IMPACT ASSESSMENT AND MANAGEMENT OF PHARMACEUTICAL INDUSTRIAL WASTE FOR SUSTAINING SOIL AND ENVIRONMENTAL HEALTH

Thesis submitted in part fulfilment of the requirement for the Degree of

Doctor of Philosophy in Environmental Sciences

to the Tamil Nadu Agricultural University, Coimbatore

By

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2000

CERTIFICATE

This is to certify that the thesis entitled "**IMPACT ASSESSMENT AND MANAGEMENT OF PHARMACEUTICAL INDUSTRIAL WASTE FOR SUSTAINING ENVIRONMENTAL HEALTH**" submitted in part fulfilment of the requirements for the degree of **Doctor of Philosophy** in **Environmental Sciences** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. S.M.HAMEED SULAIMAN LEBBAI** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

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The Pharmaceutical industries are less water intensive ones. The scientific ways and means of utilizing their solid and liquid wastes in a ecofriendly manner was the main objective of this present investigation.

It was found that the treated effluent released from the Imperial Chemical Industry (ICI) Pharmaceutical unit, Chennai was colourless and odourless in nature and the pollutant load in terms of BOD and COD and various parameters were within the permissible safe limits of Tamil Nadu Pollution Control Board. The biosludge of this industry was neutral in reaction and its organic carbon content was fairly high which was biodegradable. The nitrogen content of the biosludge was 1.24 per cent and its C/N ratio was very narrow. It has appreciable quantities of Ca and Mg hence has ameliorative property too. It was found that the spent carbon and organic waste were recalcitrant in nature.

The Ecotoxicological investigations revealed that the treated effluent at different concentrations were found to be non toxic to the aquatic fauna. Bioassay of the effluent with *Bacillus* and *Aspergillus* sp. revealed that the pharmaceutical effluent did not inhibit the growth of these microbes. The test crops, Radish and Cucumber registered higher germination percentage, dry matter production and vigour index under all dilutions levels and even under undiluted situation.

The pot culture investigations with biosludge incorporation and effluent irrigation on maize revealed that the undiluted effluent supported the growth and productivity of maize as compared to 50 per cent dilution enhancing the productivity by 4.5 per cent. The incorporation of biosludge at 200 t ha^{-1} was found to be equal in effect with that of 100 per cent NPK fertilization with reference to grain yield and DMP of maize. The incorporation of biosludge @ 50 t ha^{-1} was comparable in effect with that of FYM at 12.5 t ha^{-1}. The soil pH under 100 per cent effluent irrigation was found to be increased by 0.02 units during cropping season. The EC of soil too increased by 0.05 units. The available soil N and P were significantly higher under. 100 per cent biosludge treatment. With reference to soil enzyme activity, it was found that the enzyme activity was higher under 50 per cent effluent irrigation than under 100 per cent concentration. Among the graded levels of biosludge, biosludge @ 200 t ha^{-1} registered the highest enzyme activity revealing that 200 t ha^{-1} level was favourable for good soil-biosludge-microbial interaction.

The pot culture studies with biosludge incorporation along with various amendments and effluent irrigation on maize revealed that among the amendments tried, incorporation of poultry manure or pressmud along with biosludge significantly enhanced the drymatter production, grain yield and nutrient uptake of maize. It was observed that application of gypsum with biosludge registered higher exchangeable Ca and Mg and accordingly ESP and SAR were lowered by this amendment. The poultry manure amended soil recorded higher enzyme activity with reference to amylase, invertase, catalase and phosphatase due to favourable microbial interaction.

The investigation on the use of biosorbents on sodium adsorption and consequential reduction of sodium in the effluent revealed that spent carbon of the pharmaceutical industry adsorbed the maximum Na from the effluent followed by rice husk and saw dust and the adsorption data followed the freundlich isotherm pattern of adsorption.

Thus the characterization, toxicological evaluation, pot culture experiments and adsorption studies with the treated pharmaceutical industrial effluent and that of the biosludge indicated that there are lot of potential to use the effluent as irrigation water substitute and the biosludge as organic manure and as an ameliorant for sustaining soil health and crop productivity. However their long term effect on soil-water-plant ecosystem needs to be investigated.

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(S.M.HAMEED SULAIMAN LEBBAI)

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Chapter - I

INTRODUCTION

Rapid industrialization has brought about polluted environment. Pollution is a serious problem ever since sewage and industrial effluent are disposed into water courses and on land. Solid wastes produced in these industries are not given much importance as they are either recycled, dumped or disposed off in remote places. Liquid industrial wastes are of great concern because of their harmful effects. Like many other industries the pharmaceutical industries produce a wide variety of products. These industries use both inorganic and organic compounds as raw materials.

Some of the pharmaceutical plants do not discharge liquid waste at all, some discharge very small but concentrated liquid wastes, while some others discharge highly alkaline and toxic liquid wastes. Therefore, it is very difficult to make any generalization with regard to the characteristics of the pharmaceutical plant wastes.

The volume and composition of the liquid wastes not only vary from plant to plant, but also from unit to unit in a plant, producing different types of drugs from different raw materials using varieties of processes.

The total amount of waste water generated per kg of products produced from the Imperial Chemical Industries (ICI Pharmaceuticals) Ennore, Madras was about 100 m^3 per day.

In the present study an attempt has been made to assess the impact of effluent on different communities, their reuse for irrigation and their possible impact on the soil environment with the following objectives.

1. Characterization of the pharmaceutical industrial effluent and sludge.
2. Assessment of bio-toxicity of effluent.
3. Evaluating the reuse of the effluent with appropriate amendments as irrigation water substitute for agricultural crops.
4. Monitoring the influence of the continuous effluent irrigation and sludge application on soil properties.
5. Evaluating the impact of biosludge at graded levels with organic amendments on soil-plant ecosystem.
6. Assessing the efficiency of different bio-sorbents for removal of sodium from the effluent.

REVIEW OF LITERATURE

Chapter - II
REVIEW OF LITERATURE

The literature on various aspects related to the present study is reviewed here under different topics.

2.1. Management of pharmaceutical industrial effluent

2.1.1. Characterization of effluent.

2.1.2. Impact of effluent on soil properties.

2.1.3. Impact of effluent on crop productivity.

2.2. Solid waste management

2.2.1. Characterization of solid waste.

2.2.2. Impact on soil properties.

2.2.3. Impact on crop productivity.

2.3. Combined use of amendments and effluent on soil properties and crop productivity.

2.4. Removal of toxicants using biosorbents

2.1. Management of pharmaceutical industrial effluent

2.1.1. Characteristics of pharmaceutical effluent

Pharmaceutical industry produces varied types of products. They range from vitamins, synthetic drugs to antibiotics. The raw materials used are also numerous which include both organic and inorganic compounds. Some of the pharmaceutical plants do not generate any effluent at all, while some others discharge little quantity of strong wastes and still others let out larger volumes. Due to these wide variations, a generalization cannot be drawn on the nature of effluent of pharmaceutical industry.

The characteristics of the pharmaceutical effluents are varied and complex, as larger numbers of different types of chemicals are used. The volume and composition vary from unit to unit. Approximately 1000 - 3000 l of effluent will be discharged per 100 kg of products manufactured. Hence, no specific conclusions on the characteristics of effluent can be drawn (Brown, 1951).

2.1.1.1. Physio-chemical properties

In general, pharmaceutical effluent are either highly acidic (such as from the manufacture of organic intermediates) or highly alkaline (such as from the manufacture of sulfa drugs) (Brown, 1951).

On the contrary, the paper mill effluent was alkaline in nature with high electrical conductivity (Oblisamy and Palanisami, 1991), whereas it was highly alkaline (pH 9.8 - 11.8) with electrical conductivity of 8.5 - 13.9 dSm^{-1} in dye factory effluent (Gupta and Jain, 1992). Mahimairaja *et al.* (1997) reported that the tannery effluent had pH and electrical conductivity of 3.0 - 12.0 and 11.4 - 23.0 dSm^{-1} respectively.

Generally many of the effluents contain large amount of suspended and dissolved solids which was evident from the findings of Rajannan and Oblisamy (1979) in paper and pulpmill effluent, Kothandaraman *et al.* (1976) in the textile and dyeing factory effluent and Prasad and Uninair (1994) in the case of tannery effluent.

Ng *et al.* (1989) reported that the pharmaceutical waste water has negligible quantities of suspended material. Manivasakam (1987) reported that the effluent from the general pharmaceutical antibiotic waste contained 500 - 1000 ppm of suspended solids. He also reported that the pharmaceutical industry effluent registered high BOD and COD. The BOD of general pharmaceutical antibiotic waste was reported between 1500 - 1900 ppm. The effluent of the papermill, dye factory and tannery had the BOD and COD of 310 and 1440 mgl^{-1}, 840 and 1790 mgl^{-1} and 3215 and 3350 mgl^{-1} respectively (Dave, 1982; Kothandaraman *et al.* 1976; Sujatha and Asha, 1996).

According to Ng *et al.* (1989) nitrogen (N) and phosphorus (P) were dosed into the waste water in the form of ammonium chloride and potassium dihydrogen phosphate, respectively in the ratio of 100 : 5 : 1 for BOD : N :P).

Doraisamy (1978) reported that major inorganic nutrients were found to be in less concentration in the paper mill effluents. Same results were reported by Kothandaraman *et al.* (1976) in the case of dye factory effluents. Tannery effluent had about 100 - 200 mgl^{-1} of total N and 10 - 40 mgl^{-1} of total P (Jorgensen, 1979). However, higher concentration of calcium, magnesium, sodium, sulphate and bicarbonates and chlorides were reported by many authors in different effluents such as pulp and papermill (Kannan and Oblisamy, 1992), dye factory (Ramachandran, 1994; Agarwal and Kumar, 1990 and Kothandaraman *et al.*, 1976) and tannery (Hemphill *et al.*, 1985 and Mahimairaja *et al.*, 1997).

Some of the pharmaceutical effluents also contained toxic substance like cyanides (Manivasakam, 1987). Higher concentration of phenols were reported by Kannan and Oblisamy (1992) in papermill effluent.

Kothandaraman *et al.* (1976) and Mahimairaja *et al.* (1997) reported the presence of chromium in dye factory (5 - 20 mgl^{-1}) and tannery effluent (6 - 250 mgl^{-1}).

2.1.2. Impact of effluent on soil properties

Land application of waste water has been preferred as an alternative for its disposal since soil is believed to have a capacity for receiving and decomposing the wastes and pollutants (Young *et al.*, 1981), where organic materials were stabilized through the activity of microbial flora in the soil. The removal of different constituents was accomplished by physical, chemical and microbial interaction with the soil matrix and a cover crop or plant uptake. Soils, are a product of their environment and a sustained change of their environment of adding effluent did change soil properties (George, 1984).

Continuous irrigation with pulp and paper mill effluent resulted in increased soil pH and EC (Somashekar *et al.*, 1984). Similarly the irrigation of textile effluents increased the soil pH and EC. The same results were observed in the case of tannery effluent (Mahimairaja *et al.*, 1997).

According to Rajannan and Oblisamy (1979) the available major nutrients status of soil was increased due to effluent irrigation. Similarly continuous irrigation of textile effluents increased the available nitrogen (N), phosphorus (P) and potassium (K) of the soil. George (1984) reported that there was a decrease in fertility status of soils due to irrigation of land with tannery effluents.

Higher amounts of exchangeable cations and exchangeable sodium and potassium per cent were found in soils irrigated with paper mill effluent as stated by Palaniswami (1989). This trend was also evident in soils irrigated with textile effluent (Somasekar *et al.*, 1984) and tannery effluent (Mahimairaja, 1997).

Application of paper mill waste water on land with or without treatment will lead to deleterious effect due to high sodium content (Raman and Sundaresan, 1982). On the contrary, Reddy *et al.* (1981) concluded that there was no adverse effect on the soil characteristics due to adsorption of bases including sodium in soils treated with paper industry effluent.

Sakthivel *et al.* (1998) reported that irrigation with tannery effluent increased the sodicity of the soil.

Soil enzymes secreted by micro-organisms in the soil are involved in various decomposition and chemical transformation in the soil. The measurement of enzyme activities give an index of the extent of specific biochemical processes in soil and in many situations act as indicators of soil fertility and soil health.

The possibility of degradation of waste water in soil might be due to the microbial processes and by the involvement of enzymes. Behra (1986) observed that amylase, invertase, cellulase and protease activities were significantly higher in soil incubated with waste water than in control. But after a certain period of time, the enzyme activities decreased in waste water treated soil.

Invertase is widespread in plants and microorganisms. Its activity depends upon the depth of the soil and the time of vegetative growth. The invertase activity remains at minimum both at the beginning and end of the vegetative period (Kuprevich and Sheherbakova, 1971). According to Kannan and Oblisamy (1990), there was an increase in amylase, phosphatase and dehydrogenase activities in soils as the period of effluent irrigation increase when treated with pulp and paper mill waste water.

2.1.3. Impact of effluent irrigation on crop productivity

Recycling and reuse of water in agriculture is not only helpful for conserving the plant nutrient and water for irrigation, but also offers a low cost technology for the disposal of waste water from the view point of environmental pollution abatement. Industrial waste water is tested for its suitability by both scientists and industries. So it is essential that the implications of the use of industrial effluents in the crop field and their effect be assessed before they are recommended for use in irrigation (Abdul Baki and Anderson, 1973).

Because of the gradual deterioration in the quality of irrigation water and development of salinity hazards, crops have been affected, resulting in very low yields. Hence, most of the farmers have discontinued cultivating a variety of crops and shifted to cultivate crops like maize and ragi which are moderately resistant to salinity (Teekaraman *et al.*, 1982).

Kraft pulp and papermill waste water could safely be used to grow cereal crops *viz.*, paddy, wheat, maize and barley on coarse textured soils (Stephenson and Bollen, 1949; Subrahmanyam *et al.*, 1984). Somasekar *et al.*

(1984) reported that the diluted effluent showed favourable effect on seedling growth of maize, cotton and paddy. Oblisamy and Palaniswami (1991) inferred that the combined effluent irrigation from paper factory did not affect the germination of maize and ragi, however, there was no increase in the vigour index of maize, ragi, groundnut and cotton.

Different concentrations of raw dyeing factory effluent drastically reduced the germiability of seeds and vigour index of seedlings in paddy, finger millet, cowpea, soybean and maize (Rajannan, 1987). However, Swaminathan and Vaidheeswaran (1991) found that the diluted dyeing factory effluent favoured the groundnut seed germination, hypocotyl development and seed vigour.

Application of untreated effluent having an EC of 24.5 dSm^{-1} affected the growth of maize (the test crop) whereas, dilution with water resulted in improved growth parameters *viz.*, plant height, root length, root weight, number of grains per cob and increased the grain and straw yield (Singaram *et al.*, 1992).

2.2. Solid waste management

2.2.1. Characteristics of solid waste

Disposal of solid waste has been a problem as the availability of landfill sites had diminished and requirements for making landfills environmentally acceptable have driven up costs substantially. The treatment of solid wastes before their final disposal at landfill sites consumes a great deal of energy and the residual energy in the wastes are also wasted. Land application of solid wastes provides an effective and environmentally acceptable option of waste disposal, which also recycles valuable nutrients into the soil plant system.

2.2.1.1. Nutrient content of solid wastes

Sludge contains considerable amount of macro and micro nutrients and hence, it can substitute mineral fertilizer (Johnson *et al.*, 1987). Shinde and Chakrabarti (1987) found that nitrogen supplied by sludge was higher than crop requirements, while there was deficiency in important soil nutrients like nitrogen, phosphorus and potash with application of sludge after one or two growing seasons as observed by Fresquez *et al.* (1990).

