CONTINUOUS USE OF MUNICIPAL SEWAGE EFFLUENTS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES

By

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THESIS
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DECLARATION

I hereby declare that this thesis entitled "Continuous use of municipal sewage on soil physical and chemical properties" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or Society.

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Vellayani,
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CERTIFICATE

Certified that this thesis entitled "Continuous use of municipal sewage on soil physical and chemical properties" is a record of research work done independently by Sri KARUNAKARAN NAIR, G. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Urbanisation results in the production of increased municipal waste. Sewage and municipal wastes present immense problems of disposal. In fact, the sewage and sewage water disposal presents a more serious problem than other municipal waste, for which incineration has been developed in recent years. This presents a much clever disposal coupled with energy production during the incineration. However, disposal of sewage and sewage sludge has presented problems, though in certain locations they have been used for land fill. In some other situations they have been discharged to rivers, waterways, seas and oceans.

More than hundreds of cities and towns in this country have complete to partial sewage systems while nearly 700 have open drain sewage system. Sewage available in these areas amount to 800-1000 million gallons per day. The organic matter comes to 1500 tonnes per day or about 6 lakhs tonnes per year. The plant nutrients from these quantities would come to 35,000 tonnes of N, 8000 tonnes of P_2O_5 and 20,000 tonnes of K_2O. Huge amounts of heavy metals like Cu, Zn, Mn, Fe, Cd, Cr and Mn are also found.

The open sewage system and the discharge of sewage into the rivers from the various towns and cities on the banks of the sacred Ganga has polluted the river to such an extent as to make the Government of India take up the purification of Ganga Project at an expenditure of thousands of crores of rupees.

One of the important ways for disposal of sewage however, has been its application to agricultural land. The concern has been in terms of changes in soil properties both beneficial and harmful. The choice of crops grown in areas where sewage is disposed is also very critical. Land application of sewage is beneficial in terms of the better performance of crops grown in them and the nutrients NPK added to them. They are harmful in that heavy metals get added through the sewage to the soil and leafy vegetables especially accumulate these heavy metals when grown in such soils.

Considerable research exists on the effects of sewage on soil properties. Tamil Nadu Agricultural University has conducted some studies on the physical and chemical properties of sewage applied soils. These results are not as such applicable to the situations of our sewage farms.

The present investigation was carried out from the samples collected from the Sewage farm, Valiyathura, Trivandrum. The farm has an area of 33.33 hectares and was established in 1962. In this area plots are available with continuous irrigation with sewage water for 20 years, 15 years etc. These plots where guinea grass is mostly grown, are irrigated by the open channel system. Earthen pipes buried at 70 cm depth below the soil surface drains the water through the holes in them and such an underground drainage system takes the water to a small riverlet "Parvathiputhanar". The soils of this tract are sandy and guinea grass grown in these soils are supplied to dairy animals in Government Farms in Trivandrum City and also to others in the City.

Since no significant information is available on soil properties due to continuous irrigation for nearly 20 years, the present investigation was undertaken. The main emphasis on the study has been to bring out the results on the changes in the physical and chemical properties of the soils and of micronutrients and heavy metals in the grass produced in the farm.

Some of the major aspects covered in the study to fulfil these objectives are:-

1. Physical properties of the sewage applied soils.
2. Secondary and micronutrient status of the sewage incorporated soils.
3. Depth-wise distribution of total and available macro and micronutrients.
4. Macro and micronutrient status of sewage irrigated grass.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Though voluminous literature is available on many aspects of trace element toxicities due to additions of both liquid and solid sewage sludges on crop lands, little information is available on the effect of continuous use of sewage waste on Indian soils, especially their influence on soils of Kerala.

The review of literature pertaining to heavy metal toxicity of sewage application to crop lands, the beneficial and ill-effects of its continuous use on crop lands and its relationship to various physical and chemical properties of soil are presented in the following pages.

2.1. Influence on Sewage treatments on soil properties

2.1.1. Physical properties

2.1.1.1. Moisture holding capacity

Lunt (1953 and 1959) reported that digested sewage sludges application to loamy soils at rates upto 260 cu.yd/acre resulted in moderate increases from 3 per cent to 23 per cent in the field moisture capacity.

Hortenstine and Rothwell (1973) from a green house study reported that water retention of the Arrendando sand was generally increased when pelletized compost from municipal refuse was used as a soil amendment and plant nutrient source.

Mays *et al*. (1973) observed that incorporation of compost made from municipal refuse and sewage sludge over a period of two years significantly increased the water holding capacity from 30 per cent to 40 per cent.

Epstein (1975) found that raw sludge retained twice the amount of water as that of digested sludge.

Epstein *et al*. (1976) reported that the application of sludge and compost increased the water content as well as the water retention capacity of a silty loam soil.

Gupta *et al*.(1977) reported that incorporation of sewage sludge into a sandy soil resulted in an increase in soil water retention. Most of this increase in water retention was as a result of water adsorbed by the organic matter at 15 bar water.

Paglai, Guidi, Launarao *et al*. (1981) reported that there is increase in water retention at high and low rate of sewage application.

Jayaraman (1984) reported that the water holding capacity of the sewage farm soil improved compared to non-sewage irrigated soils with a year.

Wei and Peterson (1984) reported that soil moisture retention capacity increased as a result of sewage irrigation in a silty clay loam soil.

2.1.1.2. Soil aggregation

Lunt (1953) reported that soil aggregation increased from 25 per cent to 60 per cent when loamy soils were applied with sewage sludge upto 260 Cu.yd/acre.

Sessing (1961) reported that high sodium content sewage effluent caused severe physical impairment of the soil such as decrease in capillary pore space as well as in the moisture holding capacity, a marked deterioration in the aggregation and stability of aggregates.

Epstein (1975) observed that per cent stable aggregates increased as a result of sludge addition. Raw sludge has highest per cent stable aggregates.

Subbiah (1976) reported that addition of sewage wastes improved the structural indices such as stability index and per cent aggregates. Stability index was positively correlated with per cent aggregate stability in all the four soils - black, red, alluvial and lateriate studied.

Epstein (1975) has reported that raw and digested sewage sludge applied to silty loam soil increased the aggregate stability.

Jayaraman (1981) reported that 25 years of irrigation with sewage water prominently improved the per cent aggregate stability and stability index of the soil.

2.1.1.3. Soil clogging

Thomas *et al.* (1966) observed from Lysimeter trials that soil clogging under sewage spreading proceeded in three phases.

1. Slow decrease in infiltration under aerobic conditions.
2. Rapid decrease in infiltration under anaerobic condition.
3. Further gradual decrease under anaerobic conditions.

Thomas *et al.* (1968) reported that reduced rate of clogging under sewage spreading was related to pore gas and moisture content changes which occurred in the sewage dozing and drainage cycle.

Daniel and Bouma (1974) attributed the clogging of soil due to sewage spreading with that of the suspended solids in sewage water.

Magdoff *et al.* (1974) reported that the crust which developed on addition of septic tank effluent to a subsurface may be the reason for the cause of soil clogging.

2.1.1.4. Hydraulic conductivity

Epstein (1975) reported that addition of sewage sludge initially increased the saturated hydraulic conductivity and after 50 to 80 days the hydraulic conductivity dropped to that of the original soils. After 79 days all treatments had essentially the same hydraulic conductivity.

Subbiah (1976) reported that the addition of sewage wastes significantly decreased hydraulic conductivity with depth in soils of Tamil Nadu.

Gupta *et al.*(1977) stated that at any given water content unsaturated hydraulic conductivity and soil-water chffusivity decreased as rates of sludge addition decreased.

Jayaraman (1981) reported that sewage irrigation by contrast had a depressing effect on the hydraulic conductivity compared to sewage unirrigated field. Due to sewage irrigation the hydraulic conductivity decreased with depth.

2.1.1.5. Bulk Density and compression strength

Mays *et al*.(1973) reported that incorporation of municipal refuse, compose and sewage sludge over a period of 2 years significantly decreased bulk density and compression strength of the soil.

Jayaraman (1981) reported that there was significant decrease in Bulk density of the sewage farm soil after 25 years of sewage treatment due to the continuous irrigation of sewage water.

2.1.1.6. Soil porosity

Application of digested sludge to loamy soils at rates upto 260 cu. yd/acre resulted in moderate increase in non-capillary porosity (Lunt 1953, 1959).

Sessing (1961) reported that high sodium content sewage effluent caused severe physical impairment of the soil in decreasing capillary pore space.

Subbiah (1976) reported that addition of sewage wastes increased total capillary and non-capillary pore spaces of soils studied in Tamil Nadu. In Block soil, sewage application was better in improving the total and capillary pore spaces than control. This may be due to the colloidal nature and binding action of sewage material. In laterite soil sewage sludge addition enhanced the non-capillary pore space.

Jayaraman (1981) sewage irrigation irrespective of depth and periods of irrigation tended to improve the total and capillary pore space. By the application of sewage wastes the total and capillary pore space in Black soils of Tamil Nadu improved significantly.

2.1.2. Chemical properties

Bocko and Szerszen (1962) reported that a permanent supply of sewage resulted in a decrease of pH. This was later confirmed by Ramati and Mor (1966), Subbiah (1976) and Ramanathan et al.(1977)

Schafer and Kick (1970) reported that when the sewage sludge (3.6 to 4.2 per cent N content) applied to slightly podsolised loamy sand carrying oats in the first year and potatos in the second year found that there was little effect on soil pH apart from a slight decrease in the second year.

Molina et al.(1971) found that air drying of digested sewage sludge increased pH from near neutral to about 8.6 when sludge was in contact with air. The rise in pH was due to decrease of carbon dioxide concentration dissolved in digested sewage sludge upon aeration.

Nahedh *et al.*(1973), Cunningham *et al.*(1974) and King and Morris (1972a) reported that treatment of sludge decreased soil pH. They attributed the drop in pH to be due to nitrification of the applied NH_4 -N and organic Nitrogen and probably from oxidation of sulphides.

Epstein *et al.*(1976) reported that when the sewage sludge and sludge compost were applied over a period of two cropping seasons, the soil pH decreased less than one unit. This was particularly significant in relation to heavy metal uptake by crops, since heavy metals generally become more available to the plants as soil pH decreases.

Sidle and Kardose (1977) reported that the soil pH did not change significantly after sludge treatment in a sludge treated forest area.

Jimmy *et al.*(1978) has reported application of sewage sludge as pH increased water soluble cadmium decreased.

2.1.2.2. Soluble salts

Muravsky and Ramati (1959) did not observe any accumulation of salts with continued irrigation of sewage water on shifting sand.

Bennett *et al.*(1973) while comparing sewage effluent with that of standard irrigation water observed significant effects of sewage effluent on increasing soluble salts at

16-30 cm depth. Nehedh et al.(1973) stated that aerobic sludge produced an initial increase in soil salinity, while anaerobic sludge caused less effects on soil salinity on the free hold sandy loam soil.

Epstein et al.(1974) reported that soluble salt content was 0.41, 4.1 and 5.5 mmhos/cm in control, high compost and high sludge treatments respectively. King et al.(1974) observed no increase in conductivity due to the application of liquid sewage sludge along with town refuse.

Gaynor and Halstead (1976) reported an increase in electrical conductivity of saturation extracts ranging from 2.9 to 3.7 mmohos/cm by incubating sludge plus fertilizer for 11 months.

Jayaraman (1981) stated that there was no perceptible change in the salinity levels due to sewage water irrigation irrespective of years of sewage treatments in Tamil Nadu soils.

2.1.2.3. Cation Exchange capacity

Lunt (1953) reported that the application of digested sewage sludges to loamy soils at rates upto 260 cu.yd/acre resulted in moderate increase in cation exchange capacity. Hortenstine and Rothwell (1973) reported that pelletised municipal refuse compost in the Arredando sand increased C.E.C. in addition to water retention. Epstein et al. (1976) observed that the soil cation exchange capacity increased as much as three fold as a result of addition of sludge and sludge compost. The increase in C.E.C. was greater with sludge than with compost and at the highest sludge rates ie. 240 t/ha, C.E.C. increased nearly three fold.

Sidle and Kardos (1977) reported that the C.E.C. of the 0-7.5 cm depth was 18.4 me/100 g. soil while that of 7.5 - 15 cm depth was 8.4 me/100 g soil in the sludge treated forest soil. The higher C.E.C. in the surface depth is largely related to its organic matter content (10.6 per cent) which was approximately twice that of the 7.5-15 cm interwell (5.4 per cent).

Jayaraman (1981) viewed treatmentwise sewage irrigation tended to improve the cation exchange capacity in Tamil Nadu soils.

2.1.2.4. Exchangeable cations

Sessing (1961) observed that the application of sewage to soil caused addition of calcium magnesium and sodium, but the predominance of sodium saturation in the soil.

King and Morris (1973) reported that the addition of sludge in a sandy loam increased sodium but decreased the dilute acid extractable potassium, calcium and magnesium and had no effect on phosphorus. Epstein et al.(1976) observed that calcium, magnesium and sodium levels in soils decreased with increasing rates of both sludge and compost.

Gaynor and Halstead (1976) found that the application of sewage sludge to a sand loam and clay soil increased exchangeable calcium. Giordano and Mortvedt (1976) reported that the heavy metal contamination of gound water is not likely in heavy textured soils where sewage sludge application was accompanied by N fertilization at least for a short period of time.

Jayaraman (1981) viewed treatment sewage of irrigation tended to improve the cation exchange capacity in Tamil Nadu soils.

2.1.2.5. Soil organic matter

Lunt (1953) reported that application of digested sludge to loamy soils at rates upto 260 cu yd/acre resulted in large increases in organic matter. Muravsky and Ramati(1959) reported that organic matter content in the upper layer was substantially increased in sandy treated with urban sewage.

This was latter confirmed by Ramati and Mor (1966). Day and Strochleine (1972), Gaynor and Halstead (1976) and Lagerwerff et al.(1976)

Mays et al.(1973) observed that incorporation of compost made from Municipal refuse and sewage sludge increased the soil organic matter content from 1.58 per cent with no compost to 4.22 per cent with highest compost rates. Hortenstine and Rothwell (1973) reported that the pellattised municipal refuse compost increased the organic matter content of the soil.

Touchton et al.(1976) reported that the surface application of liquid sewage sludge increased the organic matter content in the crust with increased rate of sewage sludge.

Masand et al.(1978) observed through measurement of infiltration capacity and hydraulic conductivity of sandy soil in which sewage suspension was applied, the accumulation of organic matter mainly at the soil surface.

Hohla et al.(1978) reported that with the soil organic carbon in the top 15 cm increased from 0.95 to 2.29 per cent over the period of six years furrow irrigation with 298 t/ha of anaerobically digested sludge in the silt loam soils. No significant differences were observed below 30 cm between control and treated plots. Increase in total organic carbon due to sludge application were two to three fold from a minimum of 12.5 mg/litre in control plots to a maximum of 32.0 mg/litre in sludge treated plots.

