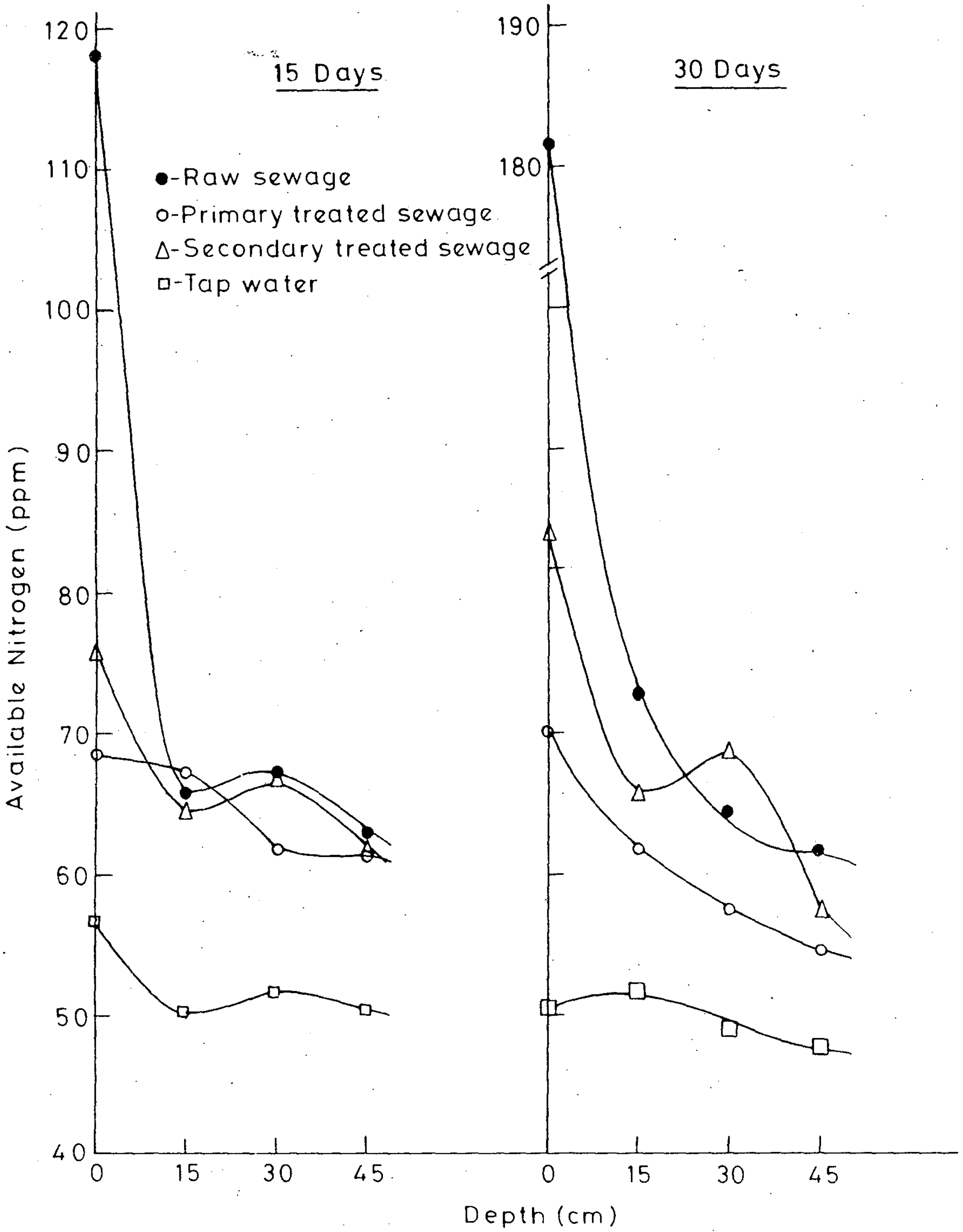


FIGURE 23. (a) Distribution of available nitrogen as a function of depth in sewage treated soil columns after 15 and 30 days.

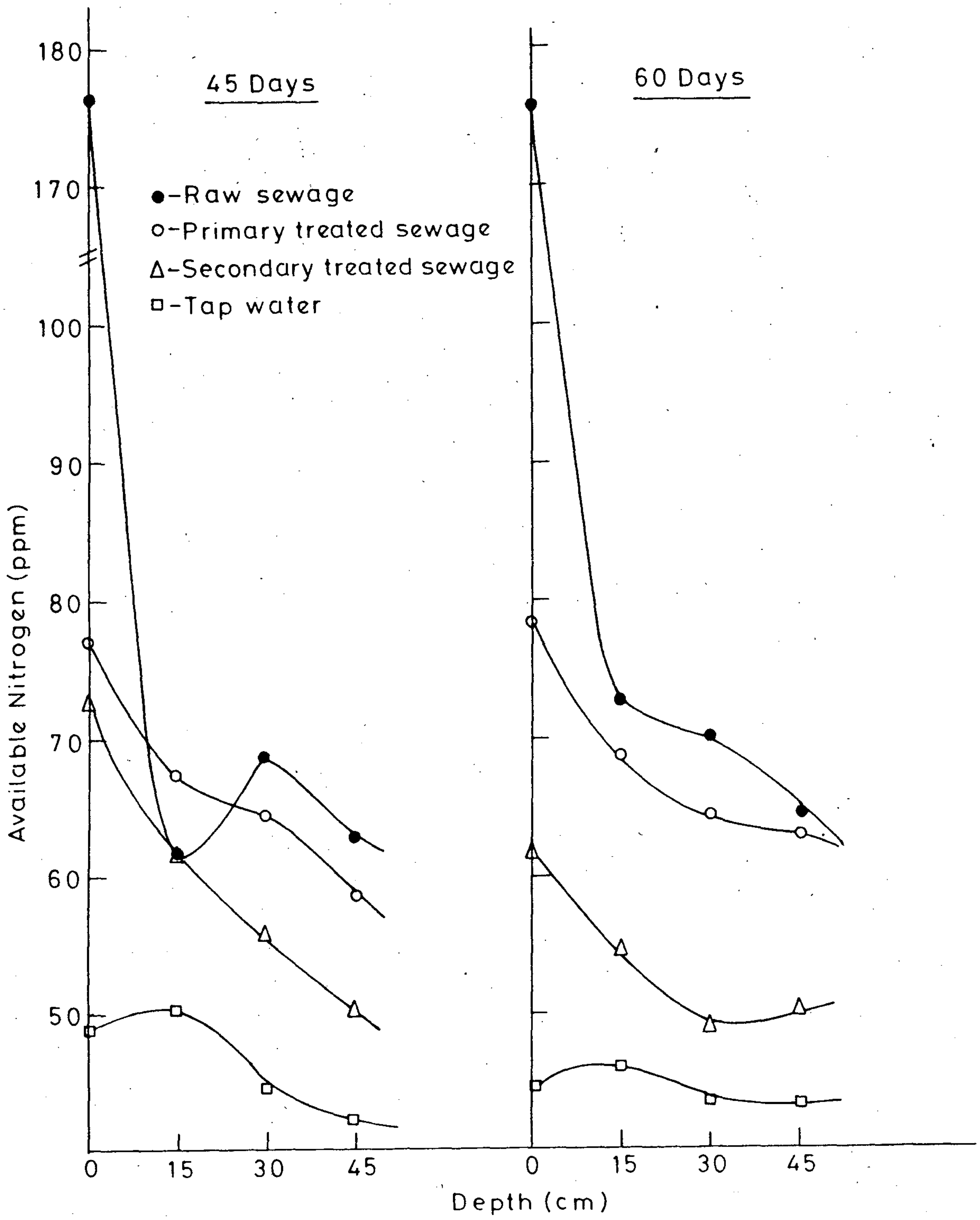


FIGURE 23. (b) Distribution of available nitrogen as a function of depth in sewage treated soil columns after 45 and 60 days.