2.2.2. Impact of solid wastes on soil properties

Solid wastes had a favourable effect on soil physical conditions. Addition of sludge to soil improved the physical properties of soil (Epstein *et al.*, 1976). Wei *et al.* (1985) reported that physical characters of soil could be best maintained using small yearly application or a single large application of sludge waste at low land. Since at high level of application, soil properties were likely to be impaired due to the presence of high concentration of metals and toxic constituents (Bhoyar *et al.*, 1977).

Sludge treatment at low levels increased the available P in the soil (Mine and Graveland, 1972). Available P and pH were increased in the 0-15 cm layer of agricultural land due to sludge treatment (King *et al.*, 1974).

2.2.3. Impact of solid wastes on the crop production

Application of solid wastes at low rates could overcome the difficulty caused by heavy metal and exert a positive effect on the yield and quality of crops. Addition of organic matter could be a method for reduction of heavy metal uptake by plants and this was in part related to sorptive capacity of the organic matter (Zindahl and Foster, 1976).

The highest rate of sludge application to soil produced maximum dry matter in maize plants as reported by Rajarajan (1978).

Ritter *et al.* (1992) inferred that mixtures containing equal parts of sludge, flyash and soil gave the best result on the plant height and biomass production of oats and white cloves. Brady and Feagley (1992) indicated that the treatments receiving sludges plus twice the amount of recommended rate of fertilizers produced the highest yield of Bermuda grass (*Cyanodon dactylon*) on mine spoiled land.

2.3. Combined use of effluents and amendments of soil properties and plant growth

Use of industrial effluents with amendments in combinations might provide a soil with enough nutrients and with better physical and microbiological environment, thus improving the soil fertility.

Pushpavalli (1990) suggested that the adverse effects of the effluent from paper factory could be alleviated by resorting to the application of N, P, K along with organic and inorganic amendments such as pressmud, farm yard manure (FYM) and gypsum, of which pressmud proved to be the best, based on its manurial value. Application of 100 per cent fertilizer plus 20 tonnes of gypsum ha^{-1} treatment along with effluent irrigation recorded better growth of crop, higher dry matter production and nutrient uptake of sugarcane and the gypsum application was found to increase the availability of micronutrients in the soil (Palaniswami, 1989). The 100 per cent effluent irrigation plus 20 tonnes gypsum ha^{-1} treatment recorded higher germination, shoot length, dry weight of sugarcane and increase in the content and uptake of N, P, K, Mn and Zn and also the uptake of Fe and Cu (Oblisami and Palanisami, 1991).

Better growth of brinjal, onion, sunflower, banana and pulpwood such as Eucalyptus were observed when paper mill sludge was applied along with effluent irrigation (Veena *et al.*, 1992).

The adverse effects of the effluent from textile and dye factory could be alleviated by resorting to the application of N, P, and K along with organic and inorganic amendments such as pressmud and farm yard manure. Pressmud application to the soils affected with dyeing factory effluent increased the availability of N, P and K (Sandhya Rani and Ramaswami, 1996).

2.4. Removal of toxicants using biosorbents

Conventional techniques for reduction and removal of salts and toxic substances from waste water like chemical precipitation and advanced waste water treatment like ion exchange, reverse osmosis and electrolysis need high capital cost and incurring expenses such as high technical equipment and chemicals, which are not suitable for small scale industries (Chand *et al.*, 1994). Though many researchers proposed the use of microorganisms in the removal of toxic materials and salts from various industrial waste water, these microorganisms would be killed at higher concentration. Therefore, the present study was undertaken with a view to assess the potential use of alternative cheap materials for the removal of sodium which is the major toxic constituent from the pharmaceutical effluent.

Certain chemical or biological materials due to their unique characteristics have the potential to adsorb the soluble salts and heavy metals from the effluent. In this regard, activated carbon (Sharma, 1993) was found to be a better alternative, but its high capital cost and less availability makes its use less attractive. Huang and Wu (1975) reported the use of calcinated coke as an alternative to activated carbon. The use of sawdust (Srinivastava *et al.*, 1986), coconut-shell based activated carbon (Alaerts *et al.*, 1989) and coconut husk fibre (Tan *et al.*, 1993) in removing the toxic pollutants was also reported. Sharma and Foster (1994) reported that the cellulosic materials like sphagnum peat moss, compost and leaf mould were found to be very effective in adsorbing the toxic heavy metals.

MATERIALS AND METHODS

Chapter - III

MATERIALS AND METHODS

The present investigation on the effect of pharmaceutical industrial effluent and solid wastes on soil characteristics and crop productivity involving laboratory analysis and field investigations were carried out in the Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore during 1997-2000.

The details regarding collection of effluent, soil, plant and solid waste samples, the pot culture experiments carried out and the analytical methods followed are presented hereunder.

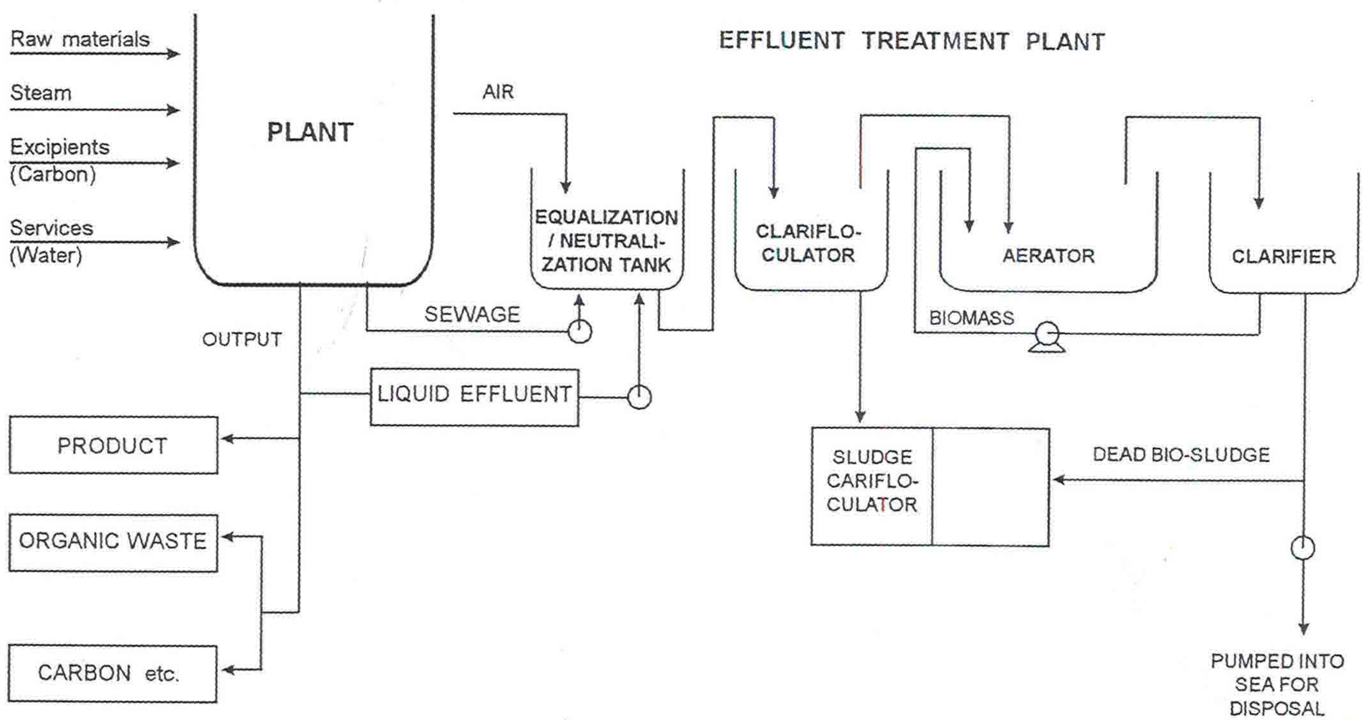
Phase I	Analysis of the pharmaceutical effluent and solid wastes
Phase II	Evaluating the biological toxicity of the effluent for plant, animal and microbial systems.
Phase III	Field trials to study the effect of effluent irrigation with organic amendments and solid waste on soil physico-chemical and biochemical properties and on the crop growth.
Phase IV	Evaluating the potential use of some biosorbents for sodium removal through batch and column experiments.

3.1. Phase I

3.1.1. Collection of effluent samples

The treated effluent samples were obtained from Imperial Chemical Industries (ICI Pharmaceuticals), Ennore, Madras (Fig.3.1). The samples

FIG.3.1. SCHEMATIC DIAGRAM OF WASTE GENERATION AND EFFLUENT TREATMENT PLANT AT ICI - PHARMA, ENNORE



were collected and studied for their chemical and biochemical properties. Samples for microbiological examinations were collected in sterilized bottles. The sampling bottles closed with a ground glass stopper was relaxed by an intervening strip of paper to prevent breakage of the bottle during sterilization. The stopper and neck of the bottles were protected by covering with aluminium foil and sterilized in an autoclave at 20 psi for 15 min. The bottles were opened only at the time of sampling.

The samples for the analysis of dissolved oxygen (DO) were added with one ml. of manganese sulphate solution and one ml. of alkaline potassium iodide solution as per standard procedure. Samples for the determination of biochemical oxygen demand (BOD) were preserved by adding five ml. of washed chloroform (Chloroform and distilled water were taken in a separating funnel, shaken well and the water layer was discarded) per litre of the sample (Anon, 1965).

3.1.1.1. Analysis of effluent samples

The physical, chemical and biological characteristics of the effluent samples were analysed as per the methods detailed in standard methods for the examination of water and waste water (Anon, 1965).

3.1.1.2. Physical properties

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

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

Initial characteristics of soil

Soil properties	Unit	Potting media
Mechanical analysis		
Clay	Per cent	28.18
Silt	Per cent	8.53
Fine sand	Per cent	25.52
Coarse sand	Per cent	36.65
Bulk density	g ml^{-1}	1.21
Particle density	g ml^{-1}	2.12
Percent pore space	per cent	44
Maximum water holding capacity	per cent	45.3
Soil reaction		7.80
Electrical conductivity	d Sm^{-1}	0.38
CEC	c mol(p+)kg^{-1}	17.5
Total N	per cent	0.035
Total P	per cent	0.034
Total K	per cent	0.023
Organic carbon	per cent	0.49
C/N ratio		14.1
Available N	m Eq $100g^{-1}$	89.6
Available P	m Eq $100g^{-1}$	7.4
Available K	m Eq $100g^{-1}$	245
Exchangeable Ca	c mol(p+)kg^{-1}	18.1
Exchangeable Mg	c mol(p+)kg^{-1}	7.4
Exchangeable Na	c mol(p+)kg^{-1}	4.11
Exchangeable K	c mol(p+)kg^{-1}	0.325
Water extractable Na	m Eq $100g^{-1}$	0.305
Water extractable K	m Eq $100g^{-1}$	0.076
Water extractable Ca	m Eq $100g^{-1}$	0.88
Water extractable Mg	m Eq $100g^{-1}$	0.42
Water extractable Co_3	m Eq $100g^{-1}$	-
Water extractable HCO_3	m Eq $100g^{-1}$	1.113
Water extractable Cl	m Eq $100g^{-1}$	0.441
Water extractable SO_4	m Eq $100g^{-1}$	0.084

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

iv. Total solids : A known quantity of the effluent was evaporated, dried at 105°C to a constant weight.

3.1.1.3. Chemical properties

	Parameter	Method	Author (s)
1.	pH	Measured using a digital pH meter with glass electrode	Jackson (1973)
2.	Electrical conductivity (EC)	Measured using a conductivity bridge (CM 180 Elico conductivity meter)	Jackson (1967)
3.	Organic carbon (OC)	Wet digestion method of Walkley and Black (1934)	Piper (1966)
4.	Dissolved oxygen (DO)	Azide modification iodimetric method	Anonymous (1965)
5.	Biochemical oxygen demand (BOD)	Incubation method	Anonymous (1965)
6.	Chemical oxygen demand (COD)	Refluxed for 2 hours and titrated against 0.5 N FAS using ferroin indicator	Anonymous (1965)
7.	Carbonate	Titrating with 0.01 N H_2SO_4 using phenol-phthalein indicator	Piper (1966)

8.	Bicarbonate	Titrating with 0.01 N H_2SO_4 using methyl orange indicator	Piper (1966)
9.	Ammoniacal nitrogen	Semi automatic Kjeldhal apparatus	Jackson (1973)
10.	Phosphorus	Vanado molybdate yellow colour method	Jackson (1973)
11.	Potassium	Flame photometer	Jackson (1967)
12.	Calcium	Versenate titration	Jackson (1967)
13.	Magnesium	Versenate titration method	Jackson (1967)
14.	Sodium	Flame photometer	Jackson (1967)
15.	Chloride	Mohr's method	Jackson (1967)
16.	Sulphate	Turbidimetric method using spectrophotometer at 420 nm	Jackson (1967)
17.	Exchangeable sodium percent (ESP)	$\frac{Na^+}{Na^+ + Ca^{++} + Mg^{++} + K^+} \times 100$	Eaton (1950)
18.	Sodium Adsorption Ratio (SAR)	$\frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+} /2}}$	Chopra and Kanwar (1982)
19.	Residual sodium carbonate (RSC)	$(CO_3 + HCO_3)$ - $(Ca+Mg)$	Eaton (1950)
20.	Potential salinity (PS)	$Cl_2 + 1/2\ SO_4$	Doneen (1965)

3.1.1.4. Biological properties

The population of different groups of microorganisms were enumerated in the effluent samples using the standard serial dilution plating technique (Jenson, 1968).

Sl. No.	Organism	Dilution Factor	Media used	Author (s)
1.	Bacteria	10^{-6}	Nutrient agar	Waksman and Fred (1922)
2.	Fungi	10^{-4}	Martin rose bengal agar	Waksman and Fred (1922)
3.	Actinomycetes	10^{-3}	Ken Knight's agar	Waksman and Fred (1922)

3.1.2. Analysis of solid waste samples

3.1.2.1. Chemical properties

S. No.	Particulars	Remarks	Author
1.	pH	Soil water suspension of 1 : 2	Jackson (1973)
2.	EC	Soil water suspension of 1 : 2	Jackson (1973)
3.	Organic carbon	Wet digestion	Piper (1966)
4.	Total N	Diacid extract	Jackson (1973)
5.	Total P	Triacid extract	Jackson (1973)
6.	Total K	Triacid extract	Jackson (1973)
7.	Total Ca, Mg and Na	Triacid extract	Jackson (1973)

3.1.3. Evaluation of biodegradability of biosludge spent carbon and organic waste of pharmaceutical industry through soil microbial activity

Parameter	Method	Author
CO_2 evolution (Incubated for 36 hrs)	Excess KOH was neutralised with 0.1 N HCl using phenol - phthalein indicator	Pramer and Schmidt (1966)

3.1.3.1. Experiment I Bio sludge No. of replications - 3.

Treatment details

	Treatments	Composition
1.	T1 (Control)	100% soil
2.	T2	2.5 % biosludge
3.	T3	5 % biosludge
4.	T4	7.5 % biosludge
5.	T5	10 % biosludge
6.	T6	100 % biosludge
7.	T7	100 % biosludge + 2% dextrose

Weight of the sample = 200 g/treatment

3.1.3.2. Experiment II Organic waste and spent carbon No. of replication-3

	Treatments	Soil (g) : Sludge (%)
1.	T1 (Control)	100 % soil
2.	T2	5% organic waste
3.	T3	10% organic waste

4.	T4	100% organic waste
5.	T5	100% organic waste + 2% dextrose
6.	T6	5% spent carbon
7.	T7	10% spent carbon
8.	T8	100% spent carbon (50 g)
9.	T9	100% spent carbon (50 g) + 2% dextrose + 1% ammonium chloride

Weight of the sample = 200 g/treatment

3.2. Phase II

3.2.1. Germination studies with pharmaceutical effluent

The influence of treated pharmaceutical effluent was studied for its toxicity on germination and vigour index of sensitive crops *viz.,* Radish and cucumber.