Jayaraman (1981) reported that enough irrigation with sewage water increased the organic matter content in the sewage amended soils supported the findings.

Rajarajan (1978) has also reported that enough irrigation with sewage water had increased the organic matter content in Tamil Nadu soils.

2.1.2.6. Soil Nitrogen

Rothwel and Hortenstine (1969) reported that nitrification of sewage sludge decreased with increased rates of sewage sludge. Braids *et al.*(1970) observed that NO_3-N was increased when an acre in ch of liquid digested sewage containing 330 lb N, 180 lb P and 40 lb K was applied.

Premi and Cornfield (1971) observed that the accumulation of mineral nitrogen during aerobic incubation of a sandy loan (pH 7.1) treated with 0.5, 1 and 2 per cent levels of dried sludge increased with the time and level of added sludge. King and Morris (1972b) observed that two highest rates of 10.0, 20.0 cm sludge applied to coastal Bermuda grass resulted in significant increases in soil nitrate in the 0-120 cm profile.

Milne and Graveland (1972) stated that nitrification increased upto 101 t/ha level of sludge on all types of soils. They reported a decrease in NH_4-N.

Lance and Whisler (1972) stated that short frequent cycles of flooding soil columns (2 days flooded and 5 days dry) with secondary sewage effluent caused no net removal of N but transformed almost all of the N to NO_3. The net N removal during longer cycles ie. 9-23 days flooding and 5 days dry was 30 per cent and half of N remaining in the water was concentrated into a wave of nitrate water, which represented 10 per cent of the total volume of reclaimed water and was collected and found that it contained 67 per cent less N than the incoming sewage water. Alternate flooding and drying periods were necessary for constant N removal. The net N removal was probably due to a combination of several reactions dominated by denitrification because the soil microorganisms nitrified most of the NH_4^+ and N can be removed from the system as inert gas by denitrification.

Kelling *et al.*(1973) conducted field experiments on two types of soils over a two year period to determine the effect of liquid digested sewage sludge on soil total N, NH_4-N and (NO_2 + NO_3)-N to 150 cm and reported that large addition of sludge caused N loss probably by leaching or denitrification on the silt loams.

King (1973) observed that when 2.5 inch depth of liquid sewage sludge was either surface applied or incorporated with a quantity of soil and incubated under laboratory conditions at the end of 18 weeks, NO_3-N accumulation was 22 per cent of the applied N, when the sludge was incorporated with soil. The gaseous N losses ranged from 16 to 22 per cent of the applied N when the sludge was incorporated with the soil and 21-36 per cent in the surface applied treatments.

Nnalmeka and Sabey (1973) studied the effect of addition of anaerobically digested sewage sludge and wood residues to soils on NO_3 and found that mixtures of 25 per cent wood bark, 75 per cent sludge had a relative NO_3 accumula tion index range of 0.51-0.83 and 0.16-0.48 respectively compared to sludge alone after four months incubation.

Epstein et al.(1974) concluded that NO_3-N at 20 cm depth was higher for all treatments with sewage sludge and sludge compost than control, whose values were almost lowest indicating denitrification. King and Morris (1974) reported that NH_4-N in the liquid fraction of sewage sludge was susceptible to volatalisation more so on bare soil than sod. Leaching loss of NO_3-N was increased by incoming water rates.

Stewart et al.(1975) found that the application of sewage sludge to a loamy soil at rates of 2.5 and 5.0 cm per ha resulted in significant increases in soil nitrogen at 90 cm soil profile.

Epstein et al.(1976) reported that the addition of sewage sludge, NO_3-N levels were highest at 15.20 cm depth and decreased sharply below that level. Gaynor and Halstead (1976) found that NO_3-N decreased in soils studied under 8 weeks incubation possibly because of microbial fixation or denitrification. Lund et al.(1976) stated that the practice of ponding liquid sewage sludge and effluents on open porous soils is a potential source of NO_3-N NH_4-N and P contamination of underground water supplies. Keefer et al.(1976) observed the total N accumulated at 0-5 cm layer where sludge was applied in a well drained sandy loam soil.

Kelling et al.(1977) reported that digested sewage sludge applied at rates from 3.75 to 60 t /ha significantly increased cone of inorganic nitrogen and organic nitrogen in a sandy loam and silt loam soil. At sludge rates of 30 t /ha or more substantial losses of sludge applied N occurred by leaching. Ramanathan et al. (1977) found that the total N content in soil irrigated with well water was greater than that in soil irrigated with sewage. But the available N content in soil irrigated with sewage water was greater than that in soil irrigated with well water, thereby suggesting that sewage application increases soil available N. Raj and Singh (1977) studied the rate of mineralisation of nitrogen in town compost mixed with different soils of Bihar and found that mineralisation rate was slow upto 4th week, but gradually increased, reaching a peak by 8th to 10th week NO_3-N/NH_4-N ratios were persistently greater than unity, indicating nitrogen mobilisation in all three soil types and no significant difference in mineralisation rate was observed between these soil types.

Yoneyama and Yoshida (1978) reported from incubation experiments that when sewage sludges applied to soils could result in the accumulation of high concentration of Ammonia Nitrite and Nitrate. However the simultaneous application of organic matter low in nitrogen such as rice straw with the sludge could reduce the accumulation of inorganic nitrogen as a result of its immobilisation by the organic matter.

Riekerk (1978) reported the difference between the sludge treatments reflected the degree of aeration and decomposition of NO_3-N production and P fixation. These differences were more pronounced deeper in the soil, except for K which was more controlled by the stage of weathering. Taylor _et_ _al_.(1978) reported that NO_3-N adjacent to and beneath the sludge was generally higher with digested than raw sludge. After 160 days NO_3-N levels in raw sludge were higher than those in digested sludge. This accumulation in raw sludge indicated that nitrification had occurred. Ammoniacal Nitrogen levels were high after 160 days in raw sludge treatments.

Soon et al.(1978) reported that high concentrations of nitrates were present in the soil to the 90 cm depth in the grass field after 3 years of sludge application at rates supplying 800 kg N/ha but not at 400 kg N/ha.

Schalscha et al.(1979) found significant amounts of NO_3-N in the surface soil irrigated with untreated sewage water. The values were around 32 mg/litre of soil solution.

Jayaraman (1981) reported that sewage irrigation different depths and periods of irrigation were significantly better than sewage unirrigated soils and accumulation of N at 0-15 cm depth was markedly brought out in Tamil Nadu soils. Similar results were also reported by Mohamed Haroon (1983) in Madurai soil.

2.1.2.7. Soil phosphorus

Joshi (1945) reported that 85 per cent of total P_2O_5 in sewage sludge in inorganic form and that nearly 37 per cent of the total P_2O_5 is in water soluble inorganic form and 68 per cent in available form.

Shemyakina (1969) found that irrigating the agricultural land for 4 years did not affect the content of mobile form of P and K or of exchangeable basis but decreased exchange acidity. Braids et al. (1970) reported that an acre inch of sludge applications increased the heavy metal, available P and K, organic carbon and pH in 0-2 inch soil layer. Milne and Graveland (1972) observed that the available P increased for all the soils treated with sewage sludge from the two week incubation study. There was an increase in total P suggesting that P was not limiting particularly at the high rates of sludge application.

Day and Stroehlein (1972) reported that irrigation with municipal waste water increased phosphorus than soil irrigated with well water. This report is in confirmity with Bennet et al.(1973) and Ramanathan et al.(1977).

Hortenstine and Rothwell (1973) reported that soil P was increased at the rates above 64 t/ha when pelletised refuse compost was applied as a soil amendment and natural source of P for sorghum. King and Morris (1973) noted that sludge application had no effect on soil P. Hortenstine (1974) reported that P content increased from 0.08 ppm to 1.25 at 60 cm, 1.00 ppm at 90 cm and 0.85 ppm at 120 cm after 3 years when the podsols irrigated with secondary treated sewage effluent. King et al. (1974) found that plant available P concentration was increased in the 0 to 15 cm layer by sludge treatment to agricultural lands. Epstein et al. (1976) reported that Bray-P which is an index of P availability increased with increasing rates of both sludge and compost.

Kardos and Hook (1976) reported that clay loam soil irrigated with secondary treated sewage effluent had an average P concentration in the treated plot. Gaynor and Halstead (1976) reported that by adding sewage sludge to a Fox sandy loam soil, $NaHCO_3$ extractable P was found to increase.

Keefer et al.(1976) reported that soil P increased with sludge rate to 15 cm depth in the first year and to 30 cm depth in the second year when different rates of sludge (0,21,42, 84 t/ha) were applied to a sandy loam soil. Lund et al.(1976) observed that the practice of ponding liquid sewage sludge and effluent in open, porous soils is a potential source of P contamination of underground water supplies. It depends upon the depth of water table, downward flow rates of soil solution and the resultant mixing.

Reneau and Pettry (1976) monitored the P accumulation in varina and Goldsboro sandy loam from septic effluent in natural soil system by placing Piezometers adjacent to the drain-field. It was found that orthophosphate (PO_4^{-3}-P) concentration in the ground water decreased with the distance from the septic tank to drain field in both the soil and soil P fraction were present predominantly as NH_4-F and NaOH extractable P with some organic P present adjacent to the drain field.

Beek et al.(1977) observed from a sewage farm which has been used during the past 50 years for treatment of raw sewage water of domestic and industrial origin that no significant difference is found for soil layers below 70-80 cm and the accumulation is predominantly limited to the top 50 cm soil layers. This indicates that the phosphate bonding mechanism is still extremely efficient in this soil.

Kelling et al. (1977) observed that liquid digested sewage sludge was found to increase Bray-P in a sandy loam and a silty loam soil in Wisconsin. Ramanathan et al. (1977) reported that both total and available P_2O_5 in soil were found to be increased when irrigated with sewage water than with well water.

Taylor et al.(1978) reported that addition of sewage sludge compost to different soils result in varying amounts of extractable P and S. Sewage sludge compost can be used to correct P or S deficient conditions in soils.

Jayaraman (1981) observed the superiority of sewage incorporation on total and available phosphorus status of soil was well brought out in Tamil Nadu soils. Similar effects were reported by Mohamed Haroon (1983) in Madurai soils.

2.1.2.8. Soil Potassium

Shemyakina (1969) observed that irrigating with sewage on soils did not effect the content of mobile form of K but decreased exchange acidity. Braids et al. (1970) reported that addition of liquid digested sewage sludge increased available K in the 0 to 2 inch soil layer. King and Morris (1973) reported that addition of sewage sludge resulted in decreased dilute acid extractable K and suggested that addition of dolomite lime stone and supplementing K fertilizing would be required for sustained productivity of soils receiving sewage sludge.

Hortenstine and Rothwell (1973) reported that application of pelletised municipal refuse compost increased soil K. Hortenstine (1974) observed that irrigating with secondary treated sewage effluent increased K content from 0.05 ppm to 14 ppm in oil.

Ramanathan et al.(1977) reported that total available and water soluble K were increased in soils with continuous sewage treatment for a number of years.

Palazzo and Jenkins (1979) suggested that concentrations of K remained low in the soil solution and tended to decline with time in the soil that received waste water over a 5 year period. The inadequate supply of K at this site was related to the low K/N ratio in the waste water applied. No evidence of leaching in his study was observed below a soil depth of 30 cm.

Rajarajan (1978) and Jayraman (1981) found a significant increase in total K due to sewage irrigation and stated that total K content increase with depth. The former did not find a favourable effect of sewage irrigation on available K. While the latter found an increase in available K content. In non-tilled plots of Madurai sewage farm Rajarajan (1978) found low available K due to high pH inspite of high total K. The K content also increased with depth.

Similar effects were reported by Mohamed Haroon (1983) in Madurai soils.

2.1.2.9. Soil Micronutrients and Heavy metals

Schafer and Kick (1970) reported that the residual action of sewage sludge containing heavy metals in a field and found that only the highest rate of sludge caused Cr and Zn and particularly Cu and Fe contents in the crops to increase. Tan *et al.*(1971) studied complex reactions of Zn with organic matter extracted from sewage sludge and found that the lower molecular weight fulvic compounds and polysaccharide infrared characteristics are chemically, the most active material in sewage sludge and that is responsible for complexing of zinc. King and Morris (1972a) found that sludge treatments increased exchangeable and water soluble Mn and exchangeable Zn in soil. Available Zn in the soil is likely to be greatly increased by the addition of sewage sludge. The same applies to lesser extend with regard to copper (Berrow and Webber 1972 and Webber 1972).

Mays _et_ _al_. (1973) observed that incorporation of compost made from municipal refuse and sewage sludge over a 2 year period increased Zn and Mg levels. Silviera and Sommers (1974) reported that the availability of metals to plants grown on sludge treated soil will depend on the sludge added and on the lapse of time since the sludge additions. Bosewell (1974) observed that application of municipal sewage sludge increased zinc content in the soil from 33 ppm to 1419 ppm. Epstein _et_ _al_. (1976) reported that chloride levels of the saturation extract increased as sludge or compost application rates increased.

Sidle _et_ _al_.(1976) reported that the accumulation of heavy metals in the treated soils was more 93 per cent of the amounts applied in 1972 and 1973 for all heavy metals in the Reed Canary grass area and slightly less in the corn area. Sidle and Sopper (1976) reported that soil cadmium levels were not significantly affected by waste water irrigation except for the increase in soil cadmium in the 0 to 5 cm depth. The Cd/Zn ratios of the vegetation foliage were not significantly different between the treated and control areas. Touchton et al. (1976) reported that the liming decreased the Zn concentration in forage from plots receiving high sludge rates and also the concentration of P, Fe, Zn, Cu, Pb, Cr and Cd in the crust.

Baerug and Martinsen (1977) observed from a plot yield experiment in potatoes with two ypes of sewage sludge, one poor and one rich in heavy metals applied in moderate and heavy quantities, that this sludge increased the content of total cadmium, Nickel and lead and the content of readily soluble copper and zinc in the soil. The increase was greatest for copper and zinc and was more pronounced in the second year than in the first year.

Sidle and Kardos (1977) reported that extractable soil copper increased significantly at all depths in both high and low sewage sludge treatments. These increases were greatest in the upper soil depth and smaller in the lower depths.

Otte and La Conde (1977) reported that the repeated sludge application have resulted in surface accumulation of cadmium, copper, Nickel and Zinc. Metals have not moved beyond the depth of incorporation at most sites studied. Zn was the most mobile of the heavy metals studied.

Iskandar (1978) reported that movement of applied heavy metals to a depth of 15-30 cm under high waste water treatment rates was thought to result from a drop in soil pH and were confined to the top 15 cm of soil.