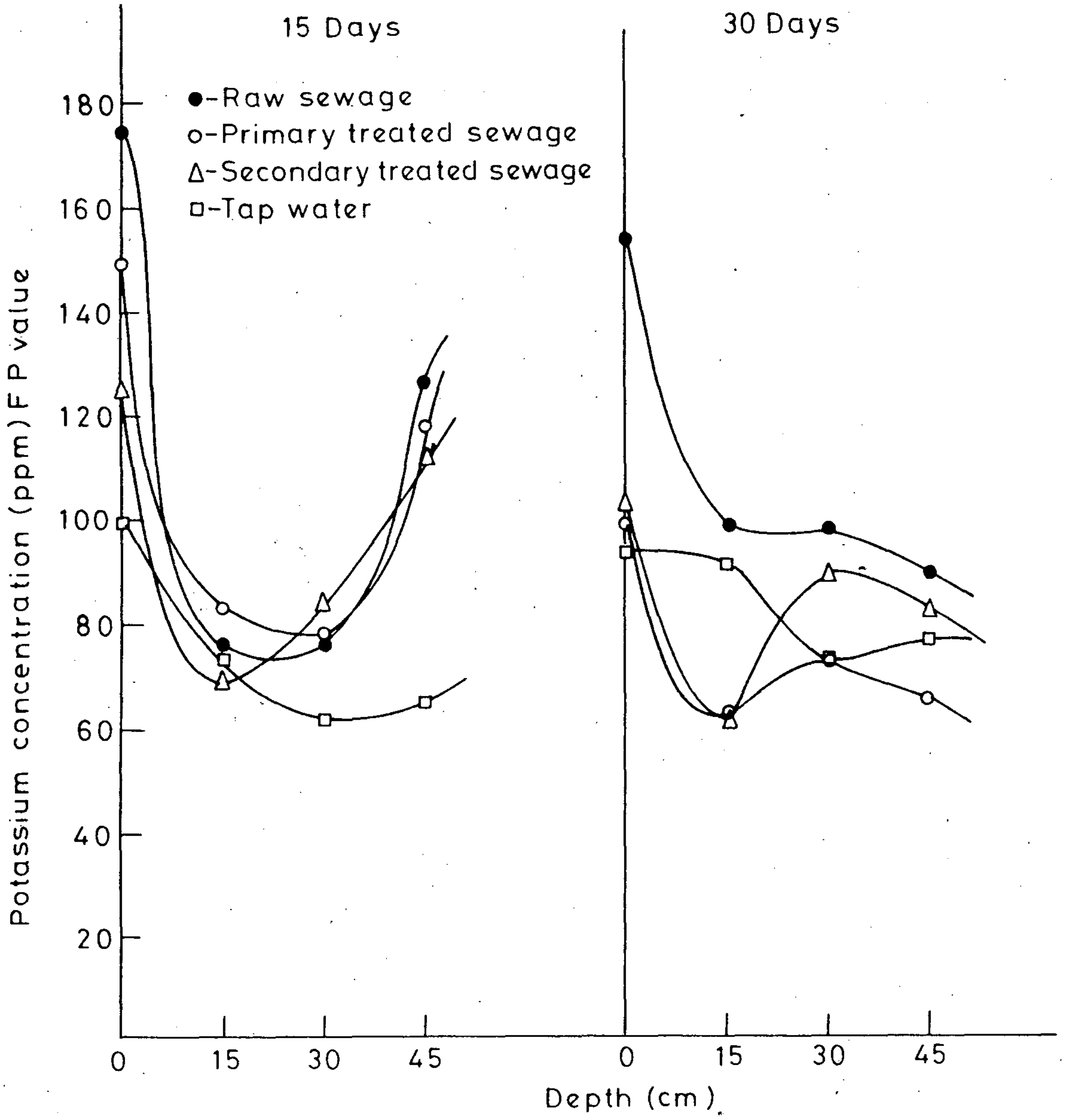


FIGURE 24. (a) Distribution of available potassium (F.P. values) as a function of depth in sewage treated soil columns after 15 and 30 days.

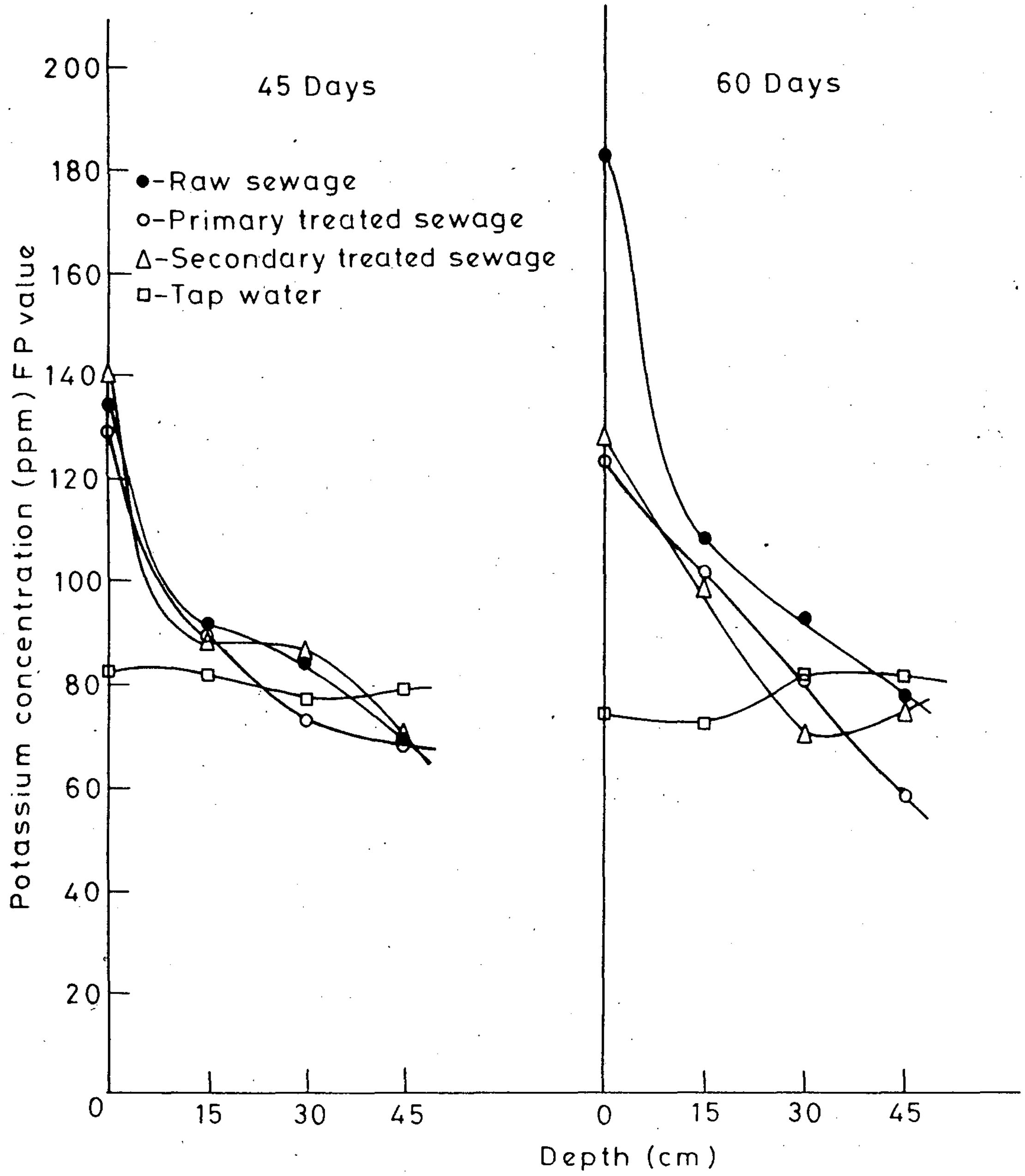


FIGURE 24: (b) Distribution of available potassium (F.P. values) as a function of depth in sewage treated soil columns after 45 and 60 days.

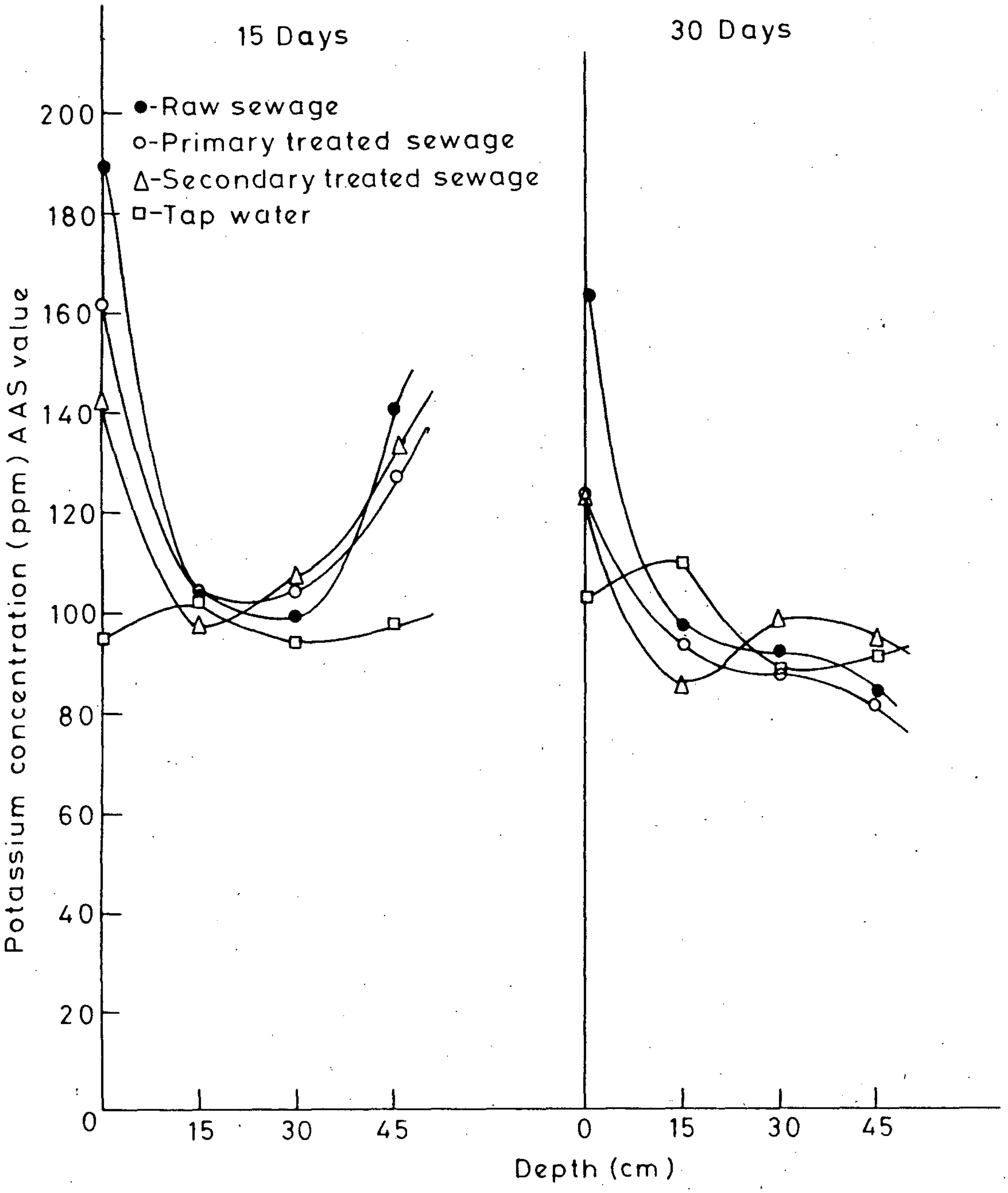


FIGURE 24. (b) Distribution of available potassium (F.P. values) as a function of depth in sewage treated soil columns after 45 and 60 days.