The experiment was conducted in a completely randomised block design with cups of 200 g capacity. Seeds were sown at the rate of 10 per cup and the treatments were replicated three times. The cups were irrigated with treated effluent at different dilutions. Observations for the percentage of germination, shoot length and root length were made on the 10th day of sowing.

Treatment details

T1 - 100% siruvani water (Control)

T2 - 25% effluent + 75% tap water

T3 - 50% effluent + 50% tap water

T4 - 75% effluent + 25% tap water

T5 - 100% effluent

3.2.1.1. Vigour index (VI)

The vigour index was calculated by using the formula suggested by Abdul Baki and Anderson (1973)

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

3.2.2. Bioassay of pharmaceutical effluent on aquatic fauna

3.2.2.1. Mosquito larvae

Twenty five numbers of mosquito larvae were let into the 100 ml of the effluent as per the treatment and the survival count was taken over a period of 10 days. The controls were maintained under identical condition in the tap water.

Treatments			Replication - 3
T1	-	Tap water (Control)	
T2	-	25% concentration	
T3	-	50% concentration	
T4	-	75% concentration	
T5	-	100% concentration	

3.2.2.2. Fingerlings

Healthy fingerlings were collected from local pond and they were maintained in the trough and acclimated for a week in the laboratory. The fingerlings (25 nos.) were exposed to basins containing 2 litres of effluent each with different concentrations over a period of 96 hrs. and the survival count was taken every 24 hrs. The controls were maintained under identical conditions in the tap water.

Treatments			Replication - 3
T1	-	Tap water (Control)	
T2	-	25% concentration	
T3	-	50% concentration	
T4	-	75% concentration	
T5	-	100% concentration	

3.2.3. Bioassay of microbes with the pharmaceutical effluent

The pharmaceutical effluent was added with glucose as carbon (C) source at the rate of 0.5 per cent and ammonium chloride (NH_4Cl) as nitrogen (N) source at the rate of 0.1 per cent to assess the toxicity of the effluent on microbial systems. The organisms used for the toxicity assessment were *Bacillus* sp., *Aspergillus* sp. and Actizyme (A commercial preparation of microbial enzyme from a consortium of bacteria available in the form of pellets).

Hundred millilitre of the pharmaceutical effluent was taken in 250 ml conical flask and was steam sterilized for about 30 minutes. Ten per cent of each culture was inoculated and incubated at shaking conditions. The growth rate for *Bacillus* and actizyme were taken from the per cent light transmitted and mycelial dry weight for *Aspergillus* sp. was taken at different days of intervals *viz.*, immediately after inoculation, 1st, 3rd and 7th day.

Treatments

T1 (Control)	-	100 ml effluent without inoculum
T2	-	100 ml effluent + inoculum alone
T3	-	100 ml effluent + carbon source + inoculum

T4	-	100 ml effluent + nitrogen source + inoculum
T5	-	100 ml effluent + carbon and nitrogen source + inoculum

3.3. Phase III

3.3.1. Pot culture experiment

Pot culture trial was conducted in the Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore to assess the effect of pharmaceutical effluent and biosludge on soil and crop growth.

Experiment I - Graded levels of biosludge and effluent irrigation on crop productivity

Experimental details

The pots were filled up with the soil mixed with the biosludge of ICI pharmaceutical at graded levels of its application as per the following treatments.

Treatments

T_1	-	Control (NPK)
T_2	-	Sludge @ 50 t ha^{-1} (S_{50})
T_3	-	Sludge @ 100 t ha^{-1} (S_{100})
T_4	-	Sludge @ 200 t ha^{-1} (S_{200})
T_5	-	Sludge @ 400 t ha^{-1} (S_{400})
T_6	-	Soil + Sludge : 1 : 1 ratio (50% S)
T_7	-	100% Sludge (100% S)

Irrigation sources

I_1	-	ICI effluent (50 %)
I_2	-	ICI effluent (100 %)

Experimental Design	:	FCRD	Replications	:	3
Test crop	:	Maize			
Date of sowing	:	21.6.99	Date of harvest	:	21.9.99

The pots were sown with 5 seeds of maize and it was thinned on the 5th day after germination, leaving only 3 healthy seedlings per pot. The experimental crop was protected with a net until the crop was 20 days old. Stagewise plant and soil samples were taken at vegetative stage, flowering stage and at harvest and the biometrics and soil nutrients were evaluated.

3.3.2. Experiment II - Biosludge with amendments under effluent irrigation on crop productivity

Experimental details

A potculture experiment was conducted with the ICI biosludge applied at 50 t ha^{-1} being mixed with the garden soil of TNAU campus. A total of 7 kg was filled up in each pot. Gypsum, pressmud, poultry manure and flyash were added as amendments as per the treatment details furnished below :

Treatments

T_1	-	Control (NPK)
T_2	-	FYM @ 12.5 t ha^{-1} (FYM)
T_3	-	Sludge @ 50 t ha^{-1} (S_{50})
T_4	-	T3 + Gypsum @ 2 t ha^{-1} (S_{50}+ GYP)
T_5	-	T3 + Pressmud @ 10 t ha^{-1} (S_{50}+ Pr.M)
T_6	-	T3 + Poultry manure @ 5 t ha^{-1} (S_{50}+ Pl.M)
T_7	-	T3 + Flyash @ 20 t ha^{-1} (S_{50}+ FA)

Irrigation water sources

I_1 - Fresh water (Siruvani water)

I_2 - ICI effluent (100 %)

Replications	: 3	Experimental Design	: FCRD
Test crop	: Maize		
Date of sowing	: 18.6.99	Date of harvest	: 18.9.99

Stagewise plant and soil samples were taken at vegetative stage, flowering stage and at harvest and the biometric characters and soil nutrients were evaluated.

3.3.3. Residue crop

After the harvest of maize, the residual crop was raised with that of blackgram (CO-5) in the pots. The seeds of blackgram at the rate of five seeds / pot were dibbled in the soil. After germination only three healthy plants were maintained in each pot upto the harvesting stage. Biometric observations on plant height, biomass and crop yield were recorded at harvest.

3.3.4. Plant analysis in maize and blackgram

3.3.4.1. Preparation of plant samples for analysis

The plant samples were collected at different stages of crop growth. Collected samples were air dried for two days, then oven dried at 60°C, powdered in a Wiley Mill and used for the analysis.

3.3.4.2. Chemical analysis for the plant sample

S. No.	Parameters	Extract	Method	Author(s)
1.	Total N	Diacid	Micro Kjeldhal	Jackson (1973)
2.	Total P	Triacid	Vanadomolybdo phosphoric yellow colour method	Jackson (1967)
3.	Total K	Triacid	Neutralised with ammonia and estimated using flame photometer	Jackson (1973)
4.	Total Ca	Triacid	Versenate method	Jackson (1967)
5.	Total Mg	Triacid	Versenate method	Jackson (1967)
6.	Total Na	Triacid	Flame photometer	Jackson (1967)

3.3.5. Soil Analysis

3.3.5.1. Collection of soil sample

The soil samples were collected at different stages of crop growth and analysed.

3.3.5.2. Preparation of soil samples

The soil samples were dried in the shade for two days, powdered gently with a wooden mallet and sieved through a 2.0 mm sieve. The material which passed through the sieve was taken for analysis.

3.3.5.3. Analysis of soil samples

The physical properties of the soil samples were analysed at initial stage before sowing of maize. The chemical and biochemical characteristics of the soil samples were analysed at all stages of crop growth.

3.3.5.3.1. Physical properties

Parameters	Author(s)
i. Water holding capacity	Chopra and Kanwar (1982)
ii. Bulk density	Chopra and Kanwar (1982)
iii. Particle density	Chopra and Kanwar (1982)
iv. Per cent pore space	Chopra and Kanwar (1982)

3.3.5.3.2. Chemical properties

	Parameters	Method	Author (s)
1.	pH	Soil : water suspension of 1 : 2.5	Jackson (1973)
2.	EC	Soil : water suspension of 1 : 2.5	Jackson (1973)
3.	Organic carbon	Wet digestion method of Walkley and Black (1934)	Piper (1966)
4.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
5.	Available P	Photoelectric colorimeter at 660 nm	Olsen *et al.* (1954)
6.	Available K	Ammonium acetate extract (Flame photometer)	Stanford and English (1948)
7.	Exchangeable Na	Ammonium acetate extract (Flame photometer)	Jackson (1973)

8.	Exchangeable Ca	Versenate titration method	Jackson (1973)
9.	Exchangeable Mg	Versenate titration method	Jackson (1973)
10.	Exchangeable K	Ammonium acetate extract (Flame photometer)	Jackson (1973)
11.	Exchangeable sodium per cent (ESP)	$\frac{Na^+}{Na^+ + Ca^{++} + Mg^{++} + K^+} \times 100$	Saxena *et al.* (1978)
12.	Sodium adsorption ratio (SAR)	$\frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}/2}}$	Chopra and Kanwar (1982)

3.3.5.3.3. Enzyme activity

	Enzyme	Substrate	Method	Author(s)
i.	Amylase	1 ml of 8% soluble starch	Reducing sugar estimates using spectrophotometer at 600 nm	Ross (1966)
ii.	Invertase	1 ml of 4% sucrose	Reducing sugar estimates using spectrophotometer at 600 nm	Galstyan (1965)
iii.	Catalase	5 ml of 20% hydrogen peroxide	Titrating against 0.025 N potassium permanganate till pink colour appears	Skujins (1976)
iv.	Phosphatase	1 ml of paranitro phenol phosphate	Using spectrophotometer at 405 nm	Tabatabai and Bremner (1969)

3.4. Phase IV

A series of laboratory experiments, consisting of batch and column studies were conducted to evaluate the potential use of cheaply available biosorbents for reducing the Na concentration from the pharmaceutical effluent. The materials used and methods adopted are described here.

Adsorbents - Treatments

A range of low cost, naturally occurring and cheaply available biological wastes (Biosorbents) were used and examined for their efficiency in removing the Na from the effluent. Soils of different bulk densities were used for the leachate studies. Some important characteristics of the adsorbents are presented hereunder.

Some important characteristics of adsorbents and soils used in this experiment

	Adsorbents	pH	EC (dSm^{-1})	Na (ppm)
1.	Sawdust	6.10	0.65	24.0
2.	Rice husk	6.57	0.83	31.0
3.	Spent carbon	6.25	0.82	54.2
4.	Vermiculite	8.80	0.10	18.1
	Soils			
1.	Black soil	8.37	0.13	22.5
2.	Red soil	8.41	0.10	17.0
3.	Mixed Red & Black Soil	8.36	0.12	20.1
4.	Sandy soil (ICI campus soil)	7.67	0.07	12.0

3.4.1. Adsorption of sodium

3.4.1.1. Batch experiments

To study the adsorption potential of each adsorbent and soil and examine the effects of effluent concentrations and pH on adsorption, this experiment was conducted. These are basic and preliminary trials before running the column experiments.

Fifty millilitre each of the treated effluent at varying concentrations of Na *viz.*, 0, 20, 40, 80 and 100 ppm were introduced into bottles containing 2 g of each adsorbent and soil. The initial pH of the solution was measured using pH meter and the reaction mixture was shaken thoroughly for 1 hr and filtered (Whatman No.1). The extract was then analysed for pH and Na concentration.

3.4.1.2. Column experiments I : (Adsorption studies)

This column experiment was conducted to evaluate the effectiveness of selected adsorbents from the batch experiments *viz.*, rice husk, sawdust and spent carbon in reducing the Na concentration from the effluent.

The column experiment was carried out using locally fabricated glass columns of 50 cm height and 5 cm internal diameter. The wire mesh (0.1 mm) and filter paper (Whatman No.1) were placed at the bottom of each column as shown in the figures (Fig. 3.2 and Plate 3.1). The head space of the column was closed using a rubber cork with a glass tube insert for air outlet. The bottom of the column had a closed end. The outlet was connected to a conical flask for the collection of treated effluent.

In the setup, two columns for each adsorbent were gently packed to a height of 30 cm with sawdust, rice husk and spent carbon. Due to variations in the texture of the materials the column had varied bulk densities. The pharmaceutical effluent with the Na concentration of 520 ppm and distilled

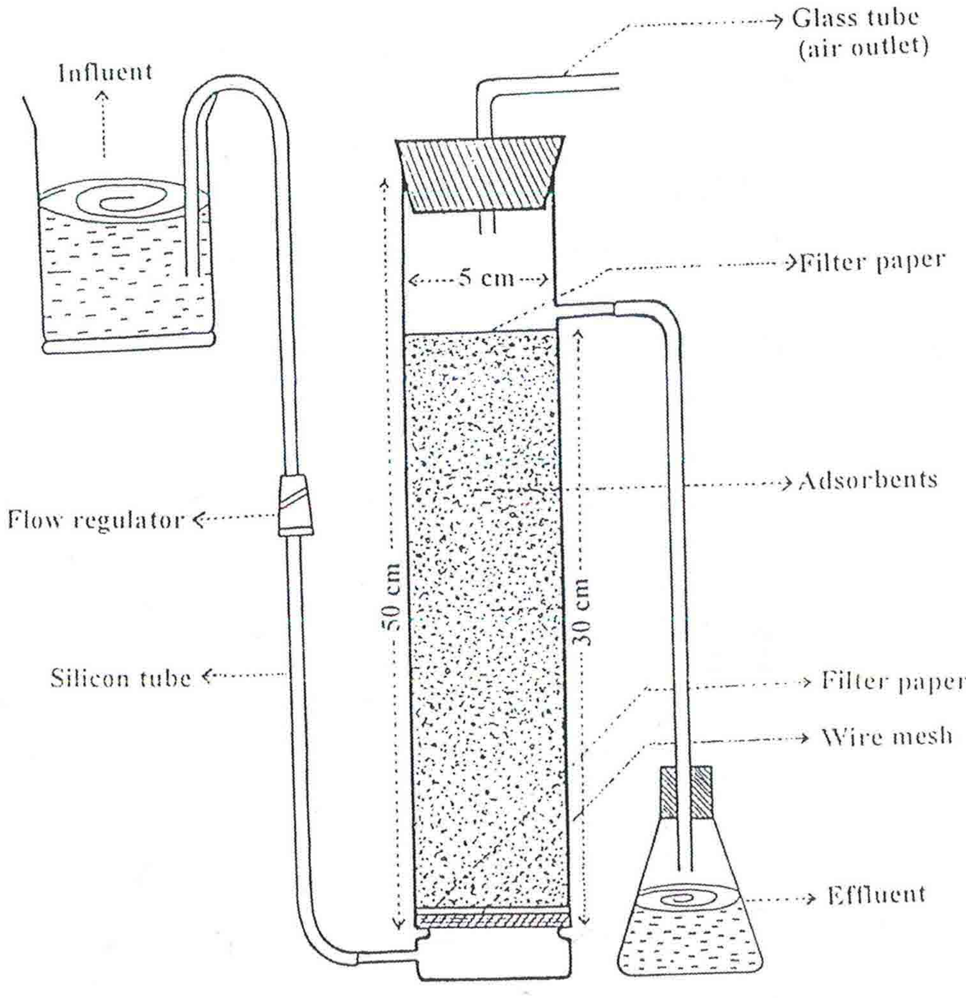


Fig. 3.2 : Schematic set-up of the glass columns used in adsorption study

Plate 3.1. Treatment of effluent by biosorbents - General view of column experiment

water (Control) from two reservoirs were allowed to pass through the column upwardly against the gravity at average flow rate ranging between 2.1 to 2.5 ml per minute. The flow rate was maintained throughout the experiment.

The treated effluent was collected in bottles for periods of 5, 12, 24, 48 and 72 hrs and then Na concentration was determined.

The columns used in the first set of experiment.

1. 100 % sawdust (165 g) column.
2. 100 % rice husk (260 g) column
3. 100 % spent carbon (234 g) column.