Subbiah and Sreeramulu (1974) reported that the application of sewage wastes increased the concentration of total and available zinc and copper and the concentration were more at surface (0 to 5 cm) compared to bottom (15 cm). They also reported that the availability increased with level of sludge addition. Jayaraman (1981) found that the total and available zinc and cadmium content of soils increased upto 30 cm by sewage irrigation whereas Fe and Mn content increased with depth.

In Madurai sewage Farm Ram raj (1982) found that the total and available Mn decreased in sewage treated plots than control. The available Fe decreased at surface (0 to 5 cm) layer and subsequently increased. The available Fe, Mn Zn and Cu content increased in all the sewage treated plots than control. The total Ni, Cr and pb contents of sewage irrigated soils also increased significantly.

Rana <u>et</u> <u>al</u>.(1983) reported that in Punjab Agricultural University that at higher pH adsorption of cadmium was greater because of less competition of H^+ ions. Sewage irrigated soils with high pH, organic carbon and C.E.C. could contain higher amounts of cadmium and with greater force than normal soils. The soils can thus act as a zinc for disposal of cadmium.

Chang et al.(1984a) reported that by repeated sludge application, changes in the distribution pattern of heavy metals remained the same. Even after termination of the sludge application the distribution pattern of heavy metals remained the same.

Chang et al.(1984b) reported that heavy metals accumulated at (0-15 cm) soil depth. He has also observed that heavy metals are often under estimated due to inability of extraction procedure and decrease in soil bulk density.

2.1.3. Chemical composition of sewage

Sommers and Nelson (1974) from their study on variations in the chemical composition of sewage sludge for heavy metal concentrations obtained at different times at the same source, revealed that data on sludge composition should be obtained at several different times prior to formulating recommendations for sludge application rates to agricultural lands.

Bradford et al.(1975) reported that metropolitan sewage sludges and effluents are characterised in relation to their total and water extractable trace elements, their reaction with soil and their effects on plants. The total concentration of trace elements in sludges and effluents are highly variable depending on the source and often much higher than concentration found in soils. The marked variability in concentrations observed is probably related to different industries discharging effluents in the sewer systems.

2.1.4. Effect of frequent application of sewage sludge on soil

Dudas and Pawluc (1975) observed that sewage application resulted in striking increases in uptake of Zn and Cd. They also revealed heavy or continued application of sewage sludge would result in build up of the insoluble trace elements.

PLANT ANALYSIS

2.2. Giordano *et al.*(1970) reported that content of Zinc and Cadmium in vegetative parts were higher than in reproductive parts.

Lagerwerf (1971) observed that an increase in the extractable metal content in the soil coincided with a significant increase in raddish yield especially in the tops of plants. Thus a ten fold increase in the lead content of the soil was reflected in an increase in lead content of raddish by a factor of less than 2.

Hook et al.(1974) reported that frequent cutting was found to be necessary for controlling Nitrogen leaching. No cut plot was effective in controlling Nitrate loss.

Vahtras and Wiklander (1974) observed that the Nitrate content was high in spring and lowest in autumn in sewage irrigated areas.

Bingham *et al.*(1975) reported that cadmium is accumulated by a wide variety of crops species in response to cadmium concentration. More over cadmium content of plant varies from according to plant species and plant tissues. Cereals accumulate less cadmium than leafy plants.

Day *et al.*(1975) showed that higher grain yield obtained from sewage irrigated fields were due to the production of more tillers.

Sabey *et al.*(1975) reported that in no case the content of any element studied was high enough in wheat grains to be outside the normal range expected in most plant tissue.

Maenom*et al.*(1978) observed that the mean content of cadmium copper, zinc and lead measured in ppm in brown rice were 0.08 ± 0.01, 3.9 ± 0.08, 22.5 ± 0.4 and 0.25 ± 0.2 respectively, when grown in upland field conditions.Cadmium concentration was high in Cocoyam and Turnip and copper content was high in Cocoyan and Groundnut. There was positive correlation between cadmium and copper or zinc contents.

Walsh *et al.*(1977) reported that sludge application shows a tendency for the sorghum to increase yield. But yield reduction due to excess salts NH_4-N is also noticed. Uptake of N increased with increased sludge application. P increase with increased sludge application.

Jimmy et al.(1978) reported that because P applied to soil did not significantly affect yield a dilution effect of plant cadmium concentration can be ruled out, as a factor causing decreased cadmium concentration. As pH increased water soluble cadmium decreased.

Williams et al.(1978) carried out a study "Cadmium accumulation by Meadows". He has found that corn fertilized with sludges was found to contain 1.82 ppm, Cd, and Sorghum herbage contained 4.50 ppm Cd. Eight diets and synthetically control diet were formulated to study these herbages. Significant accumulation of Cd in Kidneys and liver was noticed.

Kamalam et al.(1979) reported that the yield of Bhindi was adversely affected by application of Tannery effluent and the effect was more pronounced with increase in concentration.

Palazo et al.(1979) reported that amount of K taken up by plants exceed the amount of N applied or removal is increased.

Kamalam et al.(1980) reported that germination, dry matter production and nutrient uptake of the crop was reduced significantly by increased concentration of the effluent.

Marten et al.(1980) reported that grass treated with high level of effluent was more digestible and grass treated with low level are less digestible.

Gestring et al.(1983) reported that plant analysis showed that P. Zn, Fe, Mn, Cd, Ni. and Pb in high concentration.

Simconi et al.(1984) reported that Lettuse and oats differed in their ability to accumulate Cd and Zn and both give high yield.

Soon et al.(1985) stated that concentration increased in most plants for Mo, Co etc. in plants.

Logan et al.(1985) reported that high Cd content in sludge, acid pH and low organic matter will be the reason for more uptake of Cd by the Plant.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The details regarding the sewage farm on which the study is based, methods of collection of soil samples and various methods adopted for physical and chemical analysis of the samples are presented in this Chapter.

3.1. Sewage farm

The Sewage farm, Valiyathura, Trivandrum belongs to the Dairy Development Department, Kerala State. It was established in 1962 with an area of 33.33 hectares. By using the sewage water for irrigation grasses such as guinea, napier are grown. The total area under grass cultivation is 30 hectares. The whole area is divided into 60 blocks of 0.6 to 0.4 hectares. Each block is irrigated by open channel system. There are earthen pipes with holes on the sides which are buried below a depth of 70 cms. The sewage water which is flowing through the field will be filtered through different depths and the effluent water is collected through the pipes and directed to the Parvathiputhanar river. A total quantity of 30 lakh gallons of sewage water is entering for treatment everyday, of which only 20 lakh gallons are utilised for cultivation and the remaining effluent sewage water is directed to the river.

3.2. Collection and preparation of soil samples

The soil in the sewage farm is generally sandy in nature being close to the coast. Six profiles were taken upto a depth of 70 cm, ie., 3 pits each in blocks having received 20 years of irrigation and the other 3 each in 15 year sewage irrigated areas. In addition 3 controlled profile pits for purposes of comparison were dug up from the nearby farmers fields (non-sewage water irrigated area) but surrounding the sewage farm. These 9 profiles provided 36 soil samples at the rate of 4 per pit and at depths 0-15 cm, 16-30 cm, 31-45 cm and 46-70 cm.

Being in a sandy area special methods had to be improvised to enable sample collection at definite depths of the profile. Wooden planks were driven to a depth of 70 cm on all four sides of an area of 1 m^3. Samples from the entire area upto the stipulated depth were carefully scooped out.

The soil samples so collected were initially dried under shade in the Office of the sewage farm and later dried in shade in the College laboratory after transport. They were passed through a 2 mm sieve.

3.3. Collection and preparation of plant samples

The plant sample from area above the surface of the profile taken was drawn and dried in shade. It was then powdered and the powdered material was taken for analysis.

3.4. Collection and preparation of surface soil samples and plant samples

Thirty surface soil samples and plant samples corresponding to represent entire sewage farm ensuring that 50 per cent of the samples are located in 20 year sewage irrigated areas and the remaining 50 per cent in 15 year sewage irrigated areas. The soil and plant samples were dried in the shade. The soil samples were sieved through a 2 mm sieve. The plant samples were dried in an oven at 60°C and powdered through a grinding mill. The samples were stored for analysis.

3.4.1. Methods of Soil Analysis

3.4.1.1. Mechanical analysis

Mechanical analysis was conducted with reference to clay content alone by the hydrometer method (Gupta and Dakshinamoorthy 1980). The correctness of this method was checked in 4 samples by the International Pipette method.

3.4.1.2. Physical properties

3.4.1.2.1. Particle density

Particle density was calculated by the specific gravity bottle (Gupta and Dakshinamoorthi 1980).

3.4.1.2.2. Bulk density

The weight of the soil samples collected in metal container of known volume were determined. The soils were then oven dried at 105°C and the weights were again recorded. From the data the bulk density was calculated (Gupta and Dakshinamoorthi 1980). The formula used was

$$\text{Bulk density} = \frac{\text{Weight of airdry soil}}{\text{Volume of soil.}}$$

3.4.1.2.3. Hydraulic conductivity

The soil sample collected was saturated over night with water. The saturated soils were serially arranged and the water circulation maintained to a constant hand of water over the soil. The water passing through the soil column in a stipulated time was collected and measured till concordant values were obtained. Then the values were calculated using Darcy's equation (Gupta and Dakshinamoorthi, 1980). The formula used was

$$K = \frac{QL}{tAH}$$

Where

K = Hydraulic conductivity
Q = Quantity of water conducted per unit time 't'.
L = Length of the soil column.
A = Area of cross section of the soil column.
H = Hydraulic head.

3.4.1.2.4. Aggregate Analysis

The analysis was based on the technique modified Yoder method of Gupta and Dakshinamoorthi (1980), 100 g of soil sample prepared for analysis was kept on the top of a set of sieves having openings 5,2,1, 0.5, 0.25 and 0.1 mm. The set of sieves is then immersed in a shaker. Switched on the shaker for 10 minutes and then removed the sieves and collected the soil retained on each screen and the per cent soil particles in each size group is calculated using the formula

a) per cent aggregate stability =

$$= \frac{\text{Weight soil particles (0.25)} - \text{Weight of sand (0.25)} \times 1}{\text{Oven dry weight sample} - \text{weight of sand (0.25)}}$$

b) Stability index =

$$= \text{Sum of percentages of soil particles} - \text{sum of percentage of primary particl}$$

3.4.1.2.5. Water holding capacity

The maximum water holding capacity of the soil was determined from the data of the capillary porosity by determining the weight of the soil.

3.4.1.3. CHEMICAL ANALYSIS

3.4.1.3.1. Moisture

A known weight of the soil was dried in an oven at $105^{o}C$ to a constant weight and the loss in weight was expressed as percentage of moisture (A.O.A.C. 1962).

3.4.1.3.2. Loss of ignition

A known weight of the soil sample was ignited for eight hours and the loss in weight was calculated on ovendry basis.

3.4.1.3.3. Soil Reaction

The pH of the soil was estimated in pH meter in a soil water suspension of 1: 2 ratio in PerkinElmer.

3.4.1.3.4. Electrical conductivity

The electrical conductivity was determined with the soil bridge (Elico) in the supernatent solution of soil water suspension prepared for pH determination (Hesse, 1971).

3.4.1.3.5. Organic carbon and organic matter

Organic carbon was estimated by the chromic acid wet digestion method of W & B method as described by Black (1963) and organic matter was computed from the values of organic carbon.

3.4.1.3.6. Total phosphorus

The soil was digested with HNO_3 and perchloric acid and made upto a constant volume. Total phosphorus was estimated from the aliquot by the Vanadomolybdate yellow colour method (Jackson 1973).

3.4.1.3.7. Total Nitrogen

Total nitrogen was determined by the macro-Kjeldahl method (Jackson, 1973).

3.4.1.3.8. Total potassium

Total potassium was determined from an aliquot using EEL flame photometer (Jackson, 1973).

3.4.1.3.9. Total Calcium and Magnesium

From the aliquot total calcium and magnesium were also determined (Jackson, 1973).

3.4.1.3.10. Available Nitrogen

Available nitrogen in the soil was determined by the alkaline permanganate method described by Subbiah and Asija (1956)

3.4.1.3.11. Available phosphorus

Available phosphorus in the soil was extracted in Bray No.1 dilute acidflouride solution (0.03N NH_4F and 0.025 N, HCl) as described by Jackson (1973) and colorimetric determination of phosphorus in the extract by the chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system.

3.4.1.3.12. Available potassium

The extract using neutral normal ammonium acetate was employed. The potassium was estimated by flame photometer method (Stanford and English, 1949).

3.4.1.3.13. Total sodium

This was estimated by using 'EEL' flame photometer using the acid extract.

3.4.1.3.14. Available sodium

The equilibrium extract using neutral normal ammonium acetate was employed. Sodium was estimated by flame photometer method (Stanford and English, 1949).

3.4.1.3.15. Cation exchange capacity

The method of Schollenberger and Dreibetbis (1930) was followed. This was estimated by using normal ammonium acetate and expressed as milliequivalents per 100 g of soil.

3.4.1.3.16. Exchangeable plus water soluble calcium

Exchangeable plus water soluble calcium was estimated in a known volume of ammonium acetate leachate by titration with standard versenate (Disodium salt of ethylene diamine tetracetate) (Jackson, 1973).

3.4.1.3.17. Exchangeable plus water solubles Magnesium

This was estimated in a known volume of ammonium acetate leachate (Jackson, 1973).

3.4.1.3.18. Exchangeable plus watersoluble potassium and sodium

These constituents were determined in the ammonium acetate leachate by using 'EEL' flame photometer (Toth and Prince, 1949).

3.4.1.3.19. Estimation of inorganic forms of Nitrogen

(a) Ammoniacal Nitrogen

Soil samples were extracted with 10% sodium chloride solution acidified to pH 2.5 with HCl. Ammoniacal nitrogen in the extract was estimated using Nessler's reagent by measuring the colour intensity at 410nm using a photoelectric colorimeter.

(b) Nitrate nitrogen

Nitrate nitrogen was estimated by pheno-disulphonic acid yellow colour method as described by Jackson (1973) and the colour intensity was read at 420 nm using photoelectric colorimeter.

3.4.1.3.20. Total micronutrients

1. Total Copper

This was estimated in the perchloric acid extract in the atomic absorption spectrophotometer PE 3030 (Perkin Elmer) using copper cathode lamp (Holmes.1945).

2. Total Iron

This was estimated in the perchloric acid extract in the atomic absorption spectrophotometer PE 3030 using iron cathode lamp.

3. Total Manganese

The perchloric acid extract of the soil was directly read to the atomic absorption spectrophotometer PE 3030 using manganese cathode tube.

4. Total Zinc

This was estimated in the perchloric acid extract with atomic absorption spectrophotometer PE 3030 using zinc cathode tube.