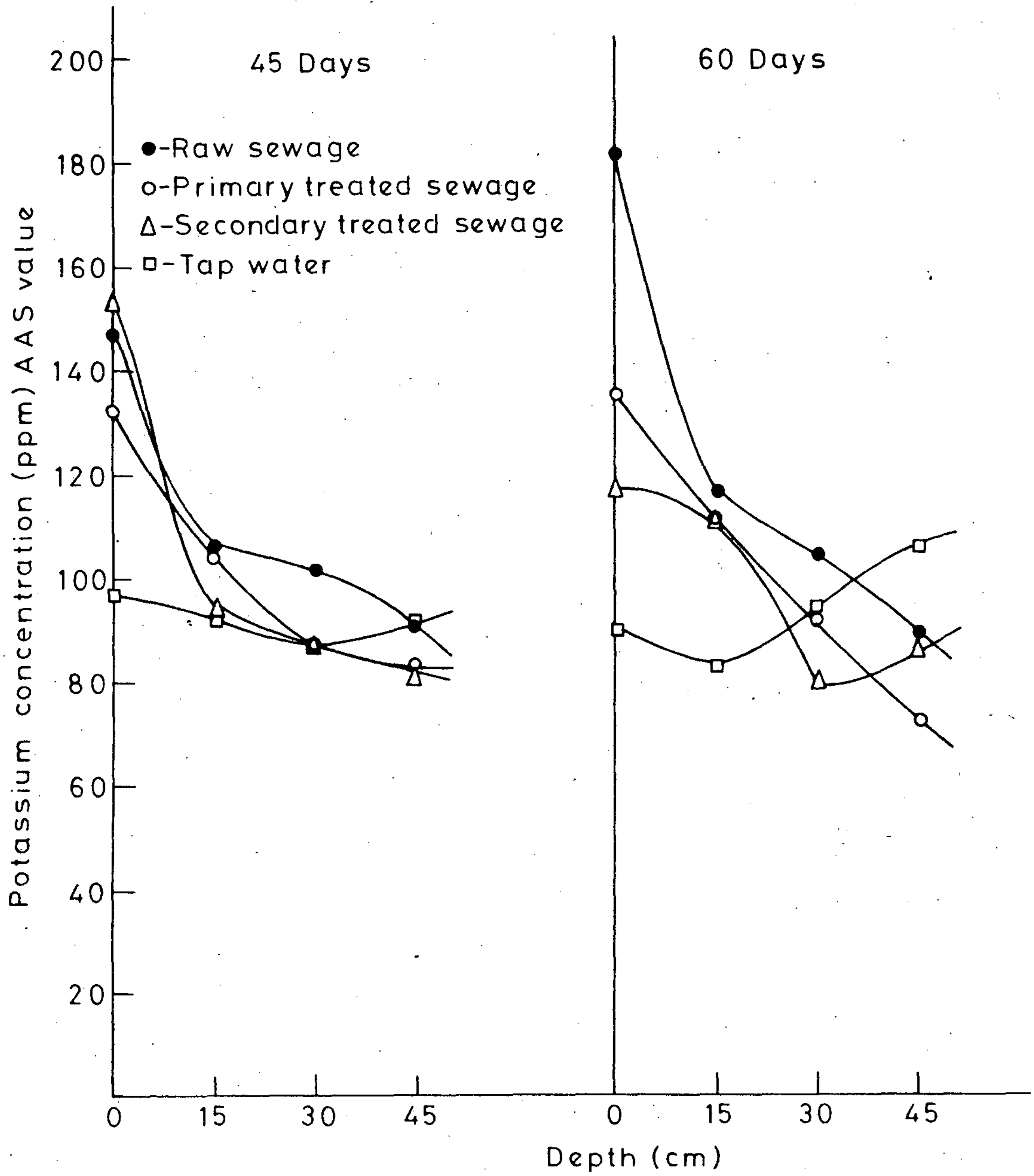


FIGURE 25. (a) Distribution of available potassium (AAS values) as a function of depth in sewage treated soil columns after 15 and 30 days.

DISCUSSION AND CONCLUSION

Physico-Chemical Characteristics of Effluents

There was considerable variation in the characteristics of the effluents collected on different dates. This might be due to seasonal variations. The chemical properties of raw sewage and other effluents are to be assessed not only to evaluate their suitability for irrigation purpose but also for managing soil productivity factors. The values of various parameters obtained for primary and secondary treated effluents in the present study were compared with the stipulated standards. It had been noticed that the range of pH, E.C. and BOD in these effluents were well below the tolerance limits as prescribed by Indian Standard Institute (Indian Standard, 1965, 1982). The observations, therefore, suggested that these effluents from Okhla Sewage Treatment Plant can be utilized for irrigation (Sekar and Bhattacharyya, 1982).

It was proposed that a model secondary effluent with a BOD concentration of 25 mg/l and an application rate of two inches (5.1 cm) per week or 11.5 lb/acre/week (12.8 kg/ha/week) would not result in appreciable accumulation of undecomposed organic matter in the soil mantle (Spyridakis and Welch, 1976). The BOD of the secondary treated effluent obtained from Okhla Treatment Plant was below this prescribed label (less than 25 mg/l) and the potassium concentration was almost same as in the case of raw sewage and primary treated sewage (Table 5). Thus secondary treated sewage could be utilized as an available source of potassium fertilization without any undesirable effect on soil properties.

The raw sewage is not advisable to be utilized for irrigation due to its high BOD and COD concentrations. Clogging usually occurs in the top few inches of soil as raw sewage contains high organic content (Noy and Feinmesser, 1977).

Physico-Chemical Properties of Soil

The soil under present investigation was poor in organic carbon and potassium content. According to Ahmad and Davis (1970) fixation started at a potassium level of 90 ppm. But the soil used for the experiment was having potassium concentration less than this level. Hence, when potassium will be added from outside in the soil, first it will be in exchangeable form and then it could be converted into fixed form.

Effect of Sewage Effluents on Soil Characteristics

pH

In the surface layers of the soil columns treated with raw or primary treated sewage, the pH values have decreased by about one unit when compared to that of the original soil. Since the pH was nearly neutral or slightly alkaline in both the cases, the transformation of applied NH_4^+ to NO_3^- (nitrification) is thought to be the main reason for the change in soil pH (Iskandar, 1978). Thus the decrease in soil pH could be attributed to the nitrification (Lance and Whisler, 1972; Broadbent et al., 1977) and resulted from hydrogen ions having been generated according to the following equation :

$$NH_4^+ + 2\ O_2 \longrightarrow NO_3^- + H_2O + 2H^+$$

Furthermore, as the surface layers were in direct contact with the atmosphere throughout the incubation period, they were subjected to aerial oxidation and microbial decomposition of organic matter (Spyridakis and Welch, 1976). As a consequence, some organic acids might have been formed during the treatment resulting in decrease in pH of the soil at the surface layer.

In the control treatment, all the layers showed a very little variation in soil pH during the incubation period of 60 days. This might be attributed to the fact that the columns in this case did not receive any organic matter from outside.

Electrical conductivity

The electrical conductivity of a soil solution depends on the ions present in the medium. Thus when soils were treated with sewage effluents, the accumulation of ions in the soil would take place resulting in the increase of electrical conductivity. Bole (1979) also reported that the electrical conductivity of surface layer upto 90 cm of soil columns increased appreciably when treated with sewage wastewater.

During the present study, the soil treated with secondary effluents, experienced relatively higher electrical conductivity than that treated with other effluents. The ions complexation and chelation of soluble ions with organic matter might account for slightly lower values of electrical conductivity in the later case (Russell, 1975). The slight decrease in the electrical conductivity of the soil treated with tap water might be due to leaching of the ions within first fifteen days. But later on subsequent days a continuous increase in electrical conductivity might be attributed to the mineralization process.

Organic carbon

The organic carbon content increased considerably after wastewater application. The same results were also reported by Iskandar (1978). The increase of organic carbon content in different layers of the soil columns treated with effluents could be due to the addition of sewage effluents that contained a significant amount of organic carbon. Since raw sewage contained more organic carbon compared to that in other effluents (Table

5), the values were higher in all the layers of the soil column treated with raw sewage. Again, the sharp increase in organic cabon within 30 days at the surface layer of the column treated with raw sewage might be due to the higher organic carbon content in the second effluent sample (Table 3) compared to the first sample (Table 2). 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 increase 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 of organic matter during the treatment.

The decrease in the percentage of organic carbon content with depth in case of raw sewage treated columns might be due to the fact that most of the organic matter in suspended form accumulated on the upper surface and only a small fraction of it moves downward in form of soluble organic matter (Spyridakis and Welch, 1976).

In the case of control treatment the decrease in organic carbon content 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 of carbon might have occurred in form of carbon dioxide through normal microbial decomposition process (Spyridakis and Welch, 1976).

Available Nitrogen

The increase in available nitrogen in all the soil columns treated with sewage effluent could be due to the addition of available nitrogen through the effluents. Available nitrogen in the surface layer of the soil column treated with raw sewage increased appreciably within 30 days. This increase could obviously be due to the fairly high amount of available nitrogen in the raw sewage effluent. Besides this, the mineralization of organic nitrogen from organic matter which accumulated on the surface layer of this coulmn could also account for the high value of available nitrogen in the surface layer.