3.4.1.3. Adsorption isotherm

The adsorption capacities of different materials at varying concentrations were examined using the following linearized Freundlich equation :

$$\log (X/M) = \log K + 1/n \log Ce.$$

where,

X/M = amount of Na adsorbed per unit mass of adsorbent, mg g^{-1}

Ce = equilibrium concentration of aqueous solution, mg l^{-1}

K = Constant related to adsorption capacity

l/n = Constant related to adsorption intensity

3.5. Statistical analysis

The data obtained from all the laboratory and pot culture experiments were statistically scrutinized using the standard statistical tests (Snedecor and Cochran, 1973) and interpretation were drawn based on them.

EXPERIMENTAL RESULTS

Chapter – IV

EXPERIMENTAL RESULTS

4.1. Characterization

4.1.1. Characteristics of pharmaceutical effluent (Table 4.1)

The physico-chemical and biological characteristics of the pharmaceutical effluent are presented in Table 4.1.

The effluent was colourless and odourless with a pH of 7.4 and EC of 1.7 to 2.8 dSm^{-1}. The TSS and TDS of the effluent were 13 - 38 mg l^{-1} and 1100 mg l^{-1} respectively. The BOD measured at 5 days incubation and COD of the effluent ranged between 15 to 50 and 130 - 280 mg l^{-1} respectively with a DO content of 4.8 mg l^{-1}. The organic carbon content of the effluent was 0.48 per cent. The nutrient content of the effluent was 29.3, 1.4 and 25 mg l^{-1} of NH_4-N, P and K respectively. The Ca, Mg and Na contents were 90, 44 and 500 mg l^{-1} respectively. The carbonate, bicarbonate, chloride and sulphate contents of the effluent were 18, 146, 312 and 700 mg l^{-1} respectively.

The microbial population of the effluent was not appreciable. The bacterial population was 8 x 10^6 ml^{-1} and that of actinomycetes 9 x 10^3 ml^{-1}. The fungal population was completely absent.

4.2. Characteristics of the solid wastes (Table 4.2)

The solid wastes such as biosludge of ICI, pressmud, poultry manure, flyash, gypsum used for this study as amendments were analysed and the results are presented in Table 4.2.

Table 4.1 Physico-chemical and biological characteristics of the pharmaceutical effluent

Properties	Unit	
Colour		Colour less
Suspended solids	mg l^{-1}	13 - 38
Dissolved solids	mg l^{-1}	1100
Total solids	mg l^{-1}	1138
pH		7.4
Electrical conductivity	dSm^{-1}	1.7 to 2.8
Organic carbon	per cent	0.48
Dissolved oxygen	mg l^{-1}	4.8
Biochemical oxygen demand	mg l^{-1}	15.-50
Chemical oxygen demand	mg l^{-1}	130-280
Carbonate	mg l^{-1}	18
Bicarbonate	mg l^{-1}	146
Ammoniacal nitrogen	mg l^{-1}	29.3
Phosphorus	mg l^{-1}	1.4
Potassium	mg l^{-1}	25
Calcium	mg l^{-1}	90
Magnesium	mg l^{-1}	44
Sodium	mg l^{-1}	500
Chloride	mg l^{-1}	312
Sulphate	mg l^{-1}	700
Exchangeable sodium percent	per cent	75.87
Sodium adsorption ratio		61.09
Bacteria	$x10^6$ ml l^{-1}	8
Actinomycetes	$x10^3$ ml l^{-1}	9
Fungi	$x10^4$ ml l^{-1}	Nil

Table 4.2 Characteristics of solid wastes

	Pressmud	Poultry manure	Flyash (Mettur)	Biosludge	FYM	Gypsum
pH	7.29	6.2	8.2	6.8	7.6	10.04
EC (dSm^{-1})	3.15	3.3	1.10	1.85	0.69	1.96
Organic carbon (%)	28.31	27.00	0.08	11.80	25.8	0.96
Total N (%)	1.16	3.2	0.01	1.24	1.10	0.0
Total P (%)	1.26	1.9	0.19	0.38	0.60	0.11
Total K (%)	0.63	1.4	0.32	0.051	0.84	-
Total Ca (%)	4.29	3.8	4.2	2.8	0.96	16.60
Total Mg (%)	1.04	0.8	1.3	1.6	0.32	3.42
Total Na (%)	0.08	0.17	0.06	0.95	0.01	0.05

The biosludge, FYM, pressmud and poultry manure showed a neutral pH with EC values of 1.85, 0.69, 3.15 and 3.30 dSm^{-1} respectively. The flyash and gypsum were alkaline in nature with EC of 1.10 and 1.96 dSm^{-1} respectively. The organic carbon contents were more or less the same (25.80 to 28.31%) in the FYM, pressmud and poultry manure except flyash (0.08%) gypsum (0.96%) and Bio sludge (11.80%). The FYM, pressmud and poultry manure had comparatively higher nutrient status than flyash, gypsum and biosludge. The Ca, Mg and Na contents of all the solid wastes were comparatively higher than FYM.

4.3. Evaluation of biodegradability of biosludge through soil microbial activity (Table 4.3)

The CO_2 evolution was the highest in 100 per cent biosludge plus carbon source added treatment (4.31 g/m^2) followed by 100 per cent biosludge alone (3.85 g/m^2). Among the different doses of biosludge application, 2.5, 5.0, 7.5 and 10.0 per cent, biosludge applied treatments, the maximum CO_2 evolution was seen in the 5 per cent biosludge treatment (3.71 g/m2) followed by equal evolution of 3.63 g/m^2 of CO_2 both in 7.5 and 10.0 per cent biosludge. The least evolution was in control without any biosludge addition (1.81 g/m^2).

4.4. Evaluation of biodegradability of spent carbon and organic waste through microbial activity (Table 4.4)

The CO_2 evolution was maximum in control (1.83 g/m^2) followed by 10 per cent spent carbon (1.82 g/m^2) and 5 per cent spent carbon (1.80 g/m^2) which were on par with each other. Lower CO_2 evolution was observed in the organic waste applied treatment in which the lowest was observed in organic waste plus carbon source added treatment (0.29 g/m^2) followed by organic

Table 4.3. CO_2 evolved in biosludge through soil microbial activity (g/m^2)

	Treatments	CO_2 evolved (g/m^2)
1.	T1 (Control) 100% soil	1.81
2.	T2 2.5 % biosludge	2.72
3.	T3 5 % biosludge	3.71
4.	T4 7.5 % biosludge	3.63
5.	T5 10 % biosludge	3.63
6.	T6 100 % biosludge	3.85
7.	T7 100 % biosludge + 2% dextrose	4.31
	CD 0.184	

Weight of the sample = 200 g/treatment

Table 4.4. CO_2 evolved in organic waste and spent carbon through microbial activity (g/m^2)

	Treatments	CO_2 evolved (g/m^2)
1.	T1 (Control) 100 % soil	1.83
2.	T2 5% organic waste	0.47
3.	T3 10% organic waste	0.48
4.	T4 100% organic waste	0.38
5.	T5 100% organic waste + 2% dextrose	0.29
6.	T6 5% spent carbon	1.80
7.	T7 10% spent carbon	1.82
8.	T8 100% spent carbon (50 g)	0.72
9.	T9 100% spent carbon (50 g) + 2% dextrose + 1% ammonium chloride	0.80
	CD 0.0595	

Weight of the sample = 200 g/treatment

waste alone treatment (0.38 g/m^2) which were on par with 5 per cent (0.47 g/m^2) and 10 per cent (0.48 g/m^2) organic waste added treatments.

4.5. Toxicity of pharmaceutical effluent on seed germination

4.5.1. Radish (Table 4.5a)

The difference among mean percentage of seed germination, shoot and root length, dry matter production and vigour index differed significantly for different effluent concentrations. The highest germination per cent was recorded in 50 per cent (90.0%) while the lowest in 100 per cent effluent concentration. The highest shoot length (10.5 cm) was recorded in 100 per cent effluent concentration and the lowest (8.8 cm) in tap water. With regard to root length, the highest value was recorded in tap water irrigation (7.5 cm) and least was in the 100 per cent effluent concentration (5.8 cm). Regarding the dry matter production and vigour index, the maximum (0.514 g and 4.626 respectively) was recorded in 50 per cent effluent concentration and it differed significantly from the rest and least vigour index was in 100 per cent effluent irrigation (2.584).

4.5.2. Cucumber (Table 4.5b)

The difference among the mean percentage of seed germination, shoot and root length, dry matter production and vigour index differed significantly for various effluent concentrations. The highest germination per cent was recorded in 100 per cent (8.6 %) while the lowest in tap water irrigation. The highest shoot length was recorded in the same treatment (14.8 cm). But the highest root length (6.7 cm) was in 75 per cent effluent concentration which was on par with other concentrations. Regarding the dry matter production and vigour index, the maximum (0.71 g and 5.68 respectively) were recorded

Table 4.5a Biotoxicity of pharmaceutical effluent on Radish

Treatments	Germination percentage	Shoot Length(cm)	Root length(cm)	Drymatter production(g)	Vigour Index
T_1	8.3	8.8	7.5	0.374	3.10
T_2	8.0	9.8	6.8	0.350	2.80
T_3	9.0	9.0	6.1	0.514	4.63
T_4	8.0	9.9	6.2	0.416	3.33
T_5	7.3	10.5	5.8	0.354	2.58
Mean	8.12	9.60	6.48	0.401	3.29
CD (p=0.05)	**0.445**	**0.525**	**0.355**	**0.022**	**0.184**

(Data represents the mean of three replications)

Table 4.5b Biotoxicity of pharmaceutical effluent on Cucumber

Treatments	Germination percentage	Shoot Length(cm)	Root length(cm)	Drymatter production(g)	Vigour Index
T_1	6.7	13.5	5.7	0.588	3.94
T_2	7.3	14.1	6.3	0.537	3.92
T_3	8.0	13.3	6.5	0.710	5.68
T_4	7.6	13.9	6.7	0.618	4.70
T_5	8.6	14.8	6.3	0.463	3.98
Mean	7.7	13.92	6.3	0.580	4.446
CD (p=0.05)	**0.423**	**0.760**	**0.344**	**0.035**	**0.253**

(Data represents the mean of three replications) in the 50 per cent effluent concentration and minimum (0.463 g and 3.981) were recorded in the 100 per cent effluent concentration.

4.6. Impact of effluent on survivability of aquatic fauna (Table 4.6)

The mosquito larva and fingerlings were found to survive under all dilutions of the effluent over a period of 10 days and 96 hrs. respectively.

4.7. Microbial assessment of toxicity of the pharmaceutical effluent

4.7.1. *Bacillus* sp. (Table 4.7a)

Toxicity of the effluent has been assessed by observing the relative growth of introduced microorganism.

When the effluent was amended with carbon + nitrogen source and inoculated with *Bacillus* sp. (T_5) has recorded maximum growth (38.76% of light transmitted) of organism at all stages of observation reflecting the least toxicity of the effluent. Effluent amended with carbon + inoculated *Bacillus* sp. (T_3) also stimulated profuse microbial biomass (40.58% light transmitted) and this was second in order. It is of interest to know that the nitrogen amendments to effluent (T_4) did not reduce the toxicity much (52.55% light transmitted).

4.7.2. Actizyme (Table 4.7b)

Toxicity of the effluent was assessed by observing the relative growth of introduced microbial enzyme from a consortia of bacteria (Actizyme).

The effluent amended with carbon + nitrogen source and inoculated with Actizyme (T_5) has recorded maximum growth (46.04 per cent light transmitted) of bacterial consortia at critical stages of observation followed by

Table 4.6 Impact of effluent on survivability of aquatic fauna

Treatments	Survival of mosquito larvae and finger lings								
	Mosquito larvae(counts)					Fingerlings(counts)			
	Days					Hours			
	2	4	6	8	10	24	48	72	96
Control (Tap water)	25	25	25	25	25	25	25	25	25
25% Effluent	25	25	25	25	25	25	25	25	25
50% Effluent	25	25	25	25	25	25	25	25	25
75% Effluent	25	25	25	25	25	25	25	25	25
100% Effluent	25	25	25	25	25	25	25	25	25

Treatment differences were statistically not significant

Table 4.7a Microbial assessment of toxicity of the pharmaceutical effluent (*Bacillus* sp)

Treatments	D1 (Before inoculation)	D2 (First day of inoculation)	D3 (Third day of inoculation)	D4 (seventh day of inoculation)	Mean
T1 (Control) Effluent	100.00	100.00	100.00	100.00	**100.00**
T2 (Control+ Inoculant)	97.83	46.70	28.90	26.03	**49.87**
T3 (Control+Carbon +Inoculant)	97.37	41.37	16.43	7.17	**40.58**
T4 (Control+Nitrogen +Inoculam)	98.50	50.00	31.80	29.90	**52.55**
T5 (Control+Carbon +Nitrogen +Inoculam)	99.30	38.10	12.77	4.87	**38.76**
Mean	**98.60**	**52.23**	**37.98**	**33.59**	**56.35**

CD(p=0.05)

D	T	D x T
0.558	0.624	1.248

(Data represents per cent light transmitted at 420 nm)

Table 4.7b Microbial assessment of toxicity of the pharmaceutical effluent (Actizyme)

Treatments	D1 (Before inoculation)	D2 (First day of inoculation)	D3 (Third day of inoculation)	D4 (seventh day of inoculation)	Mean
T1 (Control) Effluent	100.00	100.00	100.00	100.00	**100.00**
T2 (Control+ Inoculant)	98.53	67.43	56.90	51.73	**68.65**
T3 (Control+Carbon +Inoculant)	99.00	59.70	53.50	6.53	**54.68**
T4 (Control+Nitrogen +Inoculam)	98.40	62.73	60.40	55.43	**69.24**
T5 (Control+Carbon +Nitrogen +Inoculam)	98.93	63.53	13.37	8.33	**46.04**
Mean	**98.97**	**70.68**	**56.83**	**44.41**	**67.72**

CD(p=0.05)

D	T	D x T
0.636	0.711	1.422

(Data represents per cent light transmitted at 420 nm) carbon + inoculum (T_3) of Actizyme (54.68% light transmitted). Nitrogen amended to the effluent (T_4) did not reduce the toxicity much (69.24% light transmitted).

4.7.3. *Aspergillus* sp. (Table 4.7c)

Toxicity of the effluent was assessed by observing the relative growth of introduced microorganism.

The effluent amended with carbon + nitrogen source and inoculated with *Aspergillus* sp. (T_5) has recorded maximum biomass production on dry weight basis (1.756 g/100 ml) followed by carbon + inoculum of *Aspergillus* sp. (T_3) with the second next value of 1.516 per cent light transmitted. Among the treatments. nitrogen amended effluent (T_4) showed least biomass production (1.273 g/100 ml) next to control (T_1) with biomass production of 0.841 g/100 ml).

4.8. Pot culture experiment

4.8.1. Influence of graded levels of biosludge under effluent irrigation on crop growth and soil characteristics

4.8.1.1. Growth characters

4.8.1.1.1. Plant height (Table 4.8)

The plants were taller under 50 per cent effluent irrigation compared to that of 100 per cent effluent irrigation at all the critical stages of plant growth.

Regarding the different levels of biosludge application, 400 t ha^{-1} (T_5) recorded taller plants at vegetative stage (79.05 cm), flowering stage (127.50

Table 4.7c Microbial assessment of toxicity of the pharmaceutical effluent (*Aspergillus* sp.)