5. Total Cadmium

This was estimated in the perchloric acid extract with absorption spectrophotometer PE 3030 using cadmium cathode.

. Total Mercury

This was estimated in the perchloric acid extract with atomic absorption spectrophotometer PE 3030using mercury cathode.

3.4.1.3.21. Available micronutrients

The soil was extracted with DTPA extractant (DTPA extractant is prepared by mixing 0.005 M diethylene triamine pentaacetic acid with 0.1 M triethanolamine and 0.01 M calcium chloride) in the ratio of 1:2 shaken for 2 hours and estimated with atomic absorption spectrophotometer PE 3030 (Lindsay and Norvell, 1978).

"By using this method, the available Copper, Iron, Manganese, Zinc, Cadmium and Mercury were estimated".

3.4.2. Statistical analysis

3.4.2.1. Soil Samples

The data from the 15 year and 20 year sewage irrigation and control plots (without sewage irrigation) were statistically analysed by completely randomised factorial design. Correlation studies of the different factors were also done.

3.4.2.2. Plant samples

The plant samples from the 15 year and 20 year sewage irrigated plots were compared by using 'T' test.

RESULTS

CHAPTER IV

EXPERIMENTAL RESULTS

This chapter presents the various results obtained in the present investigation.

4.1. Analysis of sewage water

The sewage water samples were collected from the influent channel in polythene containers, transported to the Laboratory and analysed for EC, pH, Total solids, Total micro and macro nutrients. The results of the analysis are presented in Table 1. The daily application of about 1.355 lakhs litres of irrigation corresponds to 1.355 cm of irrigation/ha and application of 11 kg of total soluble N/day/ha. Harvesting at fifteen days intervals of the forage due to growth ensured the addition of 165 kg of Nitrogen per fortnight in the form of sewage irrigation since computations on irrigation water recorded this removal. This irrigation also leads to the application of 5 kg phosphorus /day /ha and 2.84 kg of K per day/ha. This irrigation may also cause further inclusion of 22 kg of calcium, 12 kg of magnesium and 3 kg of sodium in the soil per day. The micronutrient supplied per ha/day are 9.9 milligrams of iron, 0.04 milligrams of zinc, 0.03 milligrams of manganese, 0.06 milligrams of copper and 0.003 milligrams of cadmium. These results indicate the adequacy of sewage irrigation for N P K, secondary

Table 1

Composition of sewage water

Sl. No.	Particulars	November 1985 influent to sewage farm	January 1986 influent to sewage farm
1.	Total solids (mg/litre)	1983	2103
2.	pH	7.2	7.5
3.	Electrical conductivity (mmhos/cm)	0.95	1.00
4.	a) Total Nitrogen (mg/litre)	82.5	81.4
	b) Amoniacal Nitrogen (mg/litre)	69.8	70.5
	c) Nitrate Nitrogen(mg/litre)	0.7	0.6
5.	Total Phosphorus(mg/litre)	37.0	36.5
6.	Total Potassium (mg/litre)	21.0	17.3
7.	Total Calcium (mg/litre)	163	162
8.	Total Magnesium (mg/litre)	90	89
9.	Total Sodium (mg/litre)	173	175
10.	<u>Total Micronutrients</u>		
	a) Iron (p.p.m)	9900	8600
	b) Zinc (p.p.m.)	398	410
	c) Manganese (p.p.m)	280	275
	d) Copper (p.p.m)	580	575
	e) Cadmium	25	29

and even micronutrients in general, for forage cultivation.

4.2.1. Physical properties

4.2.1.1. Bulk density

Different periods of sewage irrigation were significant. The lowest value of bulk density was associated in the treatment T_3 without sewage irrigation viz. 20 years. Significant change in bulk density could be noticed with depth. In fact, the bulk density was the highest at the maximum depth (D_4) (1.62 g/cc) and lowest in the surface layer (D_1) (1.29 g/cc).

The interaction between depth and time has also been found to be significant. In the sewage irrigated blocks the highest and lowest value of bulk density has been noticed at the lowest depth and the surface in both the 15 years and 20 years irrigated blocks.

4.2.1.2. Per cent aggregate stability

The value of per cent aggregate stability varied significantly among treatments. Soils that have received sewage irrigation for the longest period (T_1) recorded the highest per cent aggregate stability (66.68) over those that have received sewage irrigation for a lesser period or no sewage irrigation. In fact the differences among the latter are also significant. Aggregate stability also decreased with depth.

Table 2

Effect of sewage on bulk density (g/cc)
(Mean value of 3 replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1	T_2		
	20 years	15 years		
0-15	1.63	1.25	0.98	1.29
16-30	1.68	1.33	1.08	1.36
31-45	1.73	1.42	1.24	1.46
46-70	1.85	1.64	1.37	1.62
Mean	1.72	1.41	1.17	

<u>Comparison of significant effects</u>

	Level of significance	C.D
1. Time	0.05	0.14
2. Depth	0.05	0.21
3. Time x Depth	0.05	0.25

Table 3

Effect of sewage on per cent aggregate stability
(Mean value of 3 replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation T_3	Mean
	20 years	15 years		
0-15	68.12	67.21	57.00	64.11
16-30	65.32	66.13	58.54	63.33
31-45	67.97	63.35	56.35	62.56
46-70	65.35	61.85	55.31	60.83
Mean	66.68	64.63	56.80	

Comparison of significant effects

	Level of significance	C.D.
1. Time	0.05	1.77
2. Depth	0.05	3.07
3. Time x Depth	0.05	1.53

In the case of aggregate stability also amongst the soil profiles and the samples there from depth- time interaction could be observed. Among various periods of sewage irrigation, D_1 recorded the highest value (64.11) of per cent aggregate stability, while D_4 recorded the lowest (60.83). Among various depths, 20 years of sewage treatment enhanced the per cent aggregate stability while a mild effect was found in the control. (Table 3).

4.2.1.3. Stability Index

The different periods of stability index have a significant effect in the sewage irrigation which ranges between 50.42 and 43.08 respectively. The highest value of 50.42 for the stability index was associated with the longest period viz. 20 years of sewage irrigation, while the minimum value (43.08) was observed in the control with no sewage irrigation.

The stability index differed among various depths and values ranged from 48.21 to 44.73 while it was not significant for the different depths in the profile for the 20 years irrigated plots, significant difference between the surface and the deepest layers could be noticed in the profile for 15 year sewage irrigation.

A significant interaction existed between time and depth. Among different periods of sewage irrigation, the maximum and minimum values of stability index were noticed in D_1 and D_4 depths respectively.

Table 4

Effects of sewage on stability Index
(Mean value of 3 replications)

Profile depth (cm)	Sewage Irrigation T_1 20 years	Sewage Irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	51.2	48.32	45.13	48.21
16-30	51.5	46.85	43.52	47.29
31-45	49.8	44.80	42.20	45.60
46-70	49.2	43.50	41.50	44.73
Mean	50.42	45.86	43.08	

Comparison of significant effects

	Level of significants	C.D.
1. Time	0.05	1.78
2. Depth	0.05	3.07
3. Time x Depth	0.05	1.54

Considering different depths and making a treatment comparison it may be seen that longer the duration of sewage irrigation higher, the stability index.

4.2.1.4. Hydraulic conductivity

The hydraulic conductivity expressed in cm/hr decreased from 37.69 to 21.05. The highest value was found in the profile for the plot receiving longest period of sewage irrigation while shorter duration of sewage irrigation to still lesser values and in the no sewage irrigated samples.

The influence of depth was no impressive on hydraulic conductivity. Maximum hydraulic conductivity was associated in the depth of 46-70 cm (33.16) while the minimum (29.03) hydraulic conductivity, in the top surface 0-15 cm.

The interaction between depth and time on hydraulic conductivity was found to be significant. Among different periods of sewage irrigation, the hydraulic conductivity steadily increased with depth (Table 5).

4.2.1.5. Water holding capacity

From the results, it can be seen that the duration of sewage irrigation enhances the water holding capacity. Thus, 20 year sewage treatment records the highest WHC. Similarly higher WHC is exhibited with the surface horizons of treatments T_1 and T_2. In the control profile the absolute

Table 6

Effect of sewage on water holding capacity
(per cent)

(Mean value of 3 replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	48.50	45.70	36.6	43.6
16-30	41.10	38.80	28.5	36.13
31-45	35.50	29.60	27.5	30.88
46-70	33.30	28.50	26.8	29.53
Mean	39.60	35.65	29.85	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	1.70
Depth	0.05	0.98
Time x Depth	0.05	0.85

Table 5

Effect of sewage on hydraulic conductivity (Mean value of 3 replications (cm/hr)

Profile Depth (cm)	Sewage irrigation T$_1$ 20 years	T$_2$ 15 years	With sewage irrigation T$_3$	Mean
0-15	21.76	30.17	35.17	29.03
16-30	20.95	31.31	32.87	28.37
31-45	20.54	33.31	44.40	32.75
46-70	20.98	40.17	38.32	33.16
Mean	21.05	33.74	37.69	

Comparison of significant effects

	Level of significance	C.D.
1. Time	0.05	1.78
2. Depth	0.05	1.03
3. Time x Depth	0.05	0.89

value of WHC was observed to be considerably lower though depth-wise a trend similar to one observed in T_1 and T_2 could be seen (Table 6).

The depth and time manifested significant interaction.

4.2.1.6. Total porosity

The influence of different periods of sewage irrigation on total porosity is apprent and the trend of results was similar to that of water holding capacity of the soils. Here, T_3 recorded 30.15%, T_2 32.47% and T_1 49.35%.

Effect of different depths on total porosity due to sewage irrigation was found to be significant. D_1 recorded the highest total porosity (40.90%) and the value decreased as the depth of profile increased.

The results of interaction between depth and time revealed that irrespective of depth, T_1 treatment could increase the total porosity over the others (Table 7).

4.2.1.7. Clay content

Sewage irrigation appears to increase the clay content as indicated by higher clay content in T_2 and compared to T_3. T_1 recorded the highest value (14.1 per cent) while T_2 recorded 10.69 per cent and T_3 5.70 per cent. A depthwise decrease in clay content could be noticed in all the profiles. The highest value of clay content was associated in the depth of 0-15 cm and it decreased and reached the value of 7.58 in the depth of 46-70 cm.

Table 7

Effect of sewage on total porosity (per cent)
(Mean value of 3 replications)

Profile Depth	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	With sewage irrigation T_3	Mean
0-15	54.30	35.20	33.20	40.90
16-30	51.50	32.30	29.50	37.77
31-45	46.40	31.50	29.40	35.77
46-70	45.20	30.90	28.50	34.87
Mean	49.35	32.47	30.15	

Comparison of significant effects

	Level of significance	C.D.
1. Time	0.05	2.17
2. Depth	0.05	1.25
3. Time x Depth	0.05	1.08

Interaction between time and depth showed that T_1 is the superior treatment (Table 8).

4.2.2. Chemical properties

4.2.2.1. Soil reaction

The soil reaction differed significantly in blocks receiving sewage irrigation for different periods. The Treatment T_1 recorded the highest (6.68) followed by T_2 (5.75 and T_3(4.70).

The pH was also influenced by depth of the soil, the value being high at D_4 (46-70 cm) and low at D_1(0-15 cm). But the difference was significant only in D_4.

Depth and time interaction also suggested significant difference (Table 9).

4.2.2.2. Total soluble salts

The Electrical conductivity expressed in mmhos/cm of soil ranged from 0.42 to 0.65. Since the range is only between 0.42 and 0.65 though significance exists between treatments much is not to be made out of it (Table 10).

4.2.2.3. Organic matter

The different periods of sewage irrigation recorded the superiority over the sewage unirrigated blocks in increasing the organic matter content in soils. Treatments, T_1 and T_2

Table 8

Effect of Sewage on Clay content (per cent)
(Mean value of 3 replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	16.60	14.20	8.50	13.10
16-30	14.30	11.30	7.50	11.03
31-45	13.20	9.10	4.50	8.93
46-70	12.30	8.16	2.30	7.58
Mean	14.10	10.69	5.70	

Comparison of significant values

	Levels of significance	C.D.
Time	0.05	0.76
Depth	0.05	0.44
Time x Depth	0.05	0.38

Table 9

Effect of sewage on soil reaction
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T$_1$	T$_2$	Without sewage irrigation T$_3$	Mean
	20 years	15 years		
0-15	6.50	5.30	4.10	5.30
16-30	6.10	5.80	4.80	5.57
31-45	7.10	5.80	5.00	5.97
16-70	7.00	6.10	4.90	6.00
Mean	6.68	5.75	4.70	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.35
Depth	0.05	0.59
Time x Depth	0.05	0.29

Table 10

Effect of sewage on total soluble salts (mmhos/cm)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	T_2 15 years	Without sewage irrigation T_3	Mean
0-15	0.73	0.72	0.48	0.64
16-30	0.66	0.46	0.40	0.51
31-45	0.69	0.70	0.51	0.63
46-70	0.53	0.41	0.30	0.41
Mean	0.65	0.57	0.42	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.02
Depth	0.05	0.12
Time x Depth	0.05	0.02

increased the build up of organic matter content. There is statistical significance in T_1 and T_2 where T_1 is the superior treatment.

The effect of depth on organic matter content was also well pronounced. D_1 recorded the highest organic matter content (2.57 per cent) and the same decreased as depth increased. The content of organic matter in different depths was statistically significant.

The interaction between time and depth show that there is significant difference in organic matter content among various periods of sewage irrigation. Period of irrigation had most pronounced effects on the accumulation of organic matter at depths (Table 11).

4.2.2.4. Total Nitrogen

Sewage irrigation favoured significantly the total Nitrogen content of soils. T_1 and T_2 recorded 0.08 and 0.07 per cent of total Nitrogen, while T_3 recorded only 0.03 per cent. Nitrogen content in treatment T_1 and T_2 are significant.

Total N content of the soils also showed differences depending on the sewage irrigation. Thus, treatment T_1 and T_2 sewage irrigated plots showed higher contents than control plot T_3. The N content decreased depthwise both in sewage irrigated and non-irrigated plots. In the latter

Table 11

Effect of sewage on organic matter (per cent)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	4.62	2.56	0.54	2.57
16-30	3.60	2.10	0.70	2.13
31-45	3.32	1.80	0.43	1.85
46-70	2.02	1.57	0.30	1.29
Mean	3.39	2.00	0.49	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.32
Depth	0.05	0.55
Time x Depth	0.05	0.27

it followed the usual soil profile trend while in the former this was magnified by the sewage irrigation. The total Nitrogen decreased as depth increased. The nitrogen content in different depth was statistically significant. There is significant interaction between time and depth (Table 12).