The slight decrease in available nitrogen towards the end might be due to one or more reasons. It could be due to denitrification, volatilisation of NH_4^+ N, incorporation into microbial tissues and adsorption of ammonium ions by organic matter and by clay fraction (Gilbert et al., 1979). It also indicated here that the rate of loss of nitrogen exceeded the amount entering the soil profile through the effluents.

Sekar and Bhattacharyya (1982) also found similar variations in available nitrogen while working on the effect of sewage effluents on carbon and nitrogen mineralisation in Delhi soil. A decrease in available nitrogen in the control treatment throughout the incubation period might be due to the gradual loss of nitrogen in the column treated with tap water.

Available Potassium

The raw sewage as obtained from the Okhla Sewage Treatment Plant contained on average 10.17 ppm available potassium. During first 15 days about fifteen litres of raw sewage water were added to the soil column. The initial increase in available potassium, therefore, can be attributed to the external addition (Sekar and Bhattacharyya, 1982). A significant amount was obviously retained in the surface layer and a less amount moved downwards (Patterson and Richer, 1966). The high amount of available potassium in the surface layer may be attributed to the high amount of organic matter present in the surface layer (Fagbami et al., 1985). At the 45 cm layer, the amount of available potassium was more than that in the above two layers. This could be due to the fact that potassium absorbed by the soil complexes was leached to lower depths and held in exchangeable form (Pratt and Laag, 1977). However, at subsequent days the available potassium decreased with increase in depth which also showed a slow downward movement of potassium (Rehm et al., 1984).

After an initial increase within 15 days, the available potassium started declining obviously due to the fact that with passage of time potassium tends to change into nonexchangeable form (Ghosh and Hassan, 1976; Kansal and Sekhon, 1976).

According to Ahmad and Davis (1970) fixation starts when the available potassium in soil goes beyond the critical value of 90 ppm. Again, potassium takes few days or even a month to get fixed in the soil (Sparks et al., 1980a). Thus, in the present study, the potassium fixation was delayed in the 30 cm and 45 cm layers and started only after 30 days when available potassium status reached above the critical value of 90 ppm. While in the surface layer the value of available potassium stated declining after 15 days as the fixation started earlier. The increase in available potassium towards the end could possibly be due to the subsequent release of potassium fixed in the soil. As ~~sewage~~ sewage was continuously added to the soil columns, it could be another reason for the accumulation of higher amount of available potassium at the 60th day.

Compared to tap water treatment, the soil columns treated with raw or treated-sewage effluents accumulated more available potassium. Accumulation was the highest in the case of raw sewage treatment plausibly due to its high organic carbon content. The soil columns amended with primary treated sewage did not have any tremendous difference with that treated with secondary effluents except at the surface layer on the 15th day (Table 10). This suggested that both primary treated sewage and secondary treated sewage could be used for potassium fertilization of soil as the nutrient status of both the effluents was almost the same. But it is advisable to use the secondary treated sewage effluent as it should contain less harmful pathogens (Hoadley and Goyal, 1976) and should low in suspended particles (Spyridakis and Welch, 1976). The raw sewage should be avoided from being used for irrigation as most of its parameters do not conform to the required specifications.

Correlation of Available Potassium With Other Soil Parameters

Available potassium was found to be highly correlated with organic carbon, the highest correlation being obtained at 30th and 60th days (Table 12). A highly significant correlation between available potassium and organic carbon was also reported by Unamba-Oparah (1972) and Brar and Sekhon (1985). It indicates that the potassium availability in the soil is related to the organic carbon content of the soil, as confirmed by significant correlation coefficients between these two soil parameters and as indicated by the highest exchangeable values of available potassium in the surface layer (Fagbami et al., 1985).

A significant correlation was also observed in between available potassium and available nitrogen. The maximum

TABLE - 12

Correlation Coefficient (r) of Available Potassium with other Soil Parameters at different days

Parameter	15 days (n=16)	30 days (n=16)	45 days (n=16)	60 days (n=16)	Total (n=64)
C	0.466*	0.828**	0.562*	0.831**	0.596**
N	0.735**	0.804**	0.659**	0.856**	0.702**
pH	-0.740**	-0.766**	0.754**	-0.850**	-0.747**
EC	-	-	-	-	0.240@

*P = 0.05
**P = 0.01
@ Not significant
(The available potassium was also determined by AAS and the values obtained thereby were highly correlated to those obtained by flame photometer, r = 0.9458).

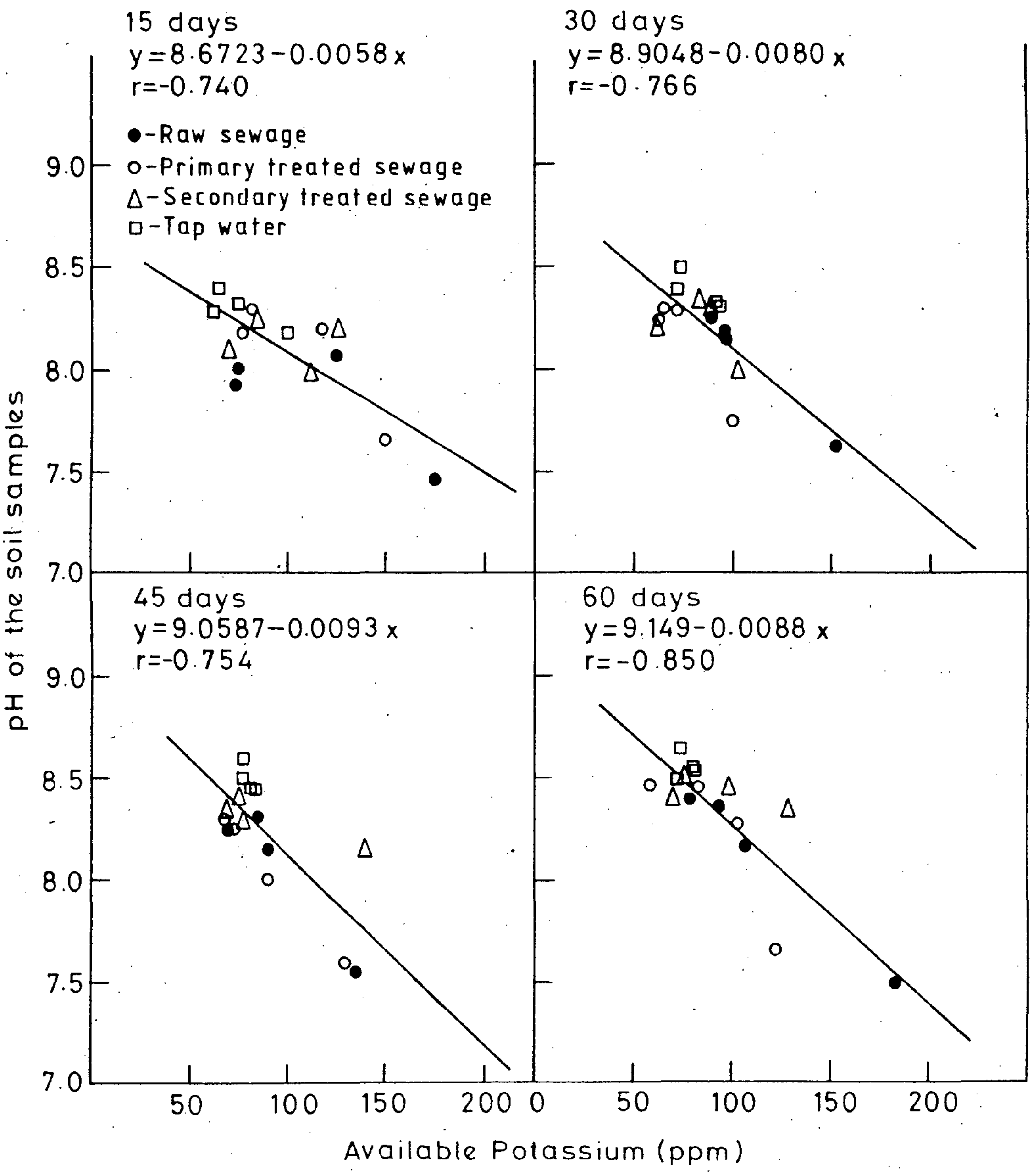


FIGURE 26. Correlation between available potassium and pH in sewage treated soil columns.