Treatments	D1 (Before inoculation)	D2 (First day of inoculation)	D3 (Third day of inoculation)	D4 (seventh day of inoculation)	Mean
T1 (Control) Effluent	0.747	0.863	0.893	0.860	**0.841**
T2 (Control +Inoculant)	0.760	0.867	1.280	2.200	**1.277**
T3 (Control+Carbon +Inoculant)	0.747	0.827	1.570	2.920	**1.516**
T4 (Control+Nitrogen +Inoculam)	0.757	0.853	1.173	2.307	**1.273**
T5 (Control+Carbon +Nitrogen +Inoculam)	0.747	0.857	1.793	3.627	**1.756**
Mean	**0.751**	**0.853**	**1.342**	**2.383**	**1.332**

CD(p=0.05)

D	T	D x T
0.065	0.073	0.145

[Data represents mycelial biomass on dry weight basis (g/100 ml of effluent)]

Table 4.8 Effect of effluent and bio-sludge on plant height (cm) of maize

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	85.00	79.00	**82.00**	121.00	124.00	**122.50**	149.00	143.00	**146.00**	118.33	115.33	**116.83**
T_2 (S_{50})	74.00	68.00	**71.00**	118.00	114.00	**116.00**	131.00	125.00	**128.00**	107.67	102.33	**105.00**
T_3 (S_{100})	75.00	70.00	**72.50**	120.00	117.00	**118.50**	136.00	129.00	**132.50**	110.33	105.33	**107.83**
T_4 (S_{200})	79.00	77.00	**78.00**	126.00	122.00	**124.00**	147.00	141.00	**144.00**	117.33	113.33	**115.33**
T_5 (S_{400})	81.10	77.00	**79.05**	132.00	123.00	**127.50**	150.00	147.00	**148.50**	121.03	115.67	**118.35**
T_6 (50% S)	63.00	59.00	**61.00**	105.00	94.00	**99.50**	120.00	109.00	**114.50**	96.00	87.33	**91.67**
T_7 (100%S)	52.00	45.00	**48.50**	81.00	75.00	**78.00**	109.00	88.00	**98.50**	80.67	69.33	**75.00**
Mean	**72.73**	**67.86**	**70.29**	**114.71**	**109.86**	**112.29**	**134.57**	**126.00**	**130.29**	**107.34**	**101.24**	**104.29**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
1.500	2.292	1.225	3.968	2.122	3.241	5.611

cm) and the harvest stage (148.50 cm) followed by 200 t ha^{-1} of biosludge which were on par with each other.

Of all the stages, the biosludge @ 400 t ha^{-1} recorded taller plants (118.35 cm) followed by NPK (116.83 cm) and biosludge @ 200 t ha^{-1} (115.33 cm) which were on par with each other. The lower plant height was recorded in 100 per cent biosludge (75.00 cm).

4.8.1.2. Dry matter production (DMP) (Table 4.9)

The increased DMP was recorded under 50 per cent effluent irrigation compared to that of 100 per cent effluent irrigation at all the stages of crop growth.

Regarding the different levels of biosludge application, T_5 with 400 t ha^{-1} recorded the maximum DMP at vegetative (11.35 g pot^{-1}), flowering (33.90 g pot^{-1}) and harvesting stage (51.35 g pot^{-1}) followed by NPK and 200 t h^{-1} biosludge applied treatment which were on par with each other.

Pooling all the stages together, the biosludge @ 400 t ha^{-1} recorded the maximum DMP (32.90 g pot^{-1}) followed by NPK (31.79 g pot^{-1}) and biosludge @ 200 t ha^{-1} (30.99 g pot^{-1}) which were on par with each other. The DMP was minimum at 100 per cent biosludge application (14.53 g pot^{-1}) which was significantly different from rest of the treatments.

4.8.2. Grain yield (Table 4.10)

The grain yield of maize ranged from 35.30 to 59.60 g pot^{-1}. Fifty per cent effluent irrigation registered higher grain yield (52.49 g pot^{-1}) compared

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Table 4.9 **Effect of bio-sludge and effluent on dry matter production (g pot^{-1}) of maize**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	12.30	11.87	**12.08**	33.70	33.00	**33.35**	50.80	49.10	**49.95**	32.27	31.32	**31.79**
T_2 (S_{50})	10.20	9.70	**9.95**	31.40	30.90	**31.15**	47.10	46.20	**46.65**	29.57	28.93	**29.25**
T_3 (S_{100})	10.50	10.00	**10.25**	32.00	31.70	**31.85**	48.30	47.50	**47.90**	30.27	29.73	**30.00**
T_4 (S_{200})	11.50	11.20	**11.35**	32.30	32.53	**32.42**	50.13	48.30	**49.22**	31.31	30.68	**30.99**
T_5 (S_{400})	11.80	10.90	**11.35**	34.20	33.60	**33.90**	52.50	50.20	**51.35**	32.83	31.57	**32.20**
T_6 (50% S)	7.50	7.10	**7.30**	18.30	17.50	**17.90**	40.10	38.60	**39.35**	21.97	21.07	**21.52**
T_7 (100%S)	5.20	4.20	**4.70**	12.10	10.80	**11.45**	29.00	25.90	**27.45**	15.43	13.63	**14.53**
Mean	**9.86**	**9.28**	**9.57**	**27.71**	**27.15**	**27.43**	**45.42**	**43.69**	**44.55**	**27.66**	**26.70**	**27.18**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.402	0.614	0.328	1.063	0.568	0.868	1.503

Table 4.10 Effect of effluent and biosludge on grain yield (g pot^{-1}) of maize

Treatments	Grain Yield (g pot^{-1})		
	I_1	I_2	MEAN
T_1 (Control)	59.60	58.13	58.87
T_2 (S_{50})	53.40	52.27	52.83
T_3 (S_{100})	54.50	53.50	54.00
T_4 (S_{200})	57.93	56.80	57.37
T_5 (S_{400})	56.90	53.30	55.10
T_6 (50% S)	42.20	41.50	42.85
T_7 (100%S)	40.87	35.30	38.08
Mean	52.49	50.11	51.30

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

	I	T	I X T
CD (p=0.05)	0.911	1.705	2.412

to 100 per cent effluent irrigation (50.11 g pot^{-1}). The interaction between 100 per cent biosludge and 100 per cent effluent recorded the lowest grain yield (35.30 g pot^{-1}). The highest yield was recorded in NPK fertilizer application under 50 per cent effluent irrigation (58.13 g pot^{-1})

Among the over all treatment effect, the mean yield was the highest (58.87 g pot^{-1}) under NPK fertilizer application and it was on par with biosludge @ 200 t ha^{-1} (57.37 g pot^{-1}). The lowest grain yield of 38.08 g pot^{-1} was recorded in the 100 per cent biosludge application which was significantly different from other treatments.

4.8.3. Plant nutrient uptake

4.8.3.1. Uptake by stalk

4.8.3.1.1. Nitrogen uptake (Table 4.11)

The uptake of nitrogen ranged from 0.117g pot^{-1} to 0.477 g pot^{-1}. The mean uptake of nitrogen during vegetative, flowering and harvesting stages of the crop were 0.157, 0.381 and 0.221 g pot^{-1} respectively. It showed an increasing trend of nitrogen uptake upto flowering stage and then showed a declining trend as the crop approached harvesting stage.

Irrespective of the stages of crop growth, the nature of irrigation water had an impact on nitrogen uptake. In general, 50 per cent effluent had higher nitrogen uptake than 100 per cent effluent. The overall mean nitrogen uptake in the aforesaid sources of irrigation were 0.256 and 0.248 g pot^{-1} respectively. The highest overall mean nitrogen uptake of 0.310 g pot^{-1} was recorded in treatment T_5 (biosludge @ 400t. ha^{-1}) under 50 per cent effluent irrigation.

Table 4.11 Effect of effluent and biosludge on nitrogen uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.207	0.200	**0.203**	0.467	0.457	**0.462**	0.250	0.250	**0.250**	0.308	0.302	**0.305**
T_2 (S_{50})	0.163	0.160	**0.162**	0.430	0.423	**0.427**	0.223	0.227	**0.225**	0.272	0.270	**0.271**
T_3 (S_{100})	0.170	0.160	**0.165**	0.440	0.440	**0.440**	0.230	0.220	**0.225**	0.280	0.273	**0.277**
T_4 (S_{200})	0.187	0.177	**0.182**	0.450	0.453	**0.452**	0.243	0.230	**0.237**	0.293	0.287	**0.290**
T_5 (S_{400})	0.190	0.183	**0.187**	0.477	0.463	**0.470**	0.263	0.250	**0.257**	0.310	0.299	**0.304**
T_6 (50% S)	0.127	0.117	**0.123**	0.253	0.243	**0.248**	0.203	0.200	**0.202**	0.194	0.187	**0.191**
T_7 (100%S)	0.087	0.070	**0.078**	0.170	0.150	**0.160**	0.147	0.137	**0.142**	0.134	0.119	**0.127**
Mean	**0.161**	**0.152**	**0.157**	**0.383**	**0.376**	**0.381**	**0.223**	**0.216**	**0.221**	**0.256**	**0.248**	**0.252**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.010	0.005	0.018	0.009	0.014	0.025

Irrespective of the sources of irrigation, the highest mean uptake of nitrogen was noticed under NPK treatment (0.305 g pot^{-1}) and it was on par with effects exerted by biosludge @ 200t ha^{-1} (0.290 g pot^{-1}). The least nitrogen uptake was observed in 100 per cent biosludge (0.127 g pot^{-1}).

4.8.3.1.2. Phosphorus uptake (4.12)

The phosphorus uptake ranged between 0.033 g pot^{-1} and 0.183 g pot^{-1}. The mean uptake of phosphorus during vegetative, flowering and harvesting stages showed an early increasing trend, till flowering, which later declined as the crop approached harvesting stage. During these stages, the uptake was 0.075, 0.144 and 0.073 g pot^{-1} respectively.

Irrespective of stages of crop growth, 50 per cent effluent irrigation increased the phosphorus uptake except with biosludge application @ 100 t ha^{-1}. With 50 per cent effluent as source of irrigation, the treatment having NPK application had registered highest phosphorus uptake (0.124 g pot^{-1}) and the lowest was in 100 per cent biosludge application. In 100 per cent effluent irrigation, the uptake of phosphorus was the highest in NPK application (0.121 g pot^{-1}) and it was the least in 100 per cent biosludge treatment (0.047 g pot^{-1}).

The overall mean uptake of phosphorus was maximum under NPK application (0.128 g pot^{-1}) and it was on par with application of biosludge @ 200t ha^{-1} (0.112 g pot^{-1}) and 400t ha^{-1} (0.113 g pot^{-1}). The least uptake was noticed in treatment having 100 per cent biosludge application (0.049 g pot^{-1}).

4.8.3.1.3. Potassium uptake (Table 4.13)

The uptake of potassium under any treatment laid between 0.100 g pot^{-1} and 0.767 g pot^{-1}. The mean uptake of potassium showed an increasing trend throughout the crop stages *viz.,* vegetative, flowering and

Table 4.12 Effect of effluent and bio-sludge on phosphorus uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.100	0.097	**0.098**	0.183	0.180	**0.182**	0.090	0.087	**0.088**	0.124	0.121	**0.123**
T_2 (S_{50})	0.080	0.073	**0.077**	0.160	0.160	**0.160**	0.073	0.077	**0.075**	0.104	0.103	**0.104**
T_3 (S_{100})	0.083	0.077	**0.080**	0.170	0.170	**0.170**	0.060	0.083	**0.072**	0.104	0.110	**0.107**
T_4 (S_{200})	0.090	0.087	**0.088**	0.170	0.167	**0.168**	0.083	0.077	**0.080**	0.114	0.110	**0.112**
T_5 (S_{400})	0.093	0.083	**0.088**	0.177	0.173	**0.175**	0.097	0.083	**0.090**	0.122	0.113	**0.118**
T_6 (50% S)	0.057	0.053	**0.055**	0.093	0.087	**0.090**	0.067	0.057	**0.062**	0.072	0.066	**0.069**
T_7 (100%S)	0.040	0.033	**0.037**	0.067	0.060	**0.063**	0.047	0.047	**0.047**	0.051	0.047	**0.049**
Mean	**0.078**	**0.072**	**0.075**	**0.146**	**0.142**	**0.144**	**0.074**	**0.073**	**0.073**	**0.099**	**0.096**	**0.097**

CD (p=0.05)

I_1 -50% Effluent **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.003	0.005	0.003	0.009	0.005	0.007	0.012

Table 4.13 **Effect of effluent and bio-sludge on potassium uptake (g pot^{-1}) by maize stalk**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.260	0.250	**0.255**	0.467	0.460	**0.463**	0.753	0.733	**0.743**	0.493	0.481	**0.487**
T_2 (S_{50})	0.210	0.197	**0.203**	0.437	0.420	**0.428**	0.690	0.683	**0.687**	0.446	0.433	**0.439**
T_3 (S_{100})	0.220	0.207	**0.213**	0.433	0.430	**0.432**	0.730	0.697	**0.713**	0.461	0.444	**0.453**
T_4 (S_{200})	0.237	0.230	**0.233**	0.433	0.437	**0.435**	0.730	0.700	**0.715**	0.467	0.456	**0.461**
T_5 (S_{400})	0.240	0.220	**0.230**	0.457	0.453	**0.455**	0.767	0.730	**0.748**	0.488	0.468	**0.478**
T_6 (50% S)	0.153	0.150	**0.152**	0.247	0.240	**0.243**	0.593	0.563	**0.578**	0.331	0.318	**0.324**
T_7 (100%S)	0.107	0.100	**0.103**	0.160	0.143	**0.152**	0.417	0.376	**0.397**	0.228	0.207	**0.217**
Mean	**0.204**	**0.193**	**0.199**	**0.376**	**0.369**	**0.373**	**0.669**	**0.641**	**0.655**	**0.416**	**0.401**	**0.409**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.011	0.006	0.019	0.010	0.016	0.027

harvesting with values of 0.199, 0.373 and 0.655 g pot^{-1} respectively. As in the previous case, irrigation with 50 per cent effluent had increased the mean uptake of potassium (0.416 g pot^{-1}) than 100 per cent effluent (0.401 g pot^{-1})

The overall mean uptake of potassium was the highest in NPK application (0.487g pot^{-1}) and was on par with application of biosludge @ 200 and 400 t ha^{-1} (0.461 and 0.478 g pot^{-1} respectively). The lowest uptake of potassium (0.217 g pot^{-1}) was noticed in 100 per cent biosludge application.

4.8.3.1.4. Calcium uptake (Table 4.14)

The uptake of calcium by maize crop laid between 0.010 and 0.217 g pot^{-1}. The uptake of calcium showed an increasing trend throughout the growth of the crop. The mean uptake of calcium by maize during vegetative, flowering and harvesting stages were 0.027, 0.089 and 0.171 g pot^{-1} respectively.

Irrespective of stages of crop growth effluent irrigation had significant effect on the calcium uptake. Th mean uptake of calcium under 50 per cent effluent irrigation was 0.098 g pot^{-1} and it was 0.094 g pot^{-1} in 100 per cent effluent irrigated crop.

Regardless of the crop stages of growth, the overall mean uptake of calcium was the highest in biosludge application @ 100t ha^{-1} (0.184 g pot^{-1}). It significantly differed from other treatments. The least uptake of calcium was noticed in NPK fertilizer application that registered 0.059 g pot^{-1}.