4.2.2.5. Available Nitrogen

The highest availabke Nitrogen content in the soil was also observed in T_1 which had received maximum duration of sewage irrigation followed by T_2 with lesser duration of sewage irrigation and T_3 with no sewage irrigation. Depth-wise also, available nitrogen significantly decreased. Thus, the highest value of available Nitrogen was recorded in D_1 and the same declined steadily and progressively upto D_4. Incidently, surface layer (D_1) recorded a two fold increase in available Nitrogen in the treatment under largest duration of sewage irrigation. Interaction between depth and time show that irrespective of irrigation both sewqge or no irrigation, the surface soils (D_1) and the lowest layer (D_4) recorded the highest and lowest values of available Nitrogen. A significant increase due to sewage irrigation in D_1 was noticed, but no such increase was found in D_2, D_3 and D_4 (Table 13).

Table 1a

Effect of sewage on Total Nitrogen (per cent)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigations		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	0.22	0.13	0.05	0.10
16-30	0.03	0.08	0.02	0.03
31-45	0.03	0.03	0.02	0.02
46-70	0.04	0.05	0.01	0.02
Mean	0.08	0.07	0.03	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.03
Depth	0.05	0.02
Time x Depth	0.05	0.03

Table 13

Effect of sewage on Available Nitrogen (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T1	Sewage irrigation T2	Without sewage irrigation T3	Mean
	20 years	15 years		
0-15	226	140	82	149.33
16-30	135	122	118	125.00
31-45	105	90	89	94.67
46-70	93	82	80	85.22
Mean	139.75	108	92.42	

<u>Comparison of significant effects</u>

	Level of significant	C.D.
Time	0.05	7.89
Depth	0.05	13.65
Time x Depth	0.05	6.83

4.2.2.6. Ammoniacal Nitrogen

Ammoniacal Nitrogen expressed in ppm ranged from 17 to 40. Sewage irrigation in T_1 significantly recorded ~~the~~ higher value of ammoniacal nitrogen than seen either in T_2 and T_3 which themselves were on par.

The Ammoniacal Nitrogen content due to depth was not significant. The pattern of distribution was a decrease in ammoniacal nitrogen as depth increased.

Depth and time interaction showed that D_1 and D_4 recorded the highest and lowest value under different periods of sewage irrigation as well as in non-sewage irrigated fields. (Table 14).

4.2.2.7. Nitrate Nitrogen

Considering Nitrate Nitrogen content each treatment significantly contributed to the Nitrate Nitrogen content over the other levels. The treatment T_1 is superior and T_2 and T_3 are on par.

Depth did not cause any significant increase in Nitrate Nitrogen content. However, D_1 and D_4 recorded the highest Nitrate Nitrogen content.

Interaction of time and Depth indicate that the lowest layer in treatment T_1 recorded the highest value (Table 15).

Table 14

Effect of sewage on Ammoniacal Nitrogen (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	65.30	36.90	18.20	40.13
16-30	36.30	29.60	19.20	28.36
31-45	28.80	21.20	13.10	21.03
46-70	29.90	22.30	17.63	23.27
Mean	40.07	27.50	17.03	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	20.45
Depth	0.05	35.40
Time x Depth	0.05	17.71

Table 15

Effect of sewage on Nitrate Nitrogen (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	20.50	17.60	8.20	15.45
16-30	17.76	13.30	7.10	12.72
31-45	14.40	12.30	11.10	12.60
46-70	23.10	20.50	14.10	19.23
Mean	18.94	15.94	10.12	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	8.46
Depth	0.05	14.65
Time x Depth	0.05	7.32

4.2.2.8. Total phosphorus

The influence of periods of sewage irrigation on total phosphorus is similar to the pattern of results obtained for Nitrate Nitrogen, though the magnitude and relative proportion of Total phosphorus content varied. The treatment T_1 was superior to both T_2 and T_3. The total phosphorus content in various treatments were statistically significant.

As depth increased total phosphorus content decreased. The total phosphorus content was 0.05 in D_1 and it decreased as depth increased and reached 0.03 in D_4. But the content of total phosphorus was not statistically significant.

Interaction between time and depth reveals that different periods of sewage irrigation has an effect in increasing the phosphorus content of the soil, T_1 was superior and it was found to be statistically significant (Table 16).

4.2.2.9. Available phosphorus

The effect of sewage irrigation on available phosphorus was also identical to that of total phosphorus, though the magnitude of available phosphorus varied considerably(25.25 in T_1 and 15.94 in T_2 and 4.08 per cent in T_3).

Table 16

Effect of sewage on Total phosphorus (per cent) (Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation T_3	Mean
	20 years	15 years		
0-15	0.076	0.050	0.036	0.050
16-30	0.080	0.060	0.010	0.050
31-45	0.070	0.040	0.010	0.040
46-70	0.080	0.040	0.010	0.030
Mean	0.070	0.047	0.016	

<u>Comparison of significant effects</u>

	Level of significance	C.D.
Time	0.05	0.02
Depth	0.05	0.04
Time x Depth	0.05	0.07

Treatments T_1 and T_2 were on par but are statistically significant over T_3.

With depth a decrease in available phosphorus is observed though not significant. The highest value (18.11 ppm) is thus for the surface soils and the least for the lowest layer.

The interaction between depth and time also established similar trends though not statistically significant (Table 17).

4.2.2.10. Total potassium

Sewage irrigation manifested a significant effect on total potassium. Continuous irrigation with sewage for 20 years produced an enhanced level of total potassium in the profile compared to a lower period, 15 years, of irrigation or no sewage irrigation. However, depth-wise, a progressive but non-significant apparent increase in potash is observed. It may be observed in general while other plant nutrients such as Nitrogen and Phosphorus decreased with depth total potassium generally increased in depth. But statistically total potassium content in D_1 and D_2 were on par and that D_3 and D_4 were on par.

The interaction between time and depth show that T_1 is the superior treatment (Table 18).

Table 17

Effect of sewage on Available Phosphorus (ppm)
(Mean value of three replications)

Profile depth (cm)	Sewage irrigation T$_1$	T$_2$	Without sewage irrigation	Mean
	20 years	15 years	T$_3$	
0-15	28.00	25.00	1.33	18.11
16-30	24.00	17.00	5.00	15.55
31-45	26.00	10.00	5.00	13.66
46-70	23.00	11.00	15.00	13.00
Mean	25.25	15.94	4.08	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	14.09
Depth	0.05	34.41
Time x Depth	0.05	12.20

Table 28

Effect of sewage on Total Potassium (per cent)
(Mean value of three replications)

Profile depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	0.02	0.16	0.18	0.05
16-30	0.13	0.10	0.04	0.06
31-45	0.13	0.13	0.08	0.11
46-70	0.20	0.07	0.19	0.15
Mean	0.13	0.09	0.08	

Comparison of significant effect

	Level of significant	C.D.
Time	0.05	0.02
Depth	0.05	0.15
Time x Depth	0.05	0.02

Table 19

Effect of sewage on Available Potassium (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation	Mean
	20 years	15 years	T_3	
0-15	320.00	310.00	210.00	280.00
16-30	360.00	320.00	213.00	264.33
31-45	375.00	330.00	202.00	302.33
46-70	380.00	360.00	182.00	307.33
Mean	358.75	305.00	201.75	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	164.96
Depth	0.05	285.71
Time x Depth	0.05	142.85

Table 20

Effect of sewage on Total Calcium (per cent)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation T_3	Mean
	20 years	15 years		
0-15	3.00	1.83	0.03	1.62
16-30	1.45	0.53	0.04	0.67
31-45	2.75	1.79	0.02	1.52
46-70	2.46	1.83	0.05	1.44
Mean	2.41	1.49	0.04	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.62
Depth	0.05	1.07
Time x Depth	0.05	0.53

4.2.2.11. Available potassium

The different periods of sewage irrigation did not influence significantly the available potassium status of the soils. The potassium status of treatment T_1 is 358.75 ppm and that of T_2 and T_3 were 305 and 201.75 ppm respectively.

The difference in available potassium status of the soil at different depths due to sewage irrigation was not significant. The lowest value was 264.33 ppm noticed in D_2 and highest value 307.33 ppm was found in D_4. The interaction particularly time-depth had no favourable effect with reference to available potassium status (Table 19).

4.2.2.12. Total Calcium

The total calcium content significant differed among the various treatments. The treatment T_1 recorded the highest value of total calcium (2.41%) while T_2 recorded a calcium status of 1.49 per cent and T_3 0.04 per cent.

The difference in total calcium status of soils at different depths exhibited a similar behavious as that of total potassium earlier reported. It decreased as depth increased. But the time and depth interaction was not conspicuous (Table 20).

Table 21

Effect of sewage on Total Magnesium (per cent)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T1 20 years	Sewage irrigation T2 15 years	Without sewage irrigation T3	Mean
0-15	2.83	1.24	0.19	1.42
16-30	2.83	1.39	0.12	1.44
31-45	1.96	1.20	0.05	1.04
46-70	1.17	0.52	0.11	0.60
Mean	2.20	1.06	0.11	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	1.04
Depth	0.05	1.80
Time x Depth	0.05	0.90

Table 22

Effect of sewage on Total Sodium (per cent)
(Mean value of three replications)

Profile depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1	T_2		
	20 years	15 years		
0-15	3.06	2.48	1.12	2.22
16-30	2.60	1.90	1.10	1.86
31-45	2.43	1.80	0.83	1.68
46-70	1.70	2.30	0.75	1.58
Mean	2.44	2.12	0.95	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.73
Depth	0.05	1.27
Time x Depth	0.05	0.63

4.2.2.13. Total magnesium

The total magnesium as influenced by different periods of sewage irrigation was not statistically significant except T_1 treatment. The highest value of 2.20 per cent was associated with treatment T_1 and lowest value of 0.11 was found in T_3. T_1 is found is the superior treatment and T_2 and T_1 are on par.

The accumulation was more in depths, D_1 and D_2 and it decreased as depth increased. The accumulation of magnesium noticed in different depths were not statistically significant. The effect of interaction on total magnesium was prominent (Table 21).

4.2.2.14. Total Sodium

Total sodium content differed markedly. The highest value was observed in soils under continuous irrigation for 20 years T_1 (2.44 per cent). The accumulation of total sodium content was more in D_1 and D_2 than in lower depths. But the difference in accumulation of total sodium in different depths was not significant.

Depth and time interaction confirmed that accumulation of total sodium in D_1 and D_2 as brought out above (Table 22).

4.2.2.15. Cation exchange capacity

The influence of periods of sewage irrigation on cation exchange capacity was found to be significant in treatment T_1. T_2 and T_3 recorded 19.20 me/100 g soil and 11.25 me/100 g soil respectively and remained on par.

The depth variations distinctly caused a change in cation exchange capacity as it was evidenced from the present investigation that with the increase in depth the cation exchange capacity decreased. Depth D_1 recorded an increased value of cation exchange capacity (19.03 me/100 g soil). But the cation exchange capacity recorded in different depths were not significant.

Depth and time interaction records that under all periods of sewage irrigation and non-sewage irrigation depths D_1 and D_4 continue to record higher and lower values respectively. Interaction also reveals that T_1 recorded the highest value of cation exchange capacity followed by T_2 and T_3 (Table 23).

4.2.2.16 Exchangeable Calcium

The effect of different periods of sewage irrigation on exchangeable calcium was well pronounced. The treatments T_1 and T_2 recorded higher values of exchangeable calcium significantly than T_3. Treatment T_1 and T_2 are on par.

Table 23.

Effect of sewage on cation exchange capacity
(mm/100 g soil)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1 20 years	T_2 15 years		
0–15	23.80	21.20	12.10	19.03
16–30	20.50	18.96	9.30	16.25
31–45	19.80	18.46	11.40	16.55
46–70	19.16	18.20	12.20	16.52
Mean	20.81	19.20	11.25	

Comparison of significance effects

	Level of Significance	C.D.
Time	0.05	8.72
Depth	0.05	15.11
Time x Depth	0.05	7.55

The varied depths clearly manifested difference in values of exchangeable calcium indicating that higher values of exchangeable calcium were being associated with the surface horizon and the same ~~value~~ markedly reduced as depth increases. But the accumulation of exchangeable calcium in different depths were not statistically significant.

Significant interaction between depth and time established the presence of higher and lower amounts of exchangeable calcium at the surface and the lowermost horizons studied under different periods of sewage irrigation. Further, the treatment under continuous sewage irrigation for 20 years viz. T_1 continued to be superior over others. (Table 24).

4.2.2.17. Exchangeable Magnesium

The exchangeable magnesium showed significant variation in the soils under sewage irrigation and non irrigation. Thus, treatments T_1 and T_2 recorded 16.33 ppm and 13.24 ppm respectively while T_3 recorded only 4.06 ppm. Treatments T_1 and T_2 are significantly superior to T_3 and they are on par.

Difference in the accumulation of exchangeable magnesium with depth could be noticed. The content of exchangeable magnesium decreased with depth. It was also

Table 24

Effect of sewage on Exchangeable Calcium
(me/100 g soil)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation	Mean
	20 years	15 years	T_3	
0-15	39.10	38.90	2.50	26.83
16-30	29.30	23.79	6.30	19.79
31-45	25.29	16.78	11.10	17.72
46-70	24.17	14.29	5.20	14.54
Mean	29.46	23.44	6.27	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	17.21
Depth	0.05	29.80
Time x Depth	0.05	14.90

inferred from the time and depth interaction that different periods of sewage irrigation have certainly increased the exchangeable magnesium irrespective at different depths (Table 25).

4.2.2.18. Exchangeable sodium

A perusal of the results showed that exchangeable sodium was high in treatment T_1 and T_2 than control T_3. T_1 and T_2 were statistically significant.

As depth increased the exchangeable sodium decreased and reached the lowest value in D_4. The value in different depths were also statistically significant.

Interaction of time and depth revealed that T_1 is superior in the accumulation of exchangeable sodium (Table 26).

4.2.2.19. Exchangeable Potassium

The values of exchangeable potassium varied significantly among the sewage and non-sewage irrigated areas. Treatments T_1 and T_2 were found to increase the value of exchangeable potassium over T_3. The treatments are in the order of T_1, T_2 and T_3.

As depth increased the value of exchangeable potassium decreased and reached the lowest value in D_4.

From the time and depth interaction studies, it was learnt that the accumulation was due to treatment T_1 (Table 27).