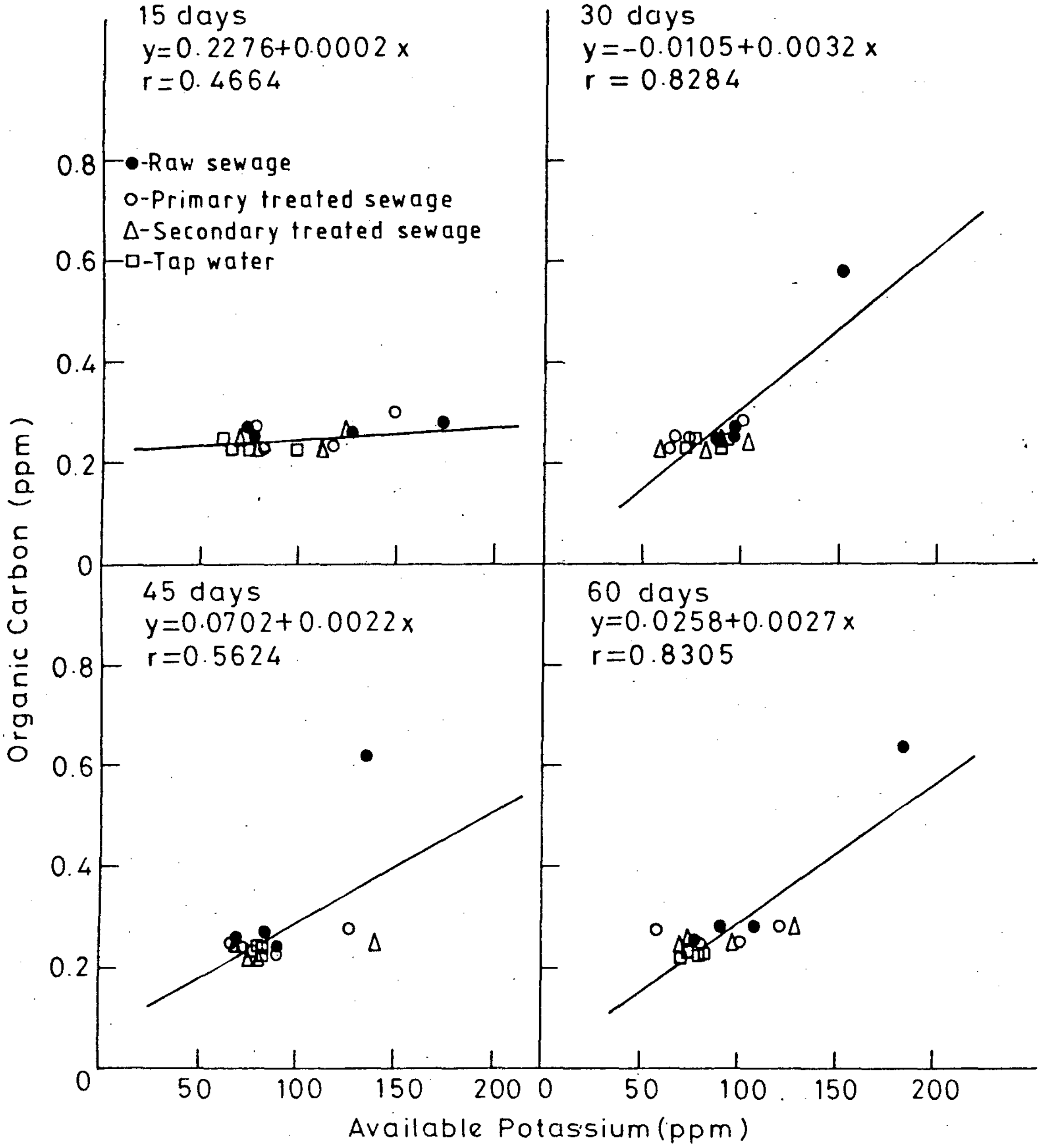


FIGURE 27. Correlation between available potassium and organic carbon in sewage treated soil columns.

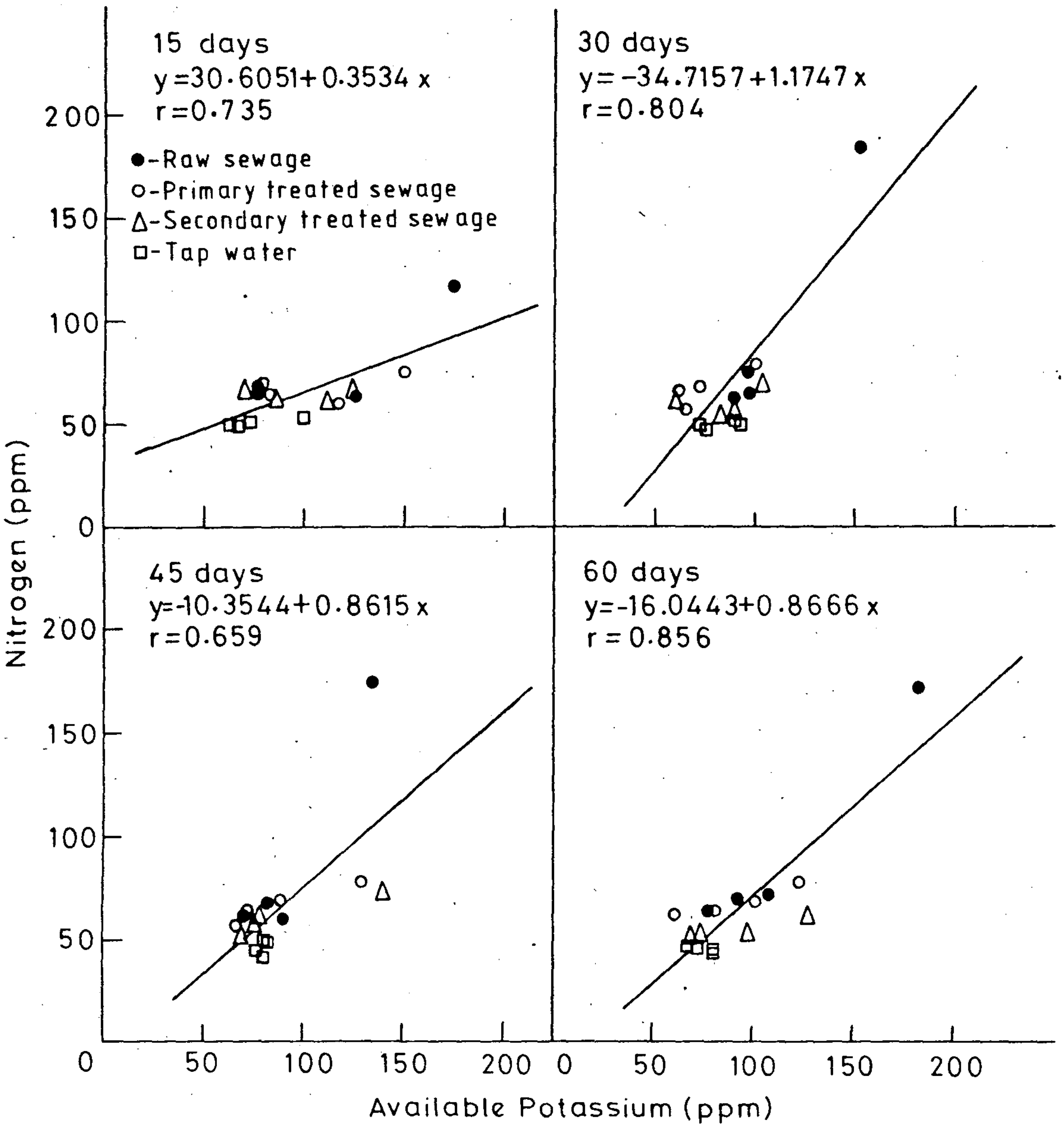


FIGURE 28. Correlation between available potassium and available nitrogen in sewage treated soil columns.

correlation was obtained at the end of 60th day (r = 0.866). Thus it could be inferred that availability of potassium depended on the nitrogen mineralization.

In the present study, the available potassium was found to have significant negative correlation with pH of the soil (r = -0.804). The formation of hydroxy-aluminium cations at pH above 5.5 is suggested to be responsible for greater adsorption of potassium in competition with other ions. Thus the potassium concentrations in solution in equilibrium with soils were greater at low than at high pH (Kansal and Sekhon, 1976).

The electrical conductivity was found to have no correlation with available potassium. Brar and Sekhon (1985), however, found that available potassium had no significant correlation with either pH or electrical conductivity.

Analytical Methods

The available potassium was also determined by atomic absorption spectrophotometer (AAS). The values obtained thereby were highly correlated to those obtained by flame photometer (r = 0.9416**). Thus both these analytical methods are useful for the determination of available potassium. However, the values obtained with AAS were slightly higher due to possible interference by other cations in flame absorption.

SUMMARY

A short term experiment was conducted to monitor the changes in available potassium content and other soil parameters under the application of raw and treated sewage effluents to evaluate the effectiveness and environmental safety in using the sewage water for irrigation on land. The experiment was carried out on different soil columns under laboratory conditions. The results obtained are summerised below :

1. The application of sewage resulted in the decrease of soil pH. While the decrease was significant in the surface layer, it was less pronounced in subsequent layers. This was attributed to the formation of hydrogen ions during nitrification and possible generation of organic acids.

2. The values of electrical conductivity, in general, increased slightly on application of sewage effluents. Electrical conductivity of the soil treated with secondary-treated-effluent was considerably higher than that in the other treatments.

3. The organic carbon content of soil increased on application of sewage effluents in the soil columns. Obviously the increase was more when raw sewage was applied which

contained more organic carbon. Irrespective of the nature of the effluents applied, the surface layers of all the soil columns experienced larger increase in the organic carbon content. This showed that the organic matter mainly accumulated on the surface of the soil.

4. Application of sewage effluent also resulted in the increase in available nitrogen content of the soil, the increase being more pronounced in the surface layer. However, there was a slight decrease in the available nitrogen towards the end, possibly due to denitrification, ammonia volatilisation and adsorption by the clay fraction or by organic matter.

5. Available potassium in soil increased due to the external addition of sewage effluent. While a significant amount was retained in surface layer, less amount move downwards. Interestingly after 15 days, it was found that available potassium in the 45 cm layer was more than that in the above two layers possibily due to leaching of the potassium absorbed by soil complex to the lower depths. However, at subsequent days the available potassium decreased with increase in depth evincing a slow downward movement of potassium.

6. After an initial increase, available potassium started

declining with the passage of time due to its possible transformation to nonexchageable forms. It was also observed that the fixation of available potassium started after it reached a critical value. The increase in available potassium towards the end could be possible due to subsequent release of fixed potassium.