Table 4.14 Effect of effluent and bio-sludge on calcium uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.033	0.030	**0.032**	0.100	0.040	**0.070**	0.030	0.120	**0.075**	0.054	0.063	**0.059**
T_2 (S_{50})	0.030	0.030	**0.030**	0.100	0.097	**0.098**	0.197	0.193	**0.195**	0.109	0.107	**0.108**
T_3 (S_{100})	0.033	0.030	**0.032**	0.100	0.090	**0.095**	0.187	0.183	**0.185**	0.107	0.101	**0.184**
T_4 (S_{200})	0.033	0.030	**0.032**	0.100	0.097	**0.098**	0.187	0.190	**0.188**	0.107	0.106	**0.106**
T_5 (S_{400})	0.030	0.030	**0.030**	0.100	0.100	**0.100**	0.203	0.200	**0.202**	0.111	0.110	**0.111**
T_6 (50% S)	0.023	0.020	**0.022**	0.110	0.107	**0.108**	0.217	0.207	**0.212**	0.117	0.111	**0.114**
T_7 (100%S)	0.017	0.010	**0.013**	0.060	0.057	**0.058**	0.167	0.110	**0.138**	0.081	0.059	**0.070**
Mean	**0.029**	**0.026**	**0.027**	**0.096**	**0.084**	**0.089**	**0.171**	**0.172**	**0.171**	**0.098**	**0.094**	**0.099**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.004	0.006	0.003	0.011	0.006	0.009	0.016

4.8.3.1.5. Magnesium uptake (Table 4.15)

The uptake of magnesium ranged from 0.010 g pot^{-1} to 0.077 g pot^{-1}. The mean uptake of magnesium during vegetative, flowering and harvesting stages of the crop were 0.015 g pot^{-1}, 0.059 g pot^{-1} and 0.05 g pot^{-1} respectively. It showed an increasing trend of magnesium uptake upto flowering stage and then showed a declining trend as the crop approached harvesting stage.

Irrespective of the stages of crop growth, effluent irrigation had an impact on magnesium uptake. In general, the irrigation with 50 per cent effluent had higher nitrogen uptake than 100 per cent effluent. The overall mean magnesium uptake in the aforesaid sources of irrigation were 0.042 g pot^{-1} and 0.041g pot^{-1} respectively. The highest magnesium uptake of 0.077 g pot^{-1} was recorded in biosludge @ 400 t ha^{-1} under 50 per cent effluent irrigation.

4.8.3.1.6. Sodium uptake (Table 4.16)

The uptake of sodium ranged between 0.009 g pot^{-1} at vegetative storage and 0.086 g pot^{-1} at the harvesting stage both under 100 per cent effluent irrigation. The uptake of sodium showed increasing trend throughout the crop growth *viz.*, vegetative, flowering and harvesting with values of 0.012, 0.036 and 0.070 g pot^{-1} respectively.

Regardless of the stages of plant growth, irrigation with 100 per cent effluent had increased the uptake of sodium (0.041 g pot^{-1}) than 50 per cent effluent (0.038 g pot^{-1}).

Table 4.15 Effect of effluent and bio-sludge on magnesium uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.017	0.017	**0.017**	0.067	0.067	**0.067**	0.050	0.053	**0.052**	0.044	0.046	**0.045**
T_2 (S_{50})	0.017	0.013	**0.015**	0.063	0.067	**0.065**	0.050	0.050	**0.050**	0.043	0.043	**0.043**
T_3 (S_{100})	0.020	0.017	**0.018**	0.070	0.067	**0.068**	0.060	0.053	**0.057**	0.050	0.046	**0.048**
T_4 (S_{200})	0.020	0.017	**0.018**	0.067	0.073	**0.070**	0.053	0.057	**0.055**	0.047	0.049	**0.048**
T_5 (S_{400})	0.020	0.013	**0.017**	0.077	0.073	**0.075**	0.057	0.057	**0.057**	0.051	0.048	**0.049**
T_6 (50% S)	0.010	0.010	**0.010**	0.040	0.040	**0.040**	0.047	0.050	**0.048**	0.032	0.033	**0.033**
T_7 (100%S)	0.010	0.013	**0.012**	0.030	0.027	**0.028**	0.033	0.030	**0.032**	0.024	0.023	**0.024**
Mean	**0.016**	**0.014**	**0.015**	**0.059**	**0.059**	**0.059**	**0.050**	**0.050**	**0.050**	**0.042**	**0.041**	**0.041**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.002	0.003	0.002	0.006	0.003	0.005	0.008

Table 4.16 Effect of effluent and biosludge on sodium uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	**Mean**	I_1	I_2	**Mean**	I_1	I_2	**Mean**	I_1	I_2	**Mean**
T_1 (Control)	0.012	0.012	**0.012**	0.035	0.036	**0.035**	0.061	0.070	**0.066**	0.036	0.039	**0.038**
T_2 (S_{50})	0.011	0.010	**0.011**	0.025	0.035	**0.030**	0.057	0.065	**0.061**	0.031	0.037	**0.034**
T_3 (S_{100})	0.011	0.010	**0.011**	0.036	0.038	**0.037**	0.062	0.068	**0.065**	0.036	0.039	**0.038**
T_4 (S_{200})	0.014	0.013	**0.014**	0.042	0.045	**0.044**	0.070	0.076	**0.073**	0.042	0.045	**0.043**
T_5 (S_{400})	0.015	0.016	**0.016**	0.049	0.051	**0.050**	0.080	0.086	**0.083**	0.048	0.051	**0.049**
T_6 (50% S)	0.013	0.012	**0.013**	0.034	0.034	**0.034**	0.078	0.082	**0.080**	0.042	0.043	**0.042**
T_7 (100%S)	0.009	0.009	**0.010**	0.026	0.024	**0.025**	0.065	0.062	**0.064**	0.034	0.032	**0.033**
Mean	**0.011**	**0.012**	**0.012**	**0.035**	**0.038**	**0.036**	**0.068**	**0.073**	**0.070**	**0.038**	**0.041**	**0.040**

CD (p=0.05)

I_1 -50% Effluent **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.002	0.002	0.001	0.002	0.004	0.003	0.006

The overall mean uptake of sodium was the highest (0.049 g pot^{-1}) in biosludge @ 400 t ha^{-1}. The least uptake was noticed in the biosludge @ 50 t ha^{-1} (0.034 g pot^{-1}) which was on par with NPK treatment (0.038 g pot^{-1}) and biosludge @ 100 t ha^{-1} (0.038 g pot^{-1}).

4.8.3.2. Uptake by grain

4.8.3.2.1. Nitrogen uptake (Table 4.17)

The uptake of nitrogen by maize grain ranged between 0.553 g pot^{-1} and 0.917 g pot^{-1}. Both the highest and lowest limits of nitrogen uptake were registered under 100 per cent effluent irrigation; the former was in NPK fertilizer application and the latter was in 100 per cent biosludge application. In most of the treatments, 50 per cent effluent irrigation had increased the nitrogen uptake except under NPK fertilizer treatment.

Regardless of the nature of irrigation, NPK application had increased the nitrogen uptake (0.915 g pot^{-1}) and excelled all other levels of application of biosludge but it was on par with application of biosludge @ 200 t ha^{-1} and 400 t ha^{-1} that had the mean nitrogen uptake of 0.898 g pot^{-1} and 0.867 g pot^{-1} respectively. The 100 per cent biosludge application had registered the lowest nitrogen uptake of 0.598 g pot^{-1}.

4.8.3.2.2. Phosphorus uptake (Table 4.17)

The uptake of phosphorus by maize grain ranged from 0.100 g pot^{-1} to 0.170 g pot^{-1}. Except the treatments namely, application of biosludge @ 50 t ha^{-1} and application of sludge and soil in equal proportion all other treatments registered higher uptake of magnesium under 50 per cent effluent.

Table 4.17 Effect of effluent and bio-sludge on nitrogen, phosphorus and potassium uptake (g pot^{-1}) by maize grain

Treatments	N uptake			P uptake			K uptake		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.913	0.917	**0.915**	0.170	0.163	**0.167**	0.427	0.420	**0.423**
T_2 (S_{50})	0.847	0.810	**0.828**	0.137	0.137	**0.137**	0.360	0.357	**0.358**
T_3 (S_{100})	0.860	0.830	**0.845**	0.137	0.133	**0.135**	0.363	0.353	**0.358**
T_4 (S_{200})	0.903	0.893	**0.898**	0.150	0.147	**0.148**	0.393	0.387	**0.390**
T_5 (S_{400})	0.890	0.843	**0.867**	0.150	0.147	**0.148**	0.387	0.360	**0.373**
T_6 (50% S)	0.690	0.657	**0.673**	0.117	0.117	**0.117**	0.303	0.287	**0.295**
T_7 (100%S)	0.643	0.553	**0.598**	0.110	0.100	**0.105**	0.283	0.250	**0.267**
Mean	**0.821**	**0.786**	**0.804**	**0.139**	**0.134**	**0.137**	**0.361**	**0.345**	**0.352**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

	I	T	I X T	I	T	I X T	I	T	I X T
	0.021	0.039	0.055	0.004	0.006	0.010	0.011	0.020	0.029

The mean uptake of phosphorus under 50 per cent effluent irrigation was 0.139 g pot^{-1} whereas it was 0.134 g pot^{-1} under 100 per cent effluent irrigation.

Regardless of the nature of irrigation, NPK fertilizer application had the highest mean phosphorus uptake (0.167 g pot^{-1}) and it differed significantly from other treatments. The least mean phosphorus uptake of 0.105 g pot^{-1} was registered in 100 per cent biosludge application, followed by 50 per cent biosludge application (0.117 g pot^{-1}).

4.8.3.2.3. Potassium uptake (Table 4.17)

The potassium uptake ranged between 0.250 g pot^{-1} and 0.427g pot^{-1} with a mean uptake of 0.352 g pot^{-1}. In general, irrigation with 50 per cent effluent had increased the potassium uptake (0.361 g pot^{-1}) than 100 per cent effluent irrigation (0.345 g pot^{-1}).

It was noticed that regardless of the nature of irrigation, the recommended dose of NPK fertilizer had registered the highest potassium uptake (0.423 g pot^{-1}) than other treatments. Application of 100 per cent biosludge had resulted in the least uptake of potassium (0.267 g pot^{-1}) and it was on par with 50 per cent application of biosludge that registered a potassium uptake of 0.295 g pot^{-1}.

4.8.3.2.4. Calcium uptake (4.18)

The calcium uptake ranged between 0.083 g pot^{-1} and 0.123 g pot^{-1}. In general, irrigation with 50 per cent effluent had registered higher mean

***Table 4.18* Effect of effluent and bio-sludge on calcium, magnesium and sodium uptake (g pot^{-1}) by maize grain**

Treatments	Ca uptake			Mg uptake			Na uptake		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.120	0.113	**0.117**	0.107	0.110	**0.108**	0.011	0.012	**0.012**
T_2 (S_{50})	0.110	0.110	**0.110**	0.100	0.090	**0.095**	0.010	0.011	**0.011**
T_3 (S_{100})	0.113	0.110	**0.112**	0.107	0.100	**0.103**	0.011	0.012	**0.012**
T_4 (S_{200})	0.123	0.117	**0.120**	0.107	0.097	**0.102**	0.012	0.013	**0.013**
T_5 (S_{400})	0.117	0.117	**0.117**	0.110	0.093	**0.102**	0.012	0.013	**0.013**
T_6 (50% S)	0.097	0.093	**0.095**	0.090	0.083	**0.087**	0.009	0.009	**0.009**
T_7 (100%S)	0.090	0.083	**0.087**	0.080	0.073	**0.077**	0.012	0.007	**0.010**
Mean	**0.110**	**0.106**	**0.108**	**0.100**	**0.092**	**0.096**	**0.011**	**0.011**	**0.011**

CD (p=0.05) **I_1-50% Effluent** **I_2 - 100% Effluent**

I	T	I X T	I	T	I X T	I	T	I X T
0.005	0.010	0.014	0.005	0.009	0.013	0.0003	0.0006	0.0008

calcium uptake (0.110g pot^{-1}) than 100 per cent effluent irrigation (0.106 g pot^{-1}).

Regardless of nature of irrigation, application of biosludge @ 200 t ha^{-1} had registered the highest mean calcium uptake (0.120 g pot^{-1}) and it was on par with application of biosludge @ 400 t ha^{-1}, 100 t ha^{-1}, 50 t ha^{-1}, and NPK application (0.117g pot^{-1}, 0.112 g pot^{-1}, 0.110 g pot^{-1} and 0.117 g pot^{-1} respectively). The least mean calcium uptake of 0.087 g pot^{-1} was found in 100 per cent biosludge application, that was on par with 50 per cent biosludge application.

4.8.3.2.5. Magnesium uptake (Table 4.18)

The uptake of magnesium by maize grain ranged from 0.073 g pot^{-1} to 0.110 g pot^{-1}. Except under NPK fertilizer application, 50 per cent effluent irrigation had registered higher uptake of magnesium. The uptake of magnesium in 50 per cent effluent irrigation was 0.100 g pot^{-1} where as it was 0.092 g pot^{-1} in 100 per cent effluent irrigation.

Regardless of the nature of irrigation, NPK fertilizer application had the highest magnesium uptake of 0.103 g pot^{-1} and it was on par with application of biosludge @ 50, 100, 200 and 400 t ha^{-1} with 0.095, 0.103, 0.102 and 0.102 g pot^{-1} respectively. The least magnesium uptake 0.077 g pot^{-1} was found in 100 per cent biosludge application and it was on par with 50% biosludge application (0.087 g pot^{-1}).

4.8.3.2.6. Sodium uptake (Table 4.18)

The sodium uptake ranged between 0.009 g pot^{-1} and 0.013 g pot^{-1}. In general there was no significant difference between the effluent concentrations which recorded the same uptake of sodium (0.011 g pot^{-1}).

Regardless of source of irrigation, application of biosludge @ 200 and 400 t ha^{-1} recorded the highest sodium uptake of 0.013 g pot^{-1} which was on par with other treatments.

4.8.4. Soil characteristics as influenced by biosludge and effluent irrigation

4.8.4.1. Chemical properties

4.8.4.1.1. Soil reaction (pH) (Table 4.19)

The data on soil reaction revealed that it was high under 100 per cent effluent irrigation compared to that of 50 per cent effluent irrigation. The soil reaction increased slightly but gradually from vegetative to harvest stage of crop growth.

Among the graded levels of biosludge application, the mean soil reaction was high in NPK treatment (7.84) and it was on par with graded levels of biosludge up to 400 t ha^{-1}. The lowest soil reaction was in 50 per cent biosludge application (7.04) which on par with 100 per cent biosludge application (7.25)

4.8.4.1.2. EC (Table 4.20)

The EC of the soil samples revealed that it was high under 100 per cent effluent irrigation than that of 50 per cent effluent irrigation. The soil EC increased gradually at all the critical stages of crop growth.

Among the treatments with graded levels of biosludge, the EC was high at 100 per cent biosludge application (1.90 dSm^{-1}) followed by 50 per cent biosludge application (1.30 dSm^{-1}). The NPK application recorded lowest

Table 4.19 Effect of effluent and biosludge on pH of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	7.81	7.83	**7.82**	7.83	7.85	**7.84**	7.84	7.85	**7.85**	7.83	7.84	**7.84**
T_2 (S_{50})	7.80	7.81	**7.81**	7.81	7.81	**7.81**	7.81	7.82	**7.82**	7.81	7.81	**7.81**
T_3 (S_{100})	7.79	7.81	**7.80**	7.79	7.81	**7.80**	7.81	7.82	**7.81**	7.80	7.81	**7.81**
T_4 (S_{200})	7.77	7.79	**7.78**	7.81	7.82	**7.81**	7.81	7.83	**7.82**	7.80	7.81	**7.80**
T_5 (S_{400})	7.75	7.78	**7.77**	7.81	7.83	**7.81**	7.82	7.83	**7.83**	7.79	7.81	**7.80**
T_6 (50% S)	7.00	7.02	**7.01**	7.04	7.05	**7.05**	7.05	7.06	**7.06**	7.03	7.04	**7.04**
T_7 (100%S)	7.22	7.23	**7.23**	7.24	7.26	**7.25**	7.25	7.27	**7.26**	7.24	7.25	**7.25**
Mean	**7.59**	**7.61**	**7.60**	**7.62**	**7.63**	**7.63**	**7.63**	**7.64**	**7.63**	**7.61**	**7.63**	**7.62**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.098	0.149	0.080	0.259	0.138	0.211	0.366

Table 4.20 Effect of effluent and bio-sludge on electrical conductivity (dSm^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.41	0.45	**0.43**	0.44	0.47	**0.46**	0.46	0.52	**0.49**	0.44	0.48	**0.46**
T_2 (S_{50})	0.43	0.48	**0.46**	0.46	0.51	**0.49**	0.47	0.56	**0.51**	0.45	0.52	**0.48**
T_3 (S_{100})	0.49	0.51	**0.50**	0.50	0.53	**0.52**	0.52	0.60	**0.56**	0.50	0.55	**0.53**
T_4 (S_{200})	0.52	0.59	**0.56**	0.57	0.63	**0.60**	0.61	0.69	**0.65**	0.57	0.64	**0.60**
T_5 (S_{400})	0.81	0.86	**0.84**	0.85	0.89	**0.87**	0.86	0.94	**0.90**	0.84	0.90	**0.87**
T_6 (50% S)	1.23	1.31	**1.27**	1.29	1.32	**1.31**	1.30	1.36	**1.33**	1.27	1.33	**1.30**
T_7 (100%S)	1.87	1.90	**1.89**	1.87	1.91	**1.89**	1.90	1.96	**1.93**	1.88	1.92	**1.90**
Mean	**0.82**	**0.87**	**0.85**	**0.85**	**0.89**	**0.87**	**0.87**	**0.95**	**0.91**	**0.85**	**0.90**	**0.88**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.014	0.022	0.012	0.037	0.020	0.030	0.053

soil EC of 0.46 dSm^{-1} followed by 50 t ha^{-1} biosludge application (0.48 dSm^{-1}) and from thereon the EC increased as the dose of sludge increased.