Table 25

Effect of sewage exchangeable magnesium (me/100 g soil)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	17.67	16.67	6.33	13.55
16-30	16.65	14.32	3.33	11.43
31-45	15.67	11.33	4.25	10.41
46.70	15.33	10.65	2.34	9.43
Mean	16.33	13.24	4.06	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	6.91
Depth	0.05	11.97
Time x Depth	0.05	5.98

Table 26

Effect of sewage on exchangeable sodium (me/100 g soil)
(Mean value of three replications)

Profile depth (cm)	Sewage irrigation T_1 20 years	T_2 15 years	Without sewage irrigation T_3	Mean
0-15	2.90	1.62	1.41	1.97
16-30	2.50	1.21	1.10	1.60
31-45	2.06	1.13	0.92	1.37
46-70	2.13	1.27	0.83	1.36
Mean	2.39	1.36	1.06	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.31
Depth	0.05	0.54
Time x Depth	0.05	0.27

Table 27

Effect of sewage on exchangeable potassium (me/100 g soil)

(mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation T_3	Mean
	20 years	15 years		
0-15	2.20	1.90	1.00	1.70
16-30	2.15	1.66	0.97	1.59
31-45	2.10	1.89	0.80	1.59
46-70	1.70	1.68	0.74	1.37
Mean	2.03	1.78	0.87	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.31
Depth	0.05	0.55
Time x Depth	0.05	0.27

4.2.2.20. Total zinc

In the case of total zinc, sewage irrigated plots recorded higher values than non-sewage irrigated ones.

Depth showed that D_1 recorded a higher value (71.13 ppm) and value of total zinc decreased as depth increased.

Interaction of Time and Depth shows that T_1 accumulated more of total zinc (Table 28).

4.2.2.21. Total Copper

Total copper content is higher in soils under sewage irrigation and much more so in the treatment subjected to a longer duration of irrigation (T_1) compared to others.

Variation in zinc due to different depths could also be noticed. However, high accumulation was found in surface horizon D_1 (0-15 cm) than at sub-surface layers.

Time and depth interaction suggests that sewage incorporation resulted in an accumulation of copper in Treatment T_1 (Table 29).

4.2.2.22. Total Iron

Sewage irrigation favoured significantly the accumulation of total iron in soil profiles. Treatment T_1 accumulated 2.96 per cent of total iron while T_2 and T_3 accumulated 2.00 per cent and 0.29 per cent respectively.

Table 28

Effect of sewage on Total zinc (ppm)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1	T_2		
	20 years	15 years		
0-15	139.10	53.10	21.21	71.13
16-30	91.30	49.10	18.30	52.90
31-45	105.00	35.10	14.11	51.40
46-70	103.00	29.50	11.34	47.94
Mean	109.00	49.70	16.24	

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	10.60
Depth	0.05	18.36
Time x Depth	0.05	9.18

Table 29

Effect of sewage on Total copper (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	122.00	111.40	21.30	84.89
16-30	111.10	53.40	18.21	60.90
31-45	72.66	53.10	18.21	47.99
46-70	51.33	32.50	18.21	34.01
Mean	89.27	62.60	18.98	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	9.95
Depth	0.05	17.23
Time x Depth	0.05	8.61

T_1 is the superior treatment followed by T_2 and T_3.

Addition of sewage tended to improve total iron at different depths. Accumulation was more at the surface (Table 30).

4.2.2.23. Total Manganese

Total manganese content was significantly influenced by sewage irrigation. Maximum accumulation was found in T_1. Treatments T_1 and T_2 are on par and significantly superior to T_3.

Variation in depth had a profound influence on manganese content. As depth increases manganese content also increases.

Time and depth interaction reveals that maximum accumulation was registered at lower depths (Table 31.)

4.2.2.24. Total Nickel

Total Nickel was increased by sewage irrigation treatments T_1 and T_2 recorded a nickel content of 1.105 ppm. But the total nickel content in the three treatments are not significant.

Variations in depth record that total nickel was associated in Treatment T_1 and the accumulation was more in Depths D_2, D_3 and D_4. Time and depth interaction suggests

Table 30.

Effect of sewage on total Iron (per cent)
(Mean value of three replications)

Profile depth (cm)	Sewage irrigation T$_1$	T$_2$	Without sewage irrigation T$_3$	Mean
	20 years	15 years		
0-15	2.61	1.70	0.17	1.49
16-30	2.53	1.58	0.18	1.43
31-45	3.46	3.06	0.40	2.31
46-70	3.23	1.66	0.42	1.77
Mean	2.96	2.00	0.29	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.33
Depth	0.05	0.57
Time x Depth	0.05	0.28

Table 38

Effect of sewage on total Manganese (ppm)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	40.21	89.80	32.21	54.07
16-30	78.52	21.30	65.32	55.04
31-45	73.65	89.80	32.21	65.22
46-70	73.65	50.08	63.33	62.35
Mean	66.50	62.74	62.35	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	7.71
Depth	0.05	13.36
Time x Depth	0.05	6.68

that accumulation is more in sewage irrigated plots and in the surface horizon D_1 (0-15 cm), since accumulation of total Nickel was found in some plots (Table 32)(transformed data (x + 1) is used).

4.2.2.25. Total Lead

Total lead content was significant in treatment T_1 & T_2 which are on par.

Depth of the profile suggests that accumulation of lead was more in surface horizon D_1(0-15 cm). As depth increases the total lead content decreases. The highest value is 1.2 ppm and lowest value is 1 ppm.

Depth and time interaction suggests that total lead accumulation was more in the surface horizon in both the treatments of sewage irrigated Blocks (since the accumulation was found only in some treatments transformed data as x + 1 is used)(Table 33).

4.2.2.26. Total Mercury

Mercury was not traceable in any of the treatments and in any of the depths.

4.2.2.27. Available Zinc

The available zinc content due to sewage and non-sewage irrigation varied significantly. Treatment T_1(20 years sewage) was significantly superior to others. The treatment

Table 32

Effect of sewage on total Nickel (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1 20 years	T_2 15 years		
0-15	1.1673	1.258	1.000	1.142
16-30	1.000	1.161	1.000	1.053
31-45	1.161	1.000	1.000	1.054
46-70	1.105	1.105	1.000	1.049
Mean	1.105	1.105	1.000	

(Transformed data X + 1)

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.02
Depth	0.05	0.02
Time x Depth	0.05	0.02

Table 33

Effect of sewage in total Lead (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation T_3	Mean
	T_1	T_2		
	20 years	15 years		
0-15	1.20	1.40	1.00	1.20
16-30	1.10	1.00	1.00	1.03
31-45	1.10	1.01	1.00	1.04
46-70	1.00	1.00	1.00	1.00
Mean	1.10	1.10	1.00	

Since all treatments does not show lead content transformed data (x + 1) is used.

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.11
Depth	0.05	0.02
Time x Depth	0.05	0.02

T_1 recorded the highest mean value of available zinc. The depth variations show that higher available zinc status at surface layers and it subsequently reduced as depth increased. The highest value of available zinc was noticed in D_1 (5.43 ppm) and lowest in D_4 (1.83 ppm).

The above finding was enlightened by a significant interaction between time and depth (Table 34).

4.2.2.28. Available copper

The tremendous influence of sewage irrigation on available copper over non-sewage irrigation was brought out. It is of interest to add that the sewage incorporated fields (T_1 and T_2) registered an increase of 94 and 89 per cent over the non-sewage irrigated fields (T_3). The prevalence of available copper was more in depths D_1 and D_2 than the other depths, where the variation in the available copper was not impressive.

From the time and depth interaction it was observed that more accumulation of copper in depths D_1 and D_2 and less at deeper layers irrespective of sewage and non-sewage irrigations. Among depths, 20 years of sewage irrigation (T_1) improved the available copper status (Table 35).

4.2.2.29. Available Iron

The available iron in the soil distinctly and progressively increased significantly as the period of sewage

Table 34

Effect of sewage on Available Zinc (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T_1 20 years	Sewage irrigation T_2 15 years	Without sewage irrigation T_3	Mean
0-15	13.10	1.10	2.10	5.43
16-30	6.20	3.80	2.50	4.16
31-45	3.50	2.10	2.30	2.63
46-70	2.20	1.20	2.10	1.83
Mean	6.25	2.05	2.25	

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	1.54
Depth	0.05	2.68
Time x Depth	0.05	1.34

Table 35

Effect of sewage on Available Copper (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T$_1$ 20 years	Sewage irrigation T$_2$ 15 years	Without sewage irrigation T$_3$	Mean
0-15	12.90	8.70	0.33	7.31
16-30	8.70	2.20	0.23	3.71
31-45	5.30	2.00	0.15	2.48
46-70	5.20	1.80	0.13	2.37
Mean	8.02	3.67	0.21	

Comparison of significant effects

	Level of significance	C.D.
Time	0.05	0.70
Depth	0.05	1.22
Time X Depth	0.05	0.61

irrigation increased. T_1 is the best treatment followed by T_2 and T_3.

The influence of different depths was found to be significant on available iron. The general observation was that the availability of iron decreased with increase in depth. In this context it is well fitting to recall that total iron increased with an increase in depth in contrast to available iron.

Interaction between time and depth showed that sewage irrigation always favoured the available iron irrespective of different depths (Table 36).

4.2.2.30. Available Manganese

The available manganese increased significantly as the period of sewage irrigation increased. The treatments (T_1 and T_2) are significantly superior to T_3.

The result of different depths on available manganese was significant. The depth D_1 recorded the highest available manganese over the remaining depths. Here also the available manganese decreased the depth increased (Table 37).

4.2.2.31. Available Nickel

The available nickel in sewage irrigated and non-sewage irrigated Blocks was not significant.

Depth also showed no significant difference in available Nickel.

Table 36

Effect of sewage on Available Iron (ppm)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2		
	20 years	15 years	T_3	
0-15	0.58	0.33	0.05	0.32
16-30	0.48	0.21	0.03	0.24
31-45	0.44	0.15	0.02	0.21
46-70	0.35	0.14	0.01	0.16
Mean	0.46	0.21	0.03	

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	0.02
Depth	0.05	0.10
Time x Depth	0.05	0.02

Table 37

Effect of sewage on Available Manganese

Profile Depth (cm)	Sewage irrigation T_1	T_2	Without sewage irrigation	Mean
	20 years	15 years	T_3	
0-15	5.20	4.25	0.04	3.16
16-30	4.58	4.12	0.03	2.89
31-45	3.21	3.21	0.03	2.15
46-70	2.42	2.11	0.01	1.51
Mean	3.83	3.42	0.02	

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	0.87
Depth	0.05	0.50
Time x Depth	0.05	0.43

Time and Depth interaction also does not give much significance (Table 38).

Since accumulation of available Nickel was not found in all Blocks X = 1 data is used for analysis.

4.2.2.32. Available Lead

Only Traces of available lead is present and only in 2 plots. The Pb content is only in traces.

4.2.2.33. Total Cadmium

Cadmium is a heavy metal. Its occurrence in traces at present will not cause alarm. It is present only in traces in some treatments and at some depths. But the total cadmium was not significant either in sewage treatment plots or with depth (Table 39).

4.2.2.34. Available Cadmium

Available cadmium was present in traces in some treatments. The available cadmium in Treatments (T_1) was significant to that of T_2 and T_3 treatments.

Different depths also show that cadmium content is not significant (Table 40).

Table 38

Effect of sewage on Available Nickle (ppm)
(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	1.01	1.02	1.00	1.01
16-30	1.00	1.04	1.00	1.01
31-45	1.02	1.00	1.00	1.00
46-70	1.02	1.00	1.00	1.00
Mean	1.01	1.01	1.00	

Since all treatments do not show available nickel content, transformed (x +1) is used

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	0.02
Depth	0.05	0.02
Time x Depth	0.05	0.02

All the Blocks do not contain available Nickel hence (x + 1) is used for analysis.

Table 39

Effect of sewage on total Cadmium

Profile Depth (cm)	Sewage irrigation		Without sewage irrigation	Mean
	T_1	T_2	T_3	
	20 years	15 years		
0-15	0.0068	0.011	0.000	0.007
16-30	0.0043	0.005	0.000	0.003
31-45	0.000	0.000	0.000	0.000
46-70	0.000	0.000	0.000	0.036
Mean	0.004	0.004	0.000	

Since values are not obtained in all treatment X = 1 transformation is used

<u>Comparison of significant effect</u>

	Level of significance	C.D.
Time	0.05	0.009
Depth	0.05	0.004
Time x Depth	0.05	0.004

Table 40

Effect of Sewage on Available Cadmium (ppm)

(Mean value of three replications)

Profile Depth (cm)	Sewage irrigation T$_1$ 20 years	Sewage irrigation T$_2$ 15 years	Without sewage irrigation T$_3$	Mean
0-15	0.003	0.005	0.000	0.0017
16-30	0.001	0.000	0.000	0.0005
31-45	0.005	0.000	0.000	0.0018
46-70	0.002	0.000	0.000	0.0008
Mean	0.002	0.001	0.000	

Since values are not obtained in all treatments X = 1 transformation is used

Comparison of significant effect

	Level of significance	C.D.
Time	0.05	0.001
Depth	0.05	0.009
Time x Depth	0.05	0.005

PLANT ANALYSIS

Twelve plant samples each were collected from the 15 year and 20 year sewage irrigated plots. These guinea grass plant samples were analysed for the different macro and micronutrients and heavy metals. These nutrients eventhough showed variation in the 20 year and 15 year sewage treatments it does not showed significant differences in the two treatments except in Calcium and Iron contents.

Nitrogen

Different periods of sewage irrigation showed slight difference even though the results were not statistically significant.

Phosphorus

Different periods of sewage irrigation does not show statistically significant results.

Potash

Different periods of irrigation does not show statistically significant difference in the content of K in plants.

Calcium

The content of Calcium was found more in 20 year sewage irrigated Block; and the difference in content was statistically significant.

Magnessium

The results show high content in 20 year sewage irrigated plants than 15 year irrigated plants even though the results are not statistically significant.

Sodium

There is not much difference in the Sodium content of plants due to different periods of irrigation.

Zinc

The content of Zinc in plant does not show significant difference in different periods of sewage application.

Copper

Plants does not show any significant difference in Copper content at different periods of sewage application.

Iron

Different periods of sewage irrigation showed significant difference in iron content in plants.

Manganese

Different periods of sewage irrigation does not show significant difference in plant manganese content.

Nickel

Plants does not show statistically significant difference in Nickel content due to different periods of application of Nickel.

Lead

Plants does not show statistically significant difference in Lead content.

Cadmium

There is no statistical difference in plant Cadmium content by application of Sewage in different periods.

PLANT ANALYSIS

(Average of 12 observations)

Sl.No.	Name of element	20 years sewage irrigation	15 years sewage irrigation	Remarks
1.	Nitrogen %	2.38	1.80	
2.	Phosphorus	0.19	0.17	
3.	Potassium %	0.99	0.93	
4.	Calcium %	0.27	0.19	
5.	Magnesium %	0.24	0.19	
6.	Sodium %	0.40	0.34	
7.	Zinc %	0.01	0.005	
8.	Copper ppm	0.05	0.03	
9.	Iron	0.005	0.002	
10.	Manganese ppm	0.002	0.001	
11.	Nickel ppm	0.003	0.001	
12.	Lead ppm	0.002	0.001	
13.	Cadmium ppm	0.002	0.001	

DISCUSSION

CHAPTER V

DISCUSSION

An attempt was made to study the influence of sewage irrigation for 15 and 20 years on soil properties in comparison to adjacent sewage non-irrigated plots from the sewage farm area of Valiathura near Trivandrum. A simultaneous attempt was made to study the plant nutrient content also in order to assess the plant effects due to sewage irrigation.