7. Available potassium was found to be highly correlated with organic carbon and available nitrogen. It could thus, be inferred that the potassium availability was related to organic carbon content and nitrogen mineralisation in soil. Again available potassium had a significant negative correlation with the pH of soil, while it had no correlation with the electrical conductivity.

BIBLIOGRAPHY

Ahenkorah, Y. (1970) Potassium-supplying power of some soils of Ghana cropped to Cacio. Soil Sci. 109: 127-135.

Ahmad, N. and C.E. Davis (1970) Forms of K fertilizers and soil moisture content on potassium status of a Trinidad soil. Soil Sci. 109: 121-126.

Ajmal, M. and A.U. Khan (1983) Effects of sugar factory effluent on soil and crop plants. Environ. Pollut. (Series A) 30: 135-141.

Allen, S.E. (1974) Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford, London, Edinburgh, Melbourne.

Allison, L.E. (1965) Organic carbon. In 'Methods of soil analysis'. Ed. C.A. Black. Am. Soc. Agron., Madison, Wis., pp. 1367-1378.

Amoozegar-Fard, A., W.H. Fuller and A.W. Warrick (1984) An approach to predicting the movement of selected polluting metals in soils. J. Environ. Qual. 13: 290-297.

APHA (1980) Standard methods for the examination of water and wastewater. 15th edn., American Public Health Association, Washington D.C., U.S.A.

Arceivala, S.J. (1977) Water reuse in India. In 'Water renovation and reuse'. Ed. H.I. Shuval, Academic Press Inc., New York, pp. 277-309.

Barber, S.A. (1984) Soil nutrient bioavailability. John Wiley and Sons, New York, pp. 229-258.

Baskaran, P. (1985) Potash for crop resistance to insect pests. J. Potassium Res. 1: 81-89.

Bear, F.E. (1965) Chemistry of the soil. Oxford and IBH Publishing Co., Calcutta.

Beek, J., F.A.M. Dettan and W. H. Van Riemsdign (1977) Phosphates in soils treated with sewage water. 1. General information on sewage farm, soil and treatment results. J. Environ. Qual. 6: 4-7.

Beringer, H. (1978) Functions of potassium in plant metabolism with particular reference to yield. In 'Potassium in soils and crops'. Potash Research Institute of India, New Delhi, pp. 185-202.

Bhargava, P.N., H.C. Jain and A.K. Bhatia (1985) Response of rice and wheat to potassium. J. Potassium Res. 1: 45-61.

Black, C.A. (1965) Methods of soil analysis. Agronomy 9. Am. Soc. Agron., Madison, Wis.

Black, C.A. (1973) Soil plant relationship. 2nd edn., Wiley Eastern Pvt. Ltd., New Delhi. pp. 654-773.

Bole, J.B. (1979) Land application of municipal sewage wastewater: Changes in soil chemistry. Agron. Abstract (Environ. Qual.) 71st Annual Meeting of American Society of Agronomy held at Fort Collins, Colorado, Aug. 5-10, 1979.

Bole, J.B. and R.G. Bell (1978) Land application of municipal sewage wastewater: yield and chemical composition of forage crops. J. Environ. Qual. 7: 222-226.

Boswell, F.C. (1975) Municipal sewage sludge and selected element applications to soil: Effect on soil and fescue. J. Environ. Qual. 4: 267-273.

Bower, C.A. (1975) Leaching of adsorbed potassium from humid tropical soils. Soil Sci. Soc. Am. Proc. 39: 594-596.

Brady, N.C. (1984) The nature and properties of soils. 9th edn. Macmillan Publishing Company, New York. pp. 328-362.

Brar, M.S. and G.S. Sekhon (1985) Potassium status of five Benchmark soils series from Northern India. J. Potassium Res. 1: 28-35.

Broadbent, F.E., D. Pal and K. Aref (1977) Nitrification and denitrification in soils receiving municipal wastewater. In 'Wastewater renovation and reuse.' Ed. F.M. D'itri, Marcel Dekker Inc., New York, pp. 321-348.

Bunderson, E.D., D.J. Weber and J.N. Davis (1985) Soil mineral composition and nutrients uptake in Juniperus osteosperma in 17 Utah sites. Soil Sci. 139: 139-148.

Campbell, W.F., R.W. Miller, J.H. Reynolds and T.M. Schreeg (1983) Alfalfa, sweetcorn and wheat responses to long-term application of municipal wastewater to cropland. J. Environ. Qual. 12: 243-249.

Chahal, R.S., O.P. Sangwan and Bharat Singh (1976) Forms of potassium in some groundnut growing soils of Ambala and Gurgaon districts (Haryana). Indian Soc. Soil Sci. Bull. No. 10: 61-65.

Chaiken, E.I., S. Poloncsik and C.D. Wilson (1973) Muskegon sprays sewage effluents on land. Civil Eng. 43(5): 49-53.

Chopra, S.L. and J.S. Kanwar (1976) Analytical agricultural chemistry. Kalyani Publishers, India.

Clapp, C.E., A.J. Palazzo, W.E. Larson, G.C. Marten and D.R. Linder (1978) Uptake of nutrients by plants irigated with municipal wastewater effluent. In 'Int. Symp.' State of Knowledge in land treatment wastewater, Hanover, N.H., 20-25 Aug. 1978. Vol. I. Cold. Reg. Res. and Eng. Lab., Hanover, N.H. pp. 395-404.

Crites, R.W. (1975) Wastewater irrigation: this city can show you how. Water Wastes Eng. 12: 49-50.

Datta, S.C. (1985) Simultaneous and intermittent measurement of K, Ca and NO_3 ion, absorption by intact bean plant (Phaseolus vulgaris L.) in aerobic and anaerobic conditions. Plant Soil 84: 193-199.

Day, A.D., J.L. Stroehlein and T.C. Tucker (1972) Effects of treatment plant effluent on soil properties. J. Water Pollut. Control Fed. 44: 372-375.

Day, A.D., F.A. Taher and F.R.H. Katterman (1975) Influence of treated municipal wastewater on growth, fiber, acid-soluble nucleotides, protein and amino acid content in wheat grain. J. Environ. Qual. 4: 167-169.

Day, A.D. and T.C. Tucker (1977) Effects of treated municipal wastewater on growth, fibre, protein and amino acid content of sorghum grain. J. Environ. Qual. 6: 325-327.

Day, A.D., J.A. McFadyen, T.C. Tucker and C.B. Cluff (1979a). Commercial production of wheat grain irrigated with municipal wastewater and pump water. J. Environ. Qual. 8: 403-406.

Day, A.D., J.A. McFadyen, T.C. Tucker and C.B. Cluff (1979b) Wastewater helps the barley grow. Water Wastes Eng. 16: 26-28.

Day, A.D., J.A. McFadyen, T.C. Tucker and C.B. Cluff (1981) Effects of municipal wastewater on the yield and quality of cotton. J. Environ. Qual. 10: 47-49.

Day, A.D., R.S. Swingle, T.C. Tucker and C.B. Cluff (1982) Alfalfa hay grown with municipal wastewater and pump water. J. Environ. Qual. 11: 23-24.

Dhillon, S.K., P.S. Sidhu, K.S. Dillon and Y.P. Sharma (1985) Distribution of various potassium forms in some Benchmark soils of North-west India. J. Potassium Res. 1(3): 154-165

Dugan, G.L., R.H.F. Young, L.S. Lau, P.C. Ekern and P.C.S. Loh (1975) Land disposal of wastewater in Hawaii. J. Water Pollut. Control Fed. 47: 2067-2087.

*Dye, E.O. (1958) Crop irrigation with sewage effluent. Sewage Ind. Wastes 30: 825-828.

Ekpete, D.M. (1972) Comparison of methods of available potassium assessment for Eastern Nigeria soils. Soil Sci. 113: 213-221.

El-Nennah, M. and T. El-Kobbia (1983) Evaluation of Cairo sewage effluents for irrigation purposes. Environ. Pollut. (Series B). 5: 233-245.

Fagbami, A., S.O. Ajayi and E.M. Ali (1985) Nutrient distribution in the basement complex soils of the tropical, dry rainforest of South Western Nigeria: 1. Macronutrients - Calcium, magnesium and potassium. Soil Sci. 139: 431-436

FAI (1974) Fertilizers statistics (1973-74) Fert. Assoc. India, New Delhi, pp. 1-20.

Ferguson, A.H. (1976) Acceptability of wastewater effluents by soils. In 'Land treatment and disposal of municipal and industrial wastewater', R.L. Sanks and T. Asano (eds.), Ann Arbor Sci. Publ. Inc. Mich. pp. 85-100.

Gaur, A.C. (1979) Organic recycling prospects in Indian agriculture. Fert. News, 24(12): 49-61.

Gensheimer, G.J. and W.L. Stout (1982) Potassium and magnesium availability in mudstone coal overburdens in West Virginia. J. Environ. Qual. 11: 226-229.

Ghosh, A.B. (1976) Non-conventional sources of fertilizer potassium. In 'Potassium in soil, crops and fetilizers'. Indian Soc. Soil Sci. Bull. No. 10: 317-323.

Ghosh, G. and S.K. Ghosh (1976) Potassium in some soils of Nagaland. In 'Potassium in soil, crops and fertilizers'. Indian Soc. Soil Sci. Bull. No. 10: 6-12.

Ghosh, A.B. and R. Hasan (1976) Available potassium status of Indian soils. In 'Potassium in soil, crops and fertilizers'. Indian Soc. Soil Sci. Bull. No. 10: 1-5.