4.8.4.1.3. Available N (Table 4.21)

The availability of nitrogen ranged between 88.00 to 262.60 m Eq/100 g of soil. The availability of nitrogen in soil continuously showed a declining trend throughout the crop growth. The mean availability decreased from 123.67 m Eq/100 of soil at vegetative stage to 115.95 m Eq/100 of soil at the harvest stage. There was no significant difference between diluted and 100 per cent effluent irrigation.

The overall availability of nitrogen was the highest in 100 per cent biosludge application (256.86 m Eq/100 of soil) which was significantly different from the rest and the least availability was in biosludge @ 50 t ha^{-1} (92.92 m Eq/100 of soil) followed by biosludge @ 100 t ha^{-1} (94.11 m Eq/100 of soil) and control (94.47 m Eq/100 of soil) which were on par with each other and graded levels of biosludge upto 400 t ha^{-1} (99.70 m Eq/100 of soil).

4.8.4.1.4. Available P (Table 4.22)

The availability of phosphorus ranged between 7.60 and 14.30 m Eq/100 g of soil. The P availability showed a declining trend throughout the crop growth. The mean availability at vegetative, flowering and harvesting stages were 9.89, 9.54 and 9.02 m Eq/100 of soil respectively.

The overall availability of phosphorus was maximum in 100 per cent biosludge (13.67 m Eq/100 of soil) and the least availability was in biosludge @ 50 t ha^{-1} (7.88 m Eq/100 of soil).

Table 4.21 Effect of effluent and biosludge on available nitrogen content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	98.50	98.71	**98.60**	96.60	95.80	**96.20**	89.20	88.00	**88.60**	94.77	94.17	**94.47**
T_2 (S_{50})	94.30	97.00	**95.65**	94.10	93.30	**93.70**	89.80	89.00	**89.40**	92.73	93.10	**92.92**
T_3 (S_{100})	97.80	97.27	**97.54**	95.30	95.10	**95.20**	89.86	89.30	**89.58**	94.32	93.89	**94.11**
T_4 (S_{200})	98.90	98.10	**98.50**	96.40	95.80	**96.10**	92.80	92.20	**92.50**	96.03	95.37	**95.70**
T_5 (S_{400})	103.50	102.70	**103.10**	99.10	98.90	**99.00**	97.30	96.70	**97.00**	99.97	99.43	**99.70**
T_6 (50% S)	111.07	111.70	**111.38**	108.70	108.50	**108.60**	103.60	103.10	**103.35**	107.79	107.77	**107.78**
T_7 (100%S)	262.60	259.23	**260.92**	258.90	258.00	**258.45**	251.50	251.90	**251.20**	257.67	256.04	**256.86**
Mean	**123.81**	**123.53**	**123.67**	**121.30**	**120.77**	**121.04**	**116.29**	**115.60**	**115.95**	**120.47**	**119.97**	**120.22**

CD (p=0.05)

I_1 -50% Effluent **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
1.667	2.547	1.361	4.411	2.358	3.602	6.239

Table 4.22 Effect of effluent and biosludge on available phosphorus content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	9.10	9.10	**9.10**	8.60	8.70	**8.65**	7.70	7.70	**7.70**	8.47	8.50	**8.48**
T_2 (S_{50})	8.10	8.20	**8.15**	7.70	7.90	**7.80**	7.60	7.80	**7.70**	7.80	7.97	**7.88**
T_3 (S_{100})	8.30	8.50	**8.40**	7.90	8.30	**8.10**	7.90	8.20	**8.05**	8.03	8.33	**8.18**
T_4 (S_{200})	8.90	9.20	**9.05**	8.60	8.90	**8.75**	8.30	8.30	**8.30**	8.60	8.80	**8.70**
T_5 (S_{400})	9.80	10.00	**9.90**	9.40	9.60	**9.50**	9.10	9.00	**9.05**	9.43	9.53	**9.48**
T_6 (50% S)	10.30	10.60	**10.45**	10.00	10.30	**10.15**	9.30	9.50	**9.40**	9.87	10.13	**10.00**
T_7 (100%S)	14.10	14.30	**14.20**	13.70	14.00	**13.85**	13.10	12.80	**12.95**	13.63	13.70	**13.67**
Mean	**9.80**	**9.99**	**9.89**	**9.41**	**9.67**	**9.54**	**9.00**	**9.04**	**9.04**	**9.44**	**9.57**	**9.49**

CD (p=0.05)

I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.124	0.190	0.102	0.329	0.176	0.269	0.465

4.8.4.1.5. Water extractable K (Table 4.23)

The water extractable potassium ranged between 0.055 and 0.089 m Eq/100 g of soil. The water extractable potassium continuously showed a declining trend throughout the crop growth. During vegetative, flowering and harvesting stages of crop, the water extractable potassium was 0.075, 0.071 and 0.070 m Eq/100 g respectively of soil. Except under application of 100 per cent biosludge in other treatments, irrigation with 100 per cent effluent had recorded significant increase in potassium availability.

Irrespective of growth stages of crop and nature of irrigation, NPK application had increased the potassium content in soil solution (0.086 m Eq/100 g of soil). The least water extractable potassium was noticed in 100 per cent biosludge application (0.056 m Eq/100 of soil).

4.8.4.1.6. Water extractable Ca (Table 4.24)

The interaction between 50 per cent effluent irrigation and NPK fertilizer application had registered the lowest calcium availability at vegetative stage (0.895 m Eq/100 g of soil), and the highest was registered in interaction between 100 per cent biosludge application and 100 per cent effluent irrigation (1.230 m Eq/100 g of soil) at the harvesting stage.

The water extractable calcium increased throughout the crop growing period from 1.019 m Eq to 1.057 m Eq/100 g of soil. Regardless of the stages of crop growth and biosludge treatments, 100 per cent effluent irrigation had increased the water extractable calcium.

Table 4.23 Effect of effluent and bio-sludge on available potassium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.088	0.089	**0.089**	0.085	0.086	**0.086**	0.082	0.083	**0.083**	0.085	0.086	**0.086**
T_2 (S_{50})	0.077	0.080	**0.079**	0.075	0.074	**0.075**	0.071	0.071	**0.071**	0.074	0.075	**0.075**
T_3 (S_{100})	0.078	0.078	**0.078**	0.070	0.077	**0.074**	0.073	0.074	**0.074**	0.074	0.076	**0.075**
T_4 (S_{200})	0.076	0.077	**0.077**	0.073	0.072	**0.073**	0.070	0.071	**0.071**	0.073	0.073	**0.073**
T_5 (S_{400})	0.074	0.075	**0.075**	0.072	0.071	**0.072**	0.070	0.069	**0.070**	0.072	0.072	**0.072**
T_6 (50% S)	0.070	0.069	**0.070**	0.060	0.068	**0.064**	0.067	0.066	**0.068**	0.066	0.068	**0.067**
T_7 (100%S)	0.058	0.055	**0.057**	0.058	0.056	**0.057**	0.055	0.055	**0.055**	0.057	0.055	**0.056**
Mean	**0.074**	**0.075**	**0.075**	**0.070**	**0.072**	**0.071**	**0.070**	**0.070**	**0.070**	**0.072**	**0.072**	**0.072**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
.001	.001	.001	.002	.001	.002	.003

Table 4.24 Effect of effluent and bio-sludge on water extractable calcium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.895	0.905	**0.900**	0.900	0.925	**0.913**	0.915	0.950	**0.933**	0.913	0.927	**0.915**
T_2 (S_{50})	0.915	0.930	**0.923**	0.925	0.950	**0.938**	0.940	0.975	**0.958**	0.927	0.952	**0.939**
T_3 (S_{100})	0.945	0.975	**0.960**	0.950	0.985	**0.968**	0.965	1.035	**1.000**	0.953	0.998	**0.976**
T_4 (S_{200})	0.990	1.020	**1.002**	0.995	1.050	**1.023**	1.010	1.090	**1.050**	0.998	1.053	**1.026**
T_5 (S_{400})	1.045	1.065	**1.055**	1.055	1.105	**1.080**	1.075	1.135	**1.105**	1.058	1.102	**1.080**
T_6 (50% S)	1.100	1.135	**1.118**	1.100	1.175	**1.138**	1.120	1.195	**1.158**	1.107	1.168	**1.138**
T_7 (100%S)	1.160	1.190	**1.175**	1.145	1.205	**1.175**	1.160	1.230	**1.195**	1.155	1.208	**1.182**
Mean	**1.007**	**1.031**	**1.019**	**1.010**	**1.057**	**1.033**	**1.026**	**1.087**	**1.057**	**1.015**	**1.058**	**1.036**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.014	0.021	0.011	0.036	0.019	0.029	0.051

Irrespective of crop growth and nature of irrigation, 100 per cent biosludge had increased the overall water extractable calcium (1.182 m Eq/100 g of soil) and it was on par with 50 per cent biosludge application (1.138 m Eq/100 g of soil). The recommended dose of NPK fertilizers had registered the least (0.915 m Eq/100 g of soil) water extractable calcium and it was on par with application of biosludge @ 50 t ha^{-1}.

4.8.4.1.7. Water extractable Mg (Table 4.25)

The least water extractable magnesium 0.341 m Eq/100 of soil was noticed in the interaction between NPK fertilizer application and 50 per cent effluent irrigation in harvesting stage of the crop. The highest water extractable magnesium (0.690 m Eq/100 of soil) was noticed in interaction between 100 per cent biosludge and 100 per effluent irrigation at vegetative stage of the crop. The mean water extractable magnesium showed a declining trend throughout the crop growth from 0.521 to 0.486 m Eq/100 g of soil.

Irrigation with 100 per cent effluent increased the water extractable magnesium in all stages of crop growth. Overall water extractable magnesium was the highest under 100 per cent biosludge (0.660 m Eq/100 g of soil) and the least was with NPK fertilizer (0.384 m Eq/100 g of soil).

4.8.4.1.8. Water extractable Na (Table 4.26)

The water extractable sodium ranged from 0.520 to 1.408 m Eq/100 g of soil. The water extractable sodium increased throughout the stages of crop growth *viz.*, vegetative, flowering and harvesting stage .with values of 0.672, 0.961 and 1.267 m Eq/100 g of soil respectively and were statistically

Table 4.25 Effect of effluent and bio-sludge on water extractable magnesium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.400	0.417	**0.409**	0.383	0.400	**0.392**	0.341	0.358	**0.350**	0.375	0.392	**0.384**
T_2 (S_{50})	0.420	0.435	**0.428**	0.409	0.435	**0.422**	0.398	0.408	**0.403**	0.409	0.426	**0.418**
T_3 (S_{100})	0.460	0.482	**0.476**	0.453	0.472	**0.463**	0.435	0.449	**0.442**	0.449	0.468	**0.459**
T_4 (S_{200})	0.505	0.525	**0.515**	0.498	0.515	**0.506**	0.487	0.491	**0.489**	0.497	0.510	**0.504**
T_5 (S_{400})	0.530	0.559	**0.545**	0.516	0.531	**0.524**	0.503	0.519	**0.511**	0.516	0.536	**0.526**
T_6 (50% S)	0.589	0.605	**0.597**	0.575	0.598	**0.587**	0.565	0.568	**0.567**	0.576	0.590	**0.583**
T_7 (100%S)	0.669	0.690	**0.680**	0.651	0.663	**0.657**	0.638	0.648	**0.643**	0.653	0.667	**0.660**
Mean	**0.512**	**0.530**	**0.521**	**0.498**	**0.516**	**0.507**	**0.481**	**0.492**	**0.486**	**0.496**	**0.513**	**0.505**

CD (p=0.05)

I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.010	0.002	0.018	0.009	0.014	0.025

Table 4.26 Effect of effluent and bio-sludge on water extractable sodium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.520	0.635	**0.578**	0.803	0.980	**0.892**	1.100	1.289	**1.195**	0.808	0.968	**0.888**
T_2 (S_{50})	0.561	0.658	**0.610**	0.823	0.996	**0.910**	1.141	1.315	**1.228**	0.842	0.980	**0.916**
T_3 (S_{100})	0.593	0.686	**0.640**	0.840	1.039	**0.940**	1.178	1.342	**1.260**	0.870	1.022	**0.946**
T_4 (S_{200})	0.638	0.703	**0.671**	0.865	1.061	**0.963**	1.190	1.359	**1.274**	0.898	1.041	**0.969**
T_5 (S_{400})	0.685	0.729	**0.707**	0.882	1.096	**0.989**	1.205	1.372	**1.289**	0.924	1.066	**0.995**
T_6 (50% S)	0.715	0.748	**0.732**	0.897	1.101	**0.999**	1.218	1.386	**1.302**	0.943	1.078	**1.011**
T_7 (100%S)	0.762	0.779	**0.771**	0.927	1.148	**1.037**	1.235	1.408	**1.322**	0.975	1.112	**1.043**
Mean	**0.639**	**0.705**	**0.672**	**0.862**	**1.060**	**0.961**	**1.181**	**1.353**	**1.267**	**0.804**	**1.040**	**0.967**

CD (p=0.05) **I_1-50% Effluent** **I_2- 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.013	0.020	0.011	0.034	0.018	0.028	0.049

significant. In general, 100 per cent effluent irrigation increased the water extractable sodium to a greater extent than 50 per cent effluent irrigation.

Regardless of the stages of crop growth, 100 per cent biosludge treatment increased the water extractable sodium (1.043 m Eq/100 g of soil) and it was on par with 50 per cent biosludge treatment (1.011 m Eq/100 of soil), biosludge @ 400 t ha^{-1} (0.995 m Eq/100 g of soil) and biosludge @ 200 t ha^{-1} (0.969 m Eq/100 of soil). The interaction between 100 per cent effluent irrigation and 100 per cent biosludge application increased the water extractable sodium to the highest quantum (1.408 m Eq/100 g of soil).

4.8.4.1.9. Water extractable chloride (Table 4.27)

The water extractable chloride ranged from 0.463 to 0.720 m Eq/100 g of soil. The least water extractable chloride was registered in the interaction between biosludge @ 50 t ha^{-1} and 50 per cent effluent in vegetative stage of maize crop. The highest water extractable chloride was noticed in the interaction between 100 per cent biosludge and 100 per cent effluent in harvesting stage of crop. The mean water extractable chloride had shown the increasing trend throughout the crop growing stages from 0.522 to 0.571 m Eq/100 g of soil.