The observation and findings reported earlier are discussed in this Chapter.

Analysis of sewage water in relation to quantities used in irrigation - Nutrient load of sewage water and possible effects based on quantities used

Based on the results obtained, it is seen that daily application of 1.355 lakh litres of irrigation water corresponds to the application of 11 kg of total soluble N_2,5 kg P_2O_5 and 2.84 kg of K_2O per day per ha. The irrigation also supplies 22 kg of CaO, 12 kg of MgO, 3 kg of Na as Nacl. It also leads to addition of micronutrients such as Fe, Zn, Mn and Cu to the extend of 9.9, 0.4, 0.03 & 0.06 mg per day per ha besides the addition of the heavy metal Cd to the extent of 0.003 mg.

These results indicate the enormous quantities of NPK added to the soil between harvest intervals of the forage at 13 to 15 days. Obviously high quantities are not being utilised for forage production. The enrichment of the soil in 15 year and 20 year plots do not account even 1 per cent of the total addition. The enormous leaching losses and removal from the site of application is mainly due to the sandy nature of the soil and the two distinct periods of monsoon viz. South-west and North-east monsoon with an average annual precipitation of 3000 mm.

5.1. Influence of sewage irrigation on soil physical properties

A significant decrease in bulk density of the sewage farm soils due to 20 years of continuous sewage irrigation was noticed. These differences are significant upto a depth of 15 cm and from 15-30 cm, from 30-45 and 45-70 the bulk density has not been significantly enhanced, indicating the depth of penetration and retention of organic matter from the sewage irrigation. Similar observations have been recorded by Morechan _et al_.(1972) and Mays _et al_. (1973) in their studies on incorporation of Municipal refuse, compost & sewage sludge to the soil. In India, Subbiah (1976) and Jayaraman (1981) reported similar effects in respect of soils studied in Tamil Nadu. Between bulk density and organic matter upto 15 cm highly significant negative correlation could be obtained (-0.958)

Significant negative correlation with organic matter in soil between 15-30 cm could also be seen.

5.1.2. Structural Indices

Twenty years of sewage irrigation prominently improved the per cent aggregate stability and stability index of the soil (Table 3 & 4). Subbiah (1976) also observed that addition of sewage wastes improved the structural indice such as stability index and per cent aggregate stability. Similar effects were reported by Jayaraman (1981) in Tamil Nadu soils. Addition of sewage waste could have a striking effect which may be due to the factors promoting aggregate stability, presence of large amounts of calcium and magnesium. Nevertheless addition of lime in any form to the soil is found to be superior to no addition in increasing the water stable aggregates of the soils. From the results discussed earlier, it has been shown that application of 1.355 lakh litres of irrigation water/day/ha is equivalent to the application of 22 kg of calcium oxide and 12 kg of magnesium oxide. As associated features, a positive correlation was established by correlating aggregate stability with organic matter under the influence of sewage incorporation (0.130 for T_1 and 0.763 for T_3). In the case of water holding capacity a positive correlation was established with aggregate stability (0.255 for T_1 and 0.848 for T_2). Available Nitrogen does not show correlation with per cent aggregate stability. Available phosphorus showed a positive correlation with per cent aggregate stability (0.633 for T_1 and 0.763 for T_2).

5.1.3. Hydraulic conductivity

The sewage irrigation had a depressing effect on hydraulic conductivity when compared to the unirrigated blocks. Due to sewage irrigation, the hydraulic conductivity of the surface soils especially upto 15 cm depth, significantly increased. This increase is mainly attributed to accumulation of organic matter. However, the lower layers are not similarly enriched with organic matter consequently the difference between hydraulic conductivity of the surface and the subsurface layer becomes larger and significant. Organic matter from the sewage waste could have clogged the sand - gravel interfaces of the sandy soil or the production of gums derived by enhanced microbial activity due to the organic matter present in the liquid waste could have increased the per cent aggregate stability (Table 3) and consequently the hydraulic conductivity. According to Thomas <u>et al</u>.(1966) soil clogging under sewage spreading proceeded in three phases.

(i) slow decrease in infiltration rate under aerobic conditions

(ii) rapid decrease in infiltration rate under anaerobic conditions and

(iii) further gradual decreases under anaerobic conditions.

In the present investigation the reduction in hydraulic conductivity observed might be due to the above stated reasons. Finely divided particles occurring in the aerated effluents could have more easily penetrated the relatively porous sandy soils reducing the overall penetrability. A significant negative correlation was registered between clay content and hydraulic conductivity (-0.818 for T_1 and -0.588 for T_2). Exchangeable sodium correlated negatively with hydraulic conductivity (-0.360 for T_1 and -0.919 for T_2).

5.1.4. Water holding capacity

Continuous irrigation with sewage water increased the water holding capacity of the farm soil as compared to the non-sewage irrigated soils. Mays et al. (1973) observed that incorporation of municipal refuse and sewage sludge compost over a period of two years, significantly improved the moisture holding capacity from 30 per cent to 40 per cent. Epstain et al.(1976) recorded that application of sludge and compost increased the water content as well as the water retention capacity of a silty loam soil. It is pertinent to point out that the accumulation of organic matter in the soil by way of sewage incorporation could have helped the formation of soil aggregates and thus improved the moisture retention capacity.

5.1.5. Soil porosity

Sewage irrigation irrespective of depth and periods of irrigation tended to improve the total and capillary pore space. In the sandy soils both 15 year and 20 year periods of continuous irrigation with sewage water had significantly increased total and capillary porosity. This increase is related to improvement in aggregation in the surface soils due to deposition of colloidal and soluble organic materials carried by the irrigation. By the application of sewage water the total and capillary pore space in the Black soils of Tamil Nadu were improved significantly (Subbiah 1976) and (Jayaraman 1981).

The colloidal nature, binding action of sewage material and increased biological activities were correlated with pore space. These in turn might have influenced the secretion of various organic compounds that are necessary for improving the physical condition of the soil. This is in conformity with the observation of Bocko and Szerszen (1962) who reported that application of sewage wastes caused accumulation of organic substances in the soil and increased biological activities.

5.2. Influence of sewage irrigation on soil chemical properties

5.2.1. Soil Reaction

The difference due to sewage treatment prominently influenced the soil reaction by lowering the pH value. The marked reduction in pH with sewage irrigation suggests that it may be due to the nitrification of some of the applied ammoniacal and organic nitrogen from oxidation of sulphides that could have brought down soil reaction. Nahedh (1973) and Cunnigham *et al.* (1974) reported that continuous sewage sludge addition to the soil was accompanied by a decrease in pH. Literature on the effect of sewage addition in pH reduction is too voluminous, neverthless there is close agreement with findings of Bocko and Szerszen (1962), Ramate and Mor (1966), Subbiah (1976), Ramanathan *et al.* (1977) Rajarajan (1978) and Jayaraman (1981) who have obtained similar results due to liquid sewage additions.

The reduction in soil pH was notable in the upper 0-30 cm than in the lower depths. This might probably be due to the increased microbial activities in the sewage amended surface layer upto 30 cm. Sewage incorporation and its positive impact on microbial activities find extensive support in the work of Gilbert and Miller (1973).

5.2.2. Total soluble salts

There was no great change in salinity levels due to sewage water irrigation irrespective of years of sewage treatment. In fact, Muravsky and Ramatic (1959) and Kelling *et al.* (1973) had shown that sewage irrigation could not alter the salinity status of the soil markedly. Nahedh et al. (1973) also reported that the application of anerobic sludge caused less effects on salinity. The conductivity values were slightly high in the surface (0-15 cm) layer than in lower depths. Similar observations were expressed by Miller (1974) who reported that sewage amendments caused slight increase in soluble salt content in the land.

5.2.3. Organic matter

Irrigation with sewage water had increased the organic matter content in the sewage amended soils. Thus, both 15 and 20 years continuously sewage irrigated soils significantly recorded higher organic matter content than the control soils. Further, the organic matter accumulation persists till 45 cm depth inspite of the fact that the profile was sandy. However, 0-15 cm accumulates the maximum amount of organic matter and this was much more so in 20 yr sewage irrigated plots. This supported the findings of Lunt (1953) Ramati and Mor (1966) Day and Stroehlein (1972) Gaynor Halstead (1976) Lagerwerff et al. (1976) Subbiah (1976), Rajarajan (1978) and Jayaraman (1981). The build up of organic matter content was 20 to 50 per cent. 20 years of sewage irrigation recorded a mean of 3.39 per cent of organic matter while only a mean of 0.49 per cent was registered with native irrigation. More organic matter was found in the surface depth of (0-15 cm). This may be due to the resistance of sewage to further decomposition by microorganism at lower depth. Murovsky and Remati (1959) emphasised that the presence of more organic matter to further decomposition. A significant and positive correlation was noticed between organic matter and macro and micro-nutrients. Available nitrogen showed a correlation (0.835 for T_1 and 0.936 for T_2 treatments) Available phosphorus (0.725 for T_1 and 0.548 for T_2 treatments) Cation exchange capacity (0.498 for T_1 and 0.282 for T_2 treatments) Available zinc (0.454 for T_1 and 0.735 for T_2 treatments).

5.2.4. Soil Nitrogen

The sewage irrigation at different depths and periods showed significantly high nitrogen content than sewage unirrigated soil and accumulation of nitrogen at 0-15 cm depth was markedly brought out. Unirrigated sewage block had a poor nitrogen content. Increased N accumulation consequent on sewage irrigation finds support in the work of Keefar *et al.* (1976) and several others. Stewart *et al.*(1975) reported that the application of sewage sludge to a loamy soil at the rate of 2.5 and 5 cm per hectare resulted in a significant increase in soil nitrogen at 90 cm soil profile. This may be probably due to the large addition of organic matter to the soil which in turn might have increased the soil total nitrogen. Similar results were obtained by Jayaraman (1981) in Tamil Nadu soils.

In general, available nitrogen also increased significantly in continuously sewage irrigated plots compared to unirrigated one. The effect was more with longer duration of sewage irrigation as evidenced by the high nitrogen content in 20 yr sewage irrigated plot. This increase further correlates well with the increase in both Ammoniacal nitrogen and nitrate nitrogen recorded in Tables 14, 15, 16 and 17. Thus, irrigation with sewage water increased the concentration of Ammoniacal nitrogen in the surface layer and decreased the same with depth. This might be due to the retarded microbial activities and subsequent poor nitrification processes, as a result of reduction in soil pH which might have resulted in the greater release of Ammoniacal Nitrogen in the sewage amended surface soil. Menzies et al. (1974) observed a higher NH_4 - N content in the soil layer just below the surface which received raw sludge. Another explanation for the increased NH_4-N content could be that NH_4-N present in the sewage might have been adsorbed by the soil colloids upon the addition of sewage wastes to soil with subsequent leaching with water. A similar observation was made by Lance (1972) that the soil intermittantly flooded with sewage adsorbed NH_4-N during the periods under flooding. Ammoniacal nitrogen was correlated positively with available phosphorus (0.917 and 0.104 for 15 and 20 years sewage irrigation). Similarly ammoniacal nitrogen was also positively correlated with total nitrogen (0.300 and 0.885 for 15 and 20 years of sewage irrigation). While Ammoniacal nitrogen was of a higher order in sewage treated soil, NO_3-N concentration was comparatively low, irrespective of the years of treatment (Taylor *et al.*(1978) and Son *et al.* (1978). The increase in nitrate nitrogen content could be attributed to the increased microbial mineralisation of organic N and also due to oxidation of NH_4-N to NO_3-N. The high content of NO_3-N in the third layer may be attributed to the favourable nitrification processes in the surface and the leaching of the nitrate so formed to the lower layers. This agrees with the findings of Jayaraman (1981) also.

Sewage irrigation showed an increase in available nitrogen status over the sewage unirrigated soils. This may be due to high organic matter addition and microbial activities which in turn might have influenced the higher availability of nitrogen. Ramanathan et al.(1977) and Jayaraman (1981) in their works showed that sewage irrigation directly influences the availability of nitrogen in soil.

5.2.5. Soil Phosphorus

Superiority of sewage incorporation on total and available phosphorus status of soil was well brought out. Twenty years of continuous irrigation with sewage water inccreased the P_2O_5 content of the soil 7 fold as compared to sewage unirrigated soil. A higher available phosphorus status in soils consequent to sewage irrigation has been reported by perusal made from Tamil Nadu Agricultural University such as Subbiah (1976), Ramanathan *et al.*(1977), Rajarajan (1978) and Jayaraman (1981). A perusal of Tables 18 and 19 reveals that the concentration of both total and available phosphorus decreased with increase in depth. This might be due to high iron and manganese contents in the lower layers which could have rendered phosphorus unavailable. Similar results were also reported by Kardose and Hook (1976). There was a slight migration of phosphorus from surface to lower depths indicating that phosphorus could move to deeper layers under conditions of non-fixation by soil agencies that are responsible for its fixation. Similar observations were reported by Hortenstine (1974). Phosphorus movement to a depth of 3 meters beneath a sewage pond was reported by Lund *et al.*(1976). Subbiah (1976), Ramanathan et al.(1977), Rajarajan (1978) and Jayaraman (1981) had similar observation in Tamil Nadu soils. Total phosphorus was correlated positively with available phosphorus (0.833 for T_1 and 0.058 for T_2).

5.2.6. Soil potassium

The total potassium in sewage incorporated soil was high. But high total potassium content was noticed in the subsurface layer (45-70 cm). This may be due to leaching down of potassium from the top layers through the sandy and porous soils. Sewage treatment does not show much difference in available potassium content due to depth. This is in agreement with Palazzo and Jenkins (1979). They have reported that the concentration of K tended to decline with time in the soil that have received waste water over a period of 5 years. Jayaraman (1981) had similar observation in Tamil Nadu soils.

5.2.7. Cation exchange capacity

Sewage irrigation tended to increase the cation exchange capacity of the soil (Table 25). The soils under study are sandy. The content of clay is extremely low. Further, continuous irrigation with sewage water has increased organic matter content in the first 15 cm of the surface. This increased level of humus in the soil is mainly responsible for the observed tendency for increased cation exchange capacity in sewage irrigated sandy soils. Similar results have been obtained in Tamil Nadu soils by Ramanathan *et al.* (1977) Rajarajan (1978) and Jayaraman (1981). Further, the cation exchange capacity has been observed to decrease with depth (Table 25). This may be due to the accumulation of organic matter in the surface layers as already discussed. Similar observations have been made by Siddle and Karolose (1977). Cation exchange capacity was correlated positively with available nitrogen (0.145 for T_1 and 0.687 for T_2) and also with other nutrients and clay content.