Goswami, N.N. and B.K. Bandyopadhyay (1978) Potassium dynamics in alluvial soils. In 'Potassium in soils and crops' Potash Research Institute of India, New Delhi, pp. 35-49.

Goswami, N.N. and B.K. Bandyopadhyay (1980) Potassium dynamics in alluvial soils. Potash Rev. 85(6): 1-15.

Goswami, N.N., S.R. Bapat, C.R. Leelawathi and R.N. Singh (1976) Potassium deficiency in rice and wheat in relation to soil type and fertility status. In 'Potassium in soil, crops and fertilizers. Indian Soc. Soil Sci. Bull. No. 10: 186-194.

Gounder, B.Y.M. and M.A. Hooli (1986) Environmental: Sewage also serves. Sci. Reporter 23(8): 528-531.

Heinrichs, H. and R. Mayer (1977) Distribution and cycling of major and trace elements in two central European forest ecosystems. J. Environ. Qual. 6: 402-407.

Heming, S.D. and D.L. Rowell (1985) Soil structure and potassium supply. I. The release of potassium from soil aggregates to Ca-resin. J. Soil Sci. 36: 45-60.

Hoadley, A.W. and S.M. Goyal (1976) Public health implications of the application of wastewaters to land. In 'Land treatment and disposal of municipal and industrial wastewater'. Eds. R.L. Sanks and T. Asano, Ann Arbor Sci. Publishers Inc., Mich. pp. 101-132.

Hook, J.E. and T.M. Burton (1979) Nitrate leaching from sewage-irrigated perennials as affected by cutting management. J. Environ. Qual. 8: 496-502.

Hussain, F. and K.A. Malik (1985) Evaluation of alkaline permanganate method and its modification as an index of soil nitrogen availability. Plant Soil 82: 279-282.

Indian Standard (1965) Tolerance limits for industrial effluents discharged on land for irrigation purposes. IS: 3307-1965. Indian Standard Institution, New Delhi.

Indian Standard (1980) Methods of sampling and test for sewage effluents (First revision), Second reprint. IS: 4473-1972, pp. 1-26. Indian Standard Institution, New Delhi.

Indian Standard (1982) Tolerance limits for inland surface waters subject to pollution. Second revision 1986. IS: 2296-1982. pp. 5-14. Indian Standard Institution, New Delhi.

Indian Standard (1983) Methods of test of soils: Part 1. Preparation of dry soil samples for various tests. IS: 2720 (Part I), pp. 1-10. Indian Standard Institution, New Delhi.

Iskandar, I.K. (1978). The effect of wastewater reuse in cold regions on land treatment systems. J. Environ. Qual. 7: 361-368.

Jackson, M.L. (1973) Soil chemical analysis. Prentice-Hall of India Private Ltd., New Delhi, India.

Jensen, J.R. (1984) Potassium dynamics in soil during steady flow. Soil Sci. 138: 285-293.

Kansal, B.D. and G.S. Sekhon (1976) Influence of amount and nature of clay on potassium availability of some alluvial soils. Indian Soc. Soil Sci. Bull No. 10: 78-85.

Kanwar, J.S., M.N. Das, M.G. Sardana and S.R. Bapat (1972) Balanced fertilizer use for maximizing return from wheat on cultivators' fields. Fert. News 17(11): 19-30.

Kanwar, J.S., M.N. Das, M.G. Sardana and S.R. Bapat (1973) Economics of fertilizer use in rice in farmers' fields. Fert. News 18(1): 71-88.

Karlen, D.L., M.L. Vitosh and R.J. Junze (1976) Irrigation of corn with simulated municipal sewage effluent. J. Environ. Qual. 5: 269-273.

King, L.D. and H.D. Morris (1973) Land disposal of liquid sewage sludge: IV Effect of soil phosphorus, potassium, calcium, magnesium and sodium. J. Environ. Qual. 2: 411-414.

Krause, H.H. (1965) Effect of pH on leaching losses of potassium applied to forest nursery soils. Soil Sci. Soc. Am. Proc. 29: 613-615.

Kresge, C.B. and S.E. Younts (1962) Effect of various rates and frequency of potassium application on yield and chemical composition of alfalfa and alfalfa-orchardgrass. Agron. J. 54: 313-316.

Krishnakumari, M., M.S. Khera and A.B. Ghosh (1984) Studies on potassium release in an inceptisol soil (Holambi series) at the minimum level of exchangeable potassium. Plant Soil 79: 3-10.

Kubo, T. and A. Sugiki (1977) Wastewater reuse in Japan. In 'Water renovation and reuse', Ed. H.I. Shuval, Academic Press Inc., New York, pp. 333-353.

Lance, J.C. and F.D. Whisler (1972) Nitrogen balance in soil columns intermittently flooded with sewage water. J. Environ. Qual. 1: 180-186.

Lance, J.C., C.P. Gerba and D.S. Wang (1982) Comparative movement of different enteroviruses in soil columns. J. Environ. Qual. 11: 347-351.

Lee, G.F. (1976) Potential problems of land application of domestic wastewaters. In 'Land treatment and disposal of municipal and industrial wastewater'. Ed. R.L. Sanks and T. Asano, Ann Arbor Science Publishers Inc. Mich. pp. 179-191.

Malcom, R.L. and V.C. Kennedy (1969) Rate of cation exchange on clay minerals as determined by specific ion electrode techniques. Soil Sci. Soc. Am. Proc. 33: 247-253.

Martini, J.A. and A. Suarez (1977) Potassium supplying and fixing capacity of some Costa Rican latosols and andosols determined by successive cropping, extractions and incubations. Soil Sci. 123: 37-47.

McLean, E.O. (1980) Influence of clay content and clay composition on potassium availability. Potash Rev. 85(6): 1-15.

Mehrotra, C.L., I. Singh and R.K. Pandey (1972) Fixation of potassium as related to the soils and their particle size distribution in some soils of Uttar Pradesh. J. Indian Soc. Soil Sci. 20: 121-128.

Moorhead, K.K. and E.O. McLean (1985) Improved corrective fertilizer recommendations based on two-step alternative usage of soil tests: 4. Studies of field plot samples. Soil Sci. 139: 131-138.

Nelson, W.L. (1978) Influence of K on tolerance to stress. In: 'Potassium in soils and crops', pp. 203-221. Potash Research Institute of India, New Delhi.

Nemeth, K. and H. Grimme (1972) Effect of soil pH on the relationship between k concentration in the saturation extract and K saturation of soils. Soil Sci. 114: 349-354.

*Noer, O.J. (1926) Activated sludge: its composition and value as a fertilizer. J. Amer. Soc. Agron. 18: 953.

Noy, J. and A. Feinmesser (1977) The use of wastewater for agricultural irrigation. In 'Water renovation and reuse'. Ed. H.I. Shuval, Academic Press Inc., New York. pp. 73-92.

Page, A.L. and A.C. Chang (1981) Trace metals in soils and plant receiving municipal wastewater irrigation. In 'Municipal wastewater in agriculture'. Ed. F.M. D'itri. Academic Press Inc., New York. pp. 351-378.

Palazzo, A.J. (1976) Land application of wastewater: Forage growth and utilization of applied nitrogen, phosphorus and potassium. In 'Land as a waste management alternative' Ed. R.C. Loehr, Proc. 1976 Cornell Agric. Waste Manage. Conf. N.Y. Ann Arbor Sci. Publ., Ann Arbor, Mich. pp. 171-180.

Palazzo, A.J. (1981) Seasonal growth and accumulation of nitrogen, phosphorus and potassium by orchardgrass irrigated with municipal wastewater. J. Environ. Qual. 10: 64-68.

Palazzo, A.J. and T.F. Jenkins (1979). Land application of wastewater: effect on soil and plant potassium. J. Environ. Qual. 8: 309-312.

Papanicolaou, E.P. (1976) Determination of cation exchange capacity of calcareous soils and their percent base saturation. Soil Sci. 121: 65-71.

Patterson, J.W. and A.C. Richer (1966) Effect of long-term fertilizer application on exchangeable and acid soluble potassium. Agron. J. 58: 589-591.

Piper, C.S. (1966) Soil and plant analysis. Hans Publishers, Bombay, India.

Pratt, P.F. and A.E. Laag (1977) Potassium accumulation and movement in an irrigated soil treated with animal manures. Soil Sci. Soc. Am. J. 41: 1130-1133.

Quin, B.F. and P.H. Wood (1978) Surface irrigation of pasture with treated sewage effluent (1) Nutrient status of soil and pasture No. 7. J. Agric. Res. 21: 419-426.

Ramanathan, K.M. and K.K. Krishnamoorthy (1976) A study of relationship between certain soil characteristics and potassium fixation. Indian Soc. Soil Sci. Bull. No. 10: 42-45.

Reddy, A.S. and R.B.L. Bhardwaj (1983) Uptake of nitrogen, phosphorus and potassium by wheat as influenced by irrigation frequencies, nitrogen and phosphorus fertilization. Indian J. Agron. 28: 398-402.

Rehm, G.W., R.C. Sorensen and R.A. Wiese (1984) Soil test values for phosphorus, potassium and zinc as affected by rate applied to corn. Soil Sci. Soc. Am. J. 48: 814-818.

Rosen, C.J. and R.M. Carlson (1984) Influence of root zone oxygen stress on potassium and ammonium absorption by Myrobalam plum rootstock. Plant Soil 80: 345-353.

Russell, W.E. (1973) Soil conditions and plant growth. 10th edn. ELBS and Longman.

Sekar, T. and A.K. Bhattacharyya (1982) Effects of sewage effluents on carbon and nitrogen mineralization of a soil. In 'Waste treatment & utilization, theory and practice of waste management'. Vol. 2, Ed. Murray Moo-Young et al. Pergamon Press, Oxford and N.Y. pp. 447-460.

Sekhon, G.S. (1980) Use of potassium for efficient crop production. In 'Proc. FAI Seminar on fertilizers in India in the eighties, Part II. pp. AGSII-4/1-28. Fertilizer Association of India, New Delhi.

Selim, H.M., R.S. Mansell and L.W. Zelazny (1976) Modelling reactions and transport of potassium in soils. Soil Sci. 122: 77-78.

Shelef, G. (1977) Water reuse in Israel. In 'Water renovation and reuse'. Ed. H.I. Shuval, Academic Press Inc., New York. pp. 311-331.

Shuval, H.I. (1977) Water renovation and reuse. Academic Press Inc., New York.

Sidhu, P.S. and S.K. Dhillon (1985) Mineralogy of potassium in some typical soils of Punjab. J. Potassium Res. 1: 17-27.

Singh, S. and P. Ram (1976) Effect of alternate submergence and drying on the release of K in soils of growing rice. Indian Soc. Soil Sci. Bull. No. 10: 129-131.

Sinha, S.K. (1978) Influence of potassium on tolerance to stress. Indian experience. In 'Potassium in soils and crops', pp. 223-239. Potash Research Institute, New Delhi, India.

Sinha, N.C. and J.N. Singh (1984) Studies in the mineral nutrition of Japanese mint. II. Influence of potassium deficiency and seasonal variation on nitrogen metabolism, respiration rate and essential oil content. Plant Soil 79: 51-59.

Smith, H.W. and M.D. Weldon (1940) A comparison of some methods for the determination of soil organic matter. Soil Sci. Soc. Am. Proc. 5: 177-178.

Sommers, L.E., D.W. Nelson and D.J. Silviera (1979) Transformation of carbon, nitrogen and metals in soils treated with waste materials. J. Environ. Qual. 8: 287-294.

Sopper, W.E. (1976) Use of soil vegetation biosystem for waste water recycling. In 'Land treatment and disposal of municipal and industrial wastewater' Eds. R.L. Sanks and T. Asano, Ann Arbor Science Publishers Inc. Mich. pp. 17-44.

Sparks, D.L., L.W. Zelazny and D.C. Martens (1980a) Kinetics of potassium exchange in a paleudult from the coastal plain of Virginia. Soil Sci. Soc. Amer. J. 44: 37-40.

Sparks, D.L., D.C. Martens and L.W. Zelazny (1980b) Plant uptake and leaching of applied and indigenous potassium in Dolan soils. Agron. J. 72: 551-555.

Spyridakis, D.E. and E.B. Welch (1976) Treatment processes and environmental impacts of waste effluent disposal on land. In 'Land treatment and disposal of municipal and industrial wastewater'. Eds. R.L. Sanks and T. Asano, Ann Arbor Science Publishers Inc., Mich. pp. 45-84.

Subbiah, B.V. and G.L. Asija (1956) A rapid procedure for estimation of available nitrogen in soil. Current Sci. 25: 259-260.

Sundaresan, B.B. (1979) A course mannual: water and wastewater analysis. pp. 19-27. National Environ. Eng. Res. Institute, Nagpur.

Swamy, S.A., R.K. Vig and S.K. Sharma (1986) Personal communication and discussion with S.A. Swamy, Engineering Personnel of Minor Irrigation Scheme (Effluents Irrigation Division) of Ministry of Agr. and Irr.,New Delhi and others.

Tan, K.H. (1980) The release of silicon, aluminum and potassium during decomposition of soil minerals by humic acid. Soil Sci. 129: 5-11.

Tan, K.H., J.H. Edwards and O.L. Bennett (1985) Effect of sewage sludge on mobilization of surface applied calcium in a Greenville soil. Soil Sci. 139: 262-269.

Tinker, P.B. (1980) Transport process in the sol as factors of potassium availability. Potash Rev. 85(6): 1-15.

Unamba-Oparah, I. (1972) Exchangeable reserve potassium and other cation reserves in the Agodi and Adio soils. Soil Sci. 113: 394-409.

Unamba-Oparah, I. (1985) The potassium status of the sandy soils of Northern Imo State, Nigeria. Soil Sci. 139: 437-445.

Vig, R.K. and S.K. Sharma (1986) Personal communication and discussion with Mr. Vig, Chemist and Mr. Sharma, water-analyst at Okhla Sewage Treatment Plant, New Delhi.

Wentworth, S.A. and N. Rossi (1972)* Release of potassium from layer silicates by plant growth and by NaTPB extraction. Soil Sci. 113: 410-416.

* Original not seen.

APPENDIX - A

Tolerance limits for Inland surface waters - For irrigation, industrial colling or controlled waste disposal.

	CHARACTERISTIC	TOLERANCE LIMIT
1.	pH value	6.0 to 8.5
2.	Electrical conductance at 25°C, Max.	2550×10^{-6} mhos
3.	Sodium absorption ratio (SAR) Max.	26
4.	Boron (as B), Max.	2 mg/1
5.	Total dissolved solids (inorganic) Max.	2100 mg/1
6.	Sulphates (as SO_4), Max.	1000 mg/1
7.	Chlorides (as Cl), Max.	600 mg/1
8.	Percent sodium, Max.	60
9.	Alpha emitters, Max.	10^{-9} µc/ml
10.	Beta emitters, Max.	10^{-8} µc/ml

* ISI Standard No. IS: 2296-1982.

APPENDIX - B

Indian Standards Institute Standard No. IS: 3307 of 1965 "Tolerance Limits for Industrial Effluents Discharged on Land for Irrigation"

Parameters	Maximum Permissible Value
BOD mg/litre	500
pH	5.5 - 9.0
Total dissolved solids (inorganic) mg/litre	2100
Oils and grease, mg/litre	30
Chlorides, mg/litre	600
Sulphates, mg/litre	1000
Boron	2.0
Percent sodium*	60

*Percent sodium, percentage of sodium in total cation content.

APPENDIX - C

Concentration of metals in the sewage effluents from Okhla Sewage Treatment Plant, New Delhi

	Metals	Raw Sewage (mg/l)	Final Effluent (mg/l)
1.	Nickel	0.008 - 0.028	0.005 - 0.024
2.	Copper	0.0044- 0.48	0.005 - 0.27
3.	Cobalt	0.002 - 0.007	0.002 - 0.005
4.	Zinc	0.034 - 1.75	0.010 - 0.98
5.	Lead	0.035 - 0.14	0.002 - 0.085
6.	Chromium	0.001 - 0.002	0.001 - 0.002
7.	Iron	2.15 - 20.2	1.05 - 10.0
8.	Manganese	0.140 - 0.925	0.11 - 0.345
9.	Calcium	34.0 - 76.0	33.5 - 70.2
10.	Magnesium	25.0 - 60.0	13.5 - 54.0
11.	Potassium	10.0 - 55.0	10.0 - 45.0
12.	Sodium	190.0 - 1480.0	160.0 - 1180.0
13.	Detergents as DBS	0.35 - 0.90	0.20 - 0.24

Note: The data were obtained from Okhal Sewage Treatment Plant, New Delhi.

APPENDIX - D

Chemical Characteristics of Sewage Effluents from Okhla Sewage Treatment Plant, New Delhi

	Characteristics	Unit	Raw Sewage	Final Effluents
1.	pH		7.5	7.5
2.	Total alkalinity as $CaCO_3$	mg/l	400	400
3.	Chlorides as Cl^-	mg/l	170	165
4.	Total Solids	mg/l	1100	740
5.	Suspended solids	mg/l	390	25
6.	O_2 absorption 4 hrs $KMnO_4$	mg/l	50	10
7.	BOD, 5 days, 20°C	mg/l	180	15
8.	COD, 2 hrs, reflex, $K_2Cr_2O_7$	mg/l	430	80
9.	Total hardness as $CaCO_3$	mg/l	350	350
10.	Free Ammonia as N	mg/l	15	10
11.	Nitrites as N	mg/l	Nil	Traces
12.	Nitrates as N	mg/l	Nil	8
13.	Sulphates as SO_4	mg/l	80	75
14.	Sulphides as S	mg/l	0.9	0.8
15.	Fluorides as F	mg/l	20	10
16.	Phosphates as PO_4	mg/l	10	6
17.	Cyanides as CN	mg/l	Traces	Nil

Note: The data were obtained from Okhla Sewage Treatment Plant, New Delhi.

APPENDIX - E

Water Quality of Reuse Water from Sewage Treatment (1964) in Japan

Characteristic	Maximum	Minimum	Mean
Temperature (°C)	27.5	9.0	18.9
Turbidity (ppm)	230.0	8.0	43.4
pH	7.0	5.8	6.5
Alkalinity (ppm)	122.0	58.0	86.0
Acidity (ppm)	39.0	13.2	27.1
Conductivity (uv/cm)	2460.0	1300.0	1286.0
Total solids (ppm)	1520.0	446.0	867.0
Iron (ppm)	2.32	0.10	0.74
Chloride (ppm)	2318.0	188.4	547.3
Sulfate (ppm)	105.0	54.0	82.6
Nitrite (ppm)	0.10	0.00	0.02
Ammonia (ppm)	7.09	0.06	1.81
Silica (ppm)	40.0	16.6	29.7
Calcium (ppm)	85.44	37.33	49.20
Magnesium (ppm)	40.01	12.67	24.20
Hardness (ppm)	285.3	136.3	213.3
DO (ppm)	7.21	2.17	5.68
Free Carbon dioxide (ppm)	34.32	11.62	23.85
COD (ppm)	12.87	3.64	10.79

Ref. Kubo and Sugik, 1977.