5.2.8. Exchangeable cations

Sewage irrigated soil contained higher concentration of cations such as calcium, magnesium, sodium and potassium. The higher concentration of exchangeable cations in the surface layers may be due to the large addition of cations through the sewage water. Similar results have been obtained in neighbouring Tamil Nadu Agricultural University (Jayaraman, 1981) by sewage addition.

5.2.9. Microhutrients

Total and available zinc under sewage irrigation tended to increase. Adsorptive forces for zinc was probably greater with the result that much of zinc was adsorbed in the surface layer. Longer periods of sewage irrigation, 20 years of sewage irrigation increased the available zinc content significantly. There was no perceptible difference in the lower layers with available zinc content. The increased content of available zinc in the surface soil probably resulted from zinc in sewage water. King and Morris (1972a) pointed out that when a solid sewage sludge was applied to a soil in which coastal Bermuda grass was cultivated and as the period of sewage irrigation was increased there was increase in the available as well as total zinc contents. Webber (1972), Berrow and Webber (1972) reported that the available zinc in the soil is likely to be increased with the addition of sewage.

Total and available copper contents showed distinct difference due to different periods of sewage irrigation. With regard to distribution pattern of total and available copper, there was increase in the concentration in the first two depths upto 30 cm than the lower depths. Similar findings were reported by Berrow and Webber (1972), Gaynor (1973) and Linnamann et al.(1973). In Tamil Nadu soils similar observations were reported by Jayaraman (1981). This higher concentration of total and available copper in the sewage farm soil are due to continuous use of sewage water which contains more copper. Similar view was expressed by Page (1974) who reported that the application of moist sludge at the rate of 400 tonnes/ha will add more copper. The surface horizons of sewage amended soils are further seen to be enriched with trace elements. Total copper was correlated positively with organic matter (0.949 for T_1 and 0.871 for T_2) and with available copper (0.903 for T_1 and 0.931 for T_2).

Concentration of total iron in the sewage farm soils was enhanced with increasing period of sewage irrigation. As regards depth, the concentration increased as depth increased. The available iron also increased in sewage treated soil. This is in line with the findings of Boswell (1974) who reported that 0.1 N HCl - extractable iron content of soil was increased by the addition of sewage sludge.

The greater availability of iron was recorded in the surface layers and the same decreased gradually as the depth increased. This may probably be due to the addition of organic matter. This is substantiated by the positive correlation obtained between the organic matter and available iron (0.906 for T_1 and 0.956 for T_2).

As regards the total and available manganese the trend observed was similar to that of total and available iron.

5.2.10. Heavy Metals

Sewage irrigation tended to increase the lead content, both total and available in soil. In fact the lead content was more in the surface layer. This higher concentration of total and available lead in the surface as compared to subsurface in continuously sewage irrigated soils is due to addition of lead through the sewage irrigation.

The concentration of available lead is also found to increase with both time and depth. Higher concentration was noticed in the surface which may be due to the higher content of organic matter. The decrease in pH at the lower layers may also contribute to the lesser concentration of lead in the lower layers. Chang _et_ _al_. (1984b) in their findings have reported that heavy metals (Cd, Cr, Cu, Ni, Pb) accumulated at 0-15 cm and crop removal was insignificant.

Col. Bourn P and Thornton (1978) have reported high concentration of Pb in Agricultural soils near lead mining and smelting sites. They further established a reliable background range of Pb in non-contaminated soils and a ratio of Pb in contaminated and non-contaminated top soil.

Nickel concentration is found to increase with continuous irrigation of sewage water. But the difference in period of application does not show much difference in concentration of Nickel. Available Nickel concentration is also increasing due to sewage irrigation. The total Ni is decreasing as the depth increases, but available Nickel increases as depth increases. This may be due to the higher mobility. Siddle et al. (1977) observed that heavy metals move downwards through the soil column by infiltration.

Higher concentration of cadmium has been observed in soils continuously under sewage irrigation. Further, the concentration of cadmium is higher in the surface layers where greater accumulation of organic matter also takes place due to surface irrigation. Available cadmium was found in traces only at some depth. It may be due to high mobility of the metal through infiltration and decrease in soil pH.

Mahler R.J. et al. (1980) has reported that in addition to the difference in the amount of cadmium added to soil concomittant decrease of soil pH explained the greater availability of cadmium. Chang et al. (1984) reported that heavy metals accumulated in 0-15 cm soil depth. Siddle et al. (1977) reported that Cu and Cd move downwards through infiltration.

Repeated sludge application gave a definite distribution pattern for heavy metals which was maintained even after cessation of sludge application. Mercury was found only in traces at some depth.

5.2.1. Plant analysis

Plant analysis revealed that nutrient composition of forage grass grown for different period of sewage irrigation did not differ significantly except for their Ca and Fe content. Further, accumulation of toxic heavy metals had not taken place to any perceptible level in the forage grasses. The results thus reveal that the heavy metals; though accumulated; are only in very moderate concentration. This is mainly because of the sandy nature of the soils and the intense leaching to which the soils are subjected both under irrigated and under rainfed condition.

Major nutrients

Milne and Graveland (1972) did not find any toxic symptoms for the sludge application rates upto 101 t/ha. In sludge amended soil, nitrogen has been the main limiting factor in crop growth. Phosphorus was released from the sludge in sufficient quantities for crop growth; provided nitrogen was available. The high residual P content of the soil also confirmed this observation.

Day et al.(1975) found that wheat grains grown with Municipal waste water contain more total protein. Soon et al. (1978) found that the sludge application at 1600 kg N/ha each year for 3 years produced hazardous levels of NO_3 in homegrass in the third year.

Soon et al.(1978) found that P and Mg concentration in corn grass and stover were unaffected by Ca sludge treatments whereas K concentration in corn stover and seedlings decreased by Ca sludge treatments. P, Ca and Mg concentration increased in homegrass with Ca sludge treatments.

Karleen et al.(1976) stated that Ammoniacal and nitrate nitrogen concentration was substantial throughout most of the growing season. P concentration in the drainage water was much. K concentration did not show large fluctuation.

Walsh (1977) reported that uptake of N increased with sludge application and phosphorus increased with increased sludge application.

Schofer et al.(1970) found in ear leaf of corn, higher levels of N, P, Ca and Mg in 112 t/ha of sludge application. In a lab. experiment, Subbiah and Sreeramulu (1979) concluded that sewage amendments increased the concentration as well as uptake of nutrients like P, K, Ca and Mg in sorghum seedlings than control.

Micronutrients and heavy metals

i) Micro nutrients

Walsh et al.(1977) found that concentration in snap bean leves and pods were less than 50 and 20 ppm respectively. Under conditions of severe copper toxicity, most of the excess copper accumulates in roots, very little translocated to aerial portion of the plant.

Cunnigham et al.(1974) reported that copper is about twice as toxic as zinc. Corn and Rye took up more copper from soil treated with sewage sludge supplying an equal amount of copper. Dowdy and Larson (1975) did not find any adverse effect of potato yields by amending the soil with sludge upto 450 t/ha.

Toxic heavy metals

Peterson (1978) found that in the soil at pH 5,1, six levels after sowing toxicity symptoms and yield depression were severe moderate and slight on plants grown in soils treated with 80, 40 and 20 kg Ni/ha respectively. At pH 7, 5 Ni treatments had no visible effect on the plants. Total Ni level greater than 20 gm/kg in soils of pH 5.5 or less may cause damage to several crops.

Investigation by Sabey and Mart et al.(1975) and Clapp et al.(1980) indicated that where sewage sludge is incorporated in the soil the lead contents of the above ground portion of the plant or seeds is not significantly changed. If the sludge is applied as a surface dressing where a crop is growing (Bose well, 1975), Chang et al. (1984b) there may be an increase in lead content. Lager Werff et al.(1977) suggested that incubation combined with an increase in pH from 5.1 to 6.5 by liming caused organic matter to fern or strengthen heavy metals complexes, thus protecting plants from deleterious effects of these metals.

Plant analysis

Comparison of results of plant analysis of the fodder guinea grass, grown in the area from 15 year sewage irrigated plots in comparison to 20 year sewage irrigated plots reveals certain interesting trends which have to be discussed in relation to the soil status and the nutrients.

Prolongation of irrigation from 15 year- 20 year results in marked increased in the nitrogen status of the surface soils (0-15 cm) (Table 12). This enhanced status in available nitrogen (Table 13), total nitrogen (Table 12), Nitrate nitrogen (Table 15) and Ammoniacal nitrogen (Table 14) reflects itself in the nitrogen status of the guinea grass grown in them. Thus, on the average the nitrogen status of the fodder from 12 locations each under 20 years and 15 years sewage irrigation are respectively, 2.38% nitrogen and 1.80% nitrogen respectively. The protein quality of the guinea grass from 20 year irrigated plots are then significantly higher than that of 15 year sewage irrigated plots.

In respect of the content of the other two major nutrients viz. P and K in the guinea grass harvested from 20 year and 15 year sewage irrigated plots, significant differences have not been noticed. The differences observed in the soil status in respect of P & K (Table 16 & 18) have not reflected itself in the uptake of the same nutrient by the grass grown in them.

However, both calcium and magnesium contents of the guinea grass grown in 20 year sewage irrigated plots were found to be higher than that in the 15 year sewage irrigated plots.

Micronutrients such as Zn, Cu, Fe and Mn show a 2 fold increased concentration in the guinea grass in 20 year when compared to 15 year sewage irrigated plots. From the results of the micronutrient status of healthy guinea grass reported by J.J. Mortvedt, DA.MAYS and G. OSBORN it can be seen that the levels reported here are lower.

From this, it is evident that the soils being sandy can take up considerable amount of sewage irrigation, since the major quantities of accumulated micro nutrients are lost by leaching and through infiltration during the rainy season.

Studies on the heavy metals such as nickel, lead, and cadmium show that they have also accumulated to the same extent. However, these heavy metals have not been accumulated to any toxic level. This moderate levels are maintained by the leaching and infiltration through the highly porous sandy soils of the area.

SUMMARY AND CONCLUSION

CHAPTER VI

SUMMARY AND CONCLUSION

An investigation was undertaken in the Sewage farm, Valiayathura to find out the influence on sewage additions on the physical and chemical properties of the Soil. The effect of sewage treatment on the availability and accumulation pattern of both macro and micronutrients in soil and plant nutrient content were also investigated. The important findings from the study are:

6.1. Physical parameters

1. Continuous application of sewage water over a period of 20 years decreased the bulk density upto 70 cm of soil profile.
2. Twenty years of sewage irrigation prominently improved the per cent aggregate stability and stability index.
3. Water holding capacity of the sewage irrigated soil improved.
4. Hydraulic conductivity decreased as the period of irrigation increased.
5. Clay content showed an increase in soils which received longer periods of sewage irrigation.

6.2. Chemical parameters

1. Sewage irrigation, irrespective of depth, decreased the pH of the soil.

2. Sewage irrigation tended to build up the organic matter status of the soil. The accumulation was more in surface layer

3. Sewage irrigation increased the accumulation of nitrogen particularly at the surface 0-15cm and sewage irrigation increased the available nitrogen status also.

4. Incorporation of sewage promoted the total and available phosphorus status of the soil.

5. Total potassium status of the soil irrigated by sewage water was increased.

6. An increase in total and available zinc was manifested. In the case of copper a similar increase in its total and available status was noticed.

7. Total iron and manganese concentration enhanced with time of sewage water application.

8. Sewage irrigation increased the cation exchange capacity of the soils.

9. Areas under sewage irrigation were definitely superior and having a higher concentration of cations such as calcium, magnesium, sodium and potassium.

10. The nitrate nitrogen and available iron were leached into the percolating waters as due to the sandy nature of the soil.

6.3, Plant characteristics

Plant analysis revealed that neither the nutrient elements ~~and~~ nor heavy metals reached toxic concentrations the grass grown in continuously sewage irrigated areas.

CONCLUSION

From the present study it is established that the sewage water irrigation can serve as a plant nutrient source as well as a soil ameliorant. However, care should be bestowed while utilising the sewage water for irrigation as the accumulation of zinc, iron and manganese in excess amounts in soils may retard the activity of some of the soil enzymes and cause disturbances in the process of nitrogen mineralisation etc. Continuous sewage irrigation has not enhanced significantly the heavy metal concentration in either the soil or the grass grown in them. This is mainly atributed to the sandy nature of the soil which allows percolation and leaching. Based on the above study it can be concluded that the sewage is a very good source of plant nutrients yet to be tapped fully.

CONTINUOUS USE OF MUNICIPAL SEWAGE EFFLUENTS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES

By

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ABSTRACT

An investigation was conducted on the physical and chemical properties of the sewage farm soil, Valiyathura in Trivandrum District. The sewage farm soil represents the loose sandy coastal alluvium. The area of the farm extends to 33 hectares under sewage water irrigation. From the farm area, 6 blocks were selected representing 20 years and another 6 blocks representing 15 years of sewage irrigation. A comparative study was also made by choosing an adjacent block irrigated with well water. The whole area is cultivated with Napier and guinea grass.

Profile soil samples from different depths (0-15, 16-30, 31-45, 46-70 cm) were collected for the determinationof physical parameters such as bulk density, aggregate stability, stability index, hydraulic conductivity, water holding capacity and capillary and noncapillary porosity. The soil chemical properties such as soil reaction electrical conductivity, organic matter content, total ammonical and nitrate nitrogen, total and available major nutrients, secondary nutrients, micronutrients, cation exchange capacity and exchangeable cations were also determined from the soil samples collected at different depths. The plant nutrient

contents due to 15 year and 20 year sewage irrigation were also examined.

The results indicated that application of sewage has decreased bulk density and hydraulic conductivity and the decrease was well pronounced upto the lowest depth of 10 cm. Sewage irrigation improved the per cent aggregate stability, stability index, capillary and total porosity irrespective of periods of irrigation.

Sewage irrigation decreased the soil reaction because of the accumulation of organic matter especially in the surface layer of 0-15 cm. Ammoniacal nitrogen content was in the higher order when compared to nitrate nitrogen. The CEC of sewage irrigated soils was superior to the adjacent blocks but irrigated with well water. Sewage treatments favourably increased the total and available NPK. The plant sample analysis showed negligible difference in the major nutrients, secondary nutrients and micronutrients. There was significant accumulation of heavy metals such as Pb, Hg, Cd or Ni in either the soils or the grass grown in them.

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* Originals not seen.