Regardless of crop growth stages and biosludge levels, irrigation with 100 per cent effluent had increased the water extractable chloride.

Irrespective of other effects, 100 per cent biosludge had registered the highest overall water extractable chloride (0.636 m Eq/100 g of soil) and statistically superior. The least water extractable chloride (0.494 m Eq/100 g

Table 4.27 Effect of effluent and bio-sludge on water extractable chloride content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.473	0.484	**0.479**	0.485	0.514	**0.498**	0.498	0.511	**0.504**	0.485	0.503	**0.494**
T_2 (S_{50})	0.463	0.497	**0.490**	0.494	0.509	**0.502**	0.504	0.524	**0.514**	0.494	0.510	**0.502**
T_3 (S_{100})	0.494	0.504	**0.499**	0.506	0.519	**0.513**	0.517	0.528	**0.523**	0.506	0.517	**0.511**
T_4 (S_{200})	0.534	0.519	**0.527**	0.515	0.524	**0.519**	0.525	0.534	**0.530**	0.525	0.526	**0.525**
T_5 (S_{400})	0.509	0.524	**0.517**	0.521	0.532	**0.527**	0.578	0.594	**0.586**	0.536	0.550	**0.543**
T_6 (50% S)	0.561	0.576	**0.568**	0.581	0.592	**0.586**	0.637	0.658	**0.648**	0.593	0.609	**0.601**
T_7 (100%S)	0.567	0.579	**0.573**	0.629	0.653	**0.641**	0.669	0.720	**0.694**	0.622	0.651	**0.636**
Mean	**0.517**	**0.526**	**0.522**	**0.533**	**0.549**	**0.541**	**0.561**	**0.581**	**0.571**	**0.537**	**0.552**	**0.545**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.008	0.012	0.007	0.011	0.011	0.017	0.030

of soil) was noticed under NPK fertilizer and it was on par with application of biosludge @ 50, 100 and 200 t ha^{-1}.

4.8.4.1.10. Water extractable sulphate (Table 4.28)

The range of water extractable sulphate was between 0.117 and 0.519 m Eq/100 g soil. The interaction between NPK application and 50 per cent effluent irrigation at vegetative stage had registered the least water extractable sulphate. The highest was registered due to the interaction between 100 per cent biosludge and 100 per cent effluent irrigation.

The water extractable sulphate during various stages of crop growth were 0.201, 0.227 and 0.281 m Eq/100 g of soil respectively. In general 100 per cent effluent irrigation had registered higher water extractable sulphate.

Regardless of stage of crop growth and nature of irrigation, 100 per cent biosludge recorded the highest overall water extractable sulphate (0.426 m Eq/100 g of soil). The least overall was observed in recommended NPK fertilizer application (0.158 m Eq/100 g of soil) and it was on par with biosludge @ 50 t ha^{-1} (0.168 m Eq/100 g of soil).

4.8.4.1.11. Water extractable bicarbonate (Table 4.29)

The statistically significant results on the water extractable bicarbonates in soil solution had shown that it was influenced by stages of crop growth, nature of irrigation water and application of various levels of biosludge.

Table 4.28 Effect of effluent and bio-sludge on water extractable sulphate content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	.117	0.141	**0.129**	0.142	0.159	**0.151**	0.180	0.206	**0.193**	0.146	0.169	**0.158**
T_2 (S_{50})	0.129	0.153	**0.141**	0.156	0.169	**0.163**	0.186	0.216	**0.201**	0.157	0.179	**0.168**
T_3 (S_{100})	0.140	0.163	**0.152**	0.163	0.175	**0.169**	0.199	0.216	**0.208**	0.167	0.185	**0.176**
T_4 (S_{200})	0.156	0.184	**0.170**	0.184	0.202	**0.193**	0.212	0.239	**0.226**	0.184	0.208	**0.196**
T_5 (S_{400})	0.175	0.202	**0.189**	0.186	0.220	**0.203**	0.257	0.290	**0.274**	0.206	0.237	**0.222**
T_6 (50% S)	0.254	0.283	**0.269**	0.283	0.305	**0.294**	0.348	0.381	**0.365**	0.295	0.323	**0.309**
T_7 (100%S)	0.344	0.374	**0.359**	0.406	0.428	**0.417**	0.486	0.519	**0.503**	0.412	0.440	**0.426**
Mean	**0.188**	**0.214**	**0.201**	**0.217**	**0.237**	**0.227**	**0.267**	**0.295**	**0.281**	**0.224**	**0.249**	**0.236**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.003	0.005	0.003	0.009	0.005	0.007	0.012

Table 4.29 Effect of effluent and bio-sludge on water extractable bicarbonate content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	1.51	1.53	**1.52**	1.51	1.56	**1.54**	1.52	1.57	**1.54**	1.51	1.55	**1.53**
T_2 (S_{50})	1.53	1.56	**1.55**	1.54	1.57	**1.55**	1.54	1.59	**1.57**	1.54	1.57	**1.56**
T_3 (S_{100})	1.56	1.58	**1.57**	1.56	1.60	**1.58**	1.57	1.61	**1.59**	1.56	1.60	**1.58**
T_4 (S_{200})	1.58	1.61	**1.60**	1.58	1.62	**1.60**	1.59	1.63	**1.61**	1.58	1.62	**1.60**
T_5 (S_{400})	1.60	1.63	**1.61**	1.61	1.64	**1.63**	1.62	1.68	**1.65**	1.61	1.65	**1.63**
T_6 (50% S)	1.62	1.64	**1.63**	1.63	1.67	**1.65**	1.63	1.68	**1.66**	1.63	1.66	**1.64**
T_7 (100%S)	1.64	1.66	**1.65**	1.64	1.68	**1.66**	1.65	1.69	**1.67**	1.64	1.68	**1.66**
Mean	**1.58**	**1.60**	**1.59**	**1.58**	**1.62**	**1.60**	**1.59**	**1.64**	**1.61**	**1.58**	**1.62**	**1.60**

CD (p=0.05) I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.207	0.032	0.017	0.055	0.292	0.045	0.077

The water extractable bicarbonates ranged between 1.51 and 1.69 m Eq/100 g of soil. The interaction between NPK and 50 per cent effluent irrigation in vegetative stage had caused the least water extractable bicarbonate. The interaction between 100 per cent biosludge and 100 per cent effluent in harvesting stage had caused the highest water extractable bicarbonates.

The mean water extractable bicarbonate had shown an increasing trend throughout the crop growth. Regardless of stage of crop growth and biosludge application, irrigation with 100 per cent effluent had increased the water extractable bicarbonate. Regardless of irrigation and biosludge application, 100 per cent biosludge had registered highest water extractable bicarbonate (1.66 m Eq/100 g of soil) and it was on par with application of biosludge @ 200 t ha^{-1}, 400 t ha^{-1} and 50 per cent that showed the water extractable bicarbonate as 1.60 1.63 and 1.64 m Eq/100 g of soil respectively.

4.8.4.1.12. Exchangeable Na (Table 4.30)

The exchangeable Na content was higher under 100 per cent effluent than under 50 per cent effluent irrigation. Irrespective of source of irrigation, the exchangeable Na increased in soil from vegetative to harvest stage of crop growth.

It ranged between 4.44 C mol (P^+) kg ha^{-1} in NPK under 50 per cent effluent irrigation at vegetative stage and 8.10 C mol (P^+) kg ha^{-1} in 100 per cent biosludge under 100 per cent effluent irrigation at the harvest stage.

Table 4.30 Effect of effluent and biosludge on exchangeable sodium content (cmol(p^+)kg^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	4.44	4.67	**4.55**	4.83	5.46	**5.15**	5.30	6.18	**5.74**	4.86	5.44	**5.15**
T_2 (S_{50})	4.61	4.88	**4.75**	5.12	5.73	**5.43**	5.65	6.40	**6.03**	5.13	5.67	**5.40**
T_3 (S_{100})	4.86	5.16	**5.01**	5.29	6.00	**5.65**	5.83	6.80	**6.32**	5.33	5.99	**5.66**
T_4 (S_{200})	4.95	5.23	**5.09**	5.37	6.06	**5.72**	5.92	6.86	**6.39**	5.41	6.05	**5.73**
T_5 (S_{400})	5.16	5.46	**5.31**	5.61	6.31	**5.96**	6.16	7.12	**6.14**	5.64	6.30	**5.97**
T_6 (50% S)	5.44	5.73	**5.59**	5.88	6.55	**6.22**	6.36	7.28	**6.82**	5.89	6.52	**6.21**
T_7 (100%S)	6.25	6.56	**6.41**	6.70	7.39	**7.05**	7.17	8.10	**7.64**	6.71	7.35	**7.03**
Mean	**5.10**	**5.38**	**5.24**	**5.54**	**6.21**	**5.88**	**6.06**	**6.96**	**6.51**	**5.57**	**6.19**	**5.88**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.077	0.118	0.063	0.204	0.109	0.167	0.288

Among the treatment combinations, 100 per cent biosludge registered higher exchangeable Na 7.03 C mol (P^+) kg ha^{-1} and NPK recorded the least exchangeable Na in soil (5.15 C mol (P^+) kg ha^{-1})

4.8.4.1.13. Exchangeable Ca (Table 4.31)

Hundred per cent effluent recorded higher exchangeable Ca in soil compared to 50 per cent effluent irrigation. Regardless of dilution, the irrigation sources increased the exchangeable Ca in soil at all critical stages of crop growth.

The values ranged between 18.30 C mol (P^+) kg ha^{-1} in NPK under 50 per cent effluent irrigation at vegetative stage and 66.70 C mol (P^+) kg ha^{-1} in 100 per cent biosludge under 50 per cent effluent irrigation at the harvest stage.

Among the treatment combinations, the highest exchangeable Ca was registered in 100 per cent biosludge (66.32 C mol (P^+) kg ha^{-1}) which was significantly different from the rest and the NPK treatment registered the lowest exchangeable Ca of 18.67 C mol (P^+) kg ha^{-1}

4.8.4.1.14. Exchangeable Mg (Table 4.32)

The exchangeable Mg content was higher in 100 per cent effluent than 50 per cent effluent irrigation. There was a gradual increase in the soil exchangeable Mg due to effluent irrigation.

The values ranged between 7.11 C mol (P^+) kg ha^{-1} in NPK under 50 per cent effluent at vegetative stage and 18.56 C mol (P^+) kg ha^{-1} in 100 per

Table 4.31 ***Effect of effluent and biosludge on exchangeable calcium content (cmol(p^+)kg^{-1}) of soil***

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	18.30	18.40	**18.35**	18.50	18.90	**18.70**	18.60	19.30	**18.95**	18.47	18.87	**18.67**
T_2 (S_{50})	20.10	20.40	**20.25**	20.20	20.60	**20.40**	20.40	21.00	**20.70**	20.23	20.67	**20.45**
T_3 (S_{100})	22.18	22.40	**22.29**	22.40	22.77	**22.58**	22.60	23.30	**22.95**	22.39	22.82	**22.61**
T_4 (S_{200})	23.50	23.70	**23.60**	23.80	24.20	**24.00**	23.90	24.50	**24.20**	23.73	24.13	**23.93**
T_5 (S_{400})	27.30	27.40	**27.35**	27.50	27.90	**27.70**	27.69	28.10	**27.90**	27.50	27.80	**27.65**
T_6 (50% S)	34.21	34.50	**34.36**	35.00	34.80	**34.90**	35.10	35.00	**35.05**	34.77	34.77	**34.77**
T_7 (100%S)	65.80	65.90	**65.85**	66.60	66.30	**66.45**	66.70	66.60	**66.65**	66.37	66.27	**66.32**
Mean	**30.20**	**30.39**	**30.29**	**30.57**	**30.78**	**30.68**	**30.71**	**31.11**	**30.91**	**30.49**	**30.76**	**30.63**

CD (p=0.05)

I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.446	0.681	0.364	1.18	0.630	0.963	1.67

Table 4.32 **Effect of effluent and biosludge on exchangeable magnesium content (cmol(p^+)kg^{-1}) of soil**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	7.11	7.14	**7.13**	7.12	7.14	**7.13**	7.13	7.17	**7.15**	7.12	7.15	**7.14**
T_2 (S_{50})	7.63	7.66	**7.64**	7.65	7.67	**7.66**	7.66	7.68	**7.67**	7.65	7.67	**7.66**
T_3 (S_{100})	7.92	7.96	**7.94**	7.93	7.98	**7.96**	7.95	8.00	**7.98**	7.93	7.98	**7.96**
T_4 (S_{200})	8.75	8.78	**8.77**	8.77	8.79	**8.78**	8.79	8.82	**8.81**	8.77	8.80	**8.78**
T_5 (S_{400})	9.31	9.33	**9.32**	9.31	9.36	**9.34**	9.32	9.38	**9.35**	9.31	9.36	**9.34**
T_6 (50% S)	10.12	10.15	**10.14**	10.14	10.17	**10.16**	10.15	10.19	**10.17**	10.14	10.17	**10.15**
T_7 (100%S)	18.51	18.55	**18.54**	18.55	18.54	**18.55**	18.54	18.56	**18.55**	18.54	18.55	**18.55**
Mean	**9.91**	**9.94**	9.92	**9.93**	**9.95**	9.94	**9.93**	**9.97**	9.95	**9.92**	**9.95**	9.94

CD (p=0.05)

I_1 -50% Effluent **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.140	0.213	0.114	0.370	0.198	0.302	0.523

cent biosludge under 100 per cent effluent irrigation at harvesting stage of crop growth.

Among the graded levels of biosludge application, 100 per cent biosludge registered the highest exchangeable Mg of 18.55 C mol (P^+) kg ha^{-1} in soil which was significantly different from the rest and the lowest value was recorded in the control (7.14 C mol (P^+) kg ha^{-1}).

4.8.4.1.15. Exchangeable K (Table 4.33)

Hundred per cent effluent registered higher exchangeable K in soil than 50 per cent effluent irrigation. Regardless of dilution, there was a gradual decrease in the exchangeable K due to effluent irrigation from vegetative to harvest stage of crop growth.

The values ranged from 0.109 C mol (P^+) kg ha^{-1} in 100 per cent biosludge under 50 per cent effluent irrigation at harvest stage to 0.363 C mol (P^+) kg ha^{-1} in control under 100 per cent effluent irrigation at vegetative stage of crop growth.

Among the treatment combinations, the NPK treatment registered highest exchangeable K of 0.355 and the lowest value was recorded in 100 per cent biosludge treatment (0.117 C mol (P^+) kg ha^{-1}).

4.8.4.1.16. Exchangeable sodium per cent (ESP) (Table 4.34)

ESP was higher under cent per cent effluent than 50 per cent effluent irrigation at all stages of crop growth. ESP increased from 12.52 at vegetative stage to 14.87 at the harvest stage, irrespective of irrigation source.

Table 4.33 Effect of effluent and biosludge on exchangeable potassium content ($cmol(p^+)kg^{-1}$) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.352	0.363	**0.358**	0.351	0.361	**0.356**	0.348	0.356	**0.352**	0.350	0.360	**0.355**
T_2 (S_{50})	0.323	0.324	**0.324**	0.320	0.323	**0.322**	0.315	0.316	**0.316**	0.319	0.321	**0.320**
T_3 (S_{100})	0.316	0.329	**0.323**	0.314	0.326	**0.320**	0.310	0.322	**0.316**	0.313	0.326	**0.319**
T_4 (S_{200})	0.285	0.298	**0.292**	0.281	0.294	**0.288**	0.278	0.290	**0.284**	0.281	0.294	**0.288**
T_5 (S_{400})	0.252	0.263	**0.258**	0.249	0.261	**0.255**	0.246	0.258	**0.252**	0.249	0.261	**0.255**
T_6 (50% S)	0.194	0.206	**0.200**	0.192	0.203	**0.198**	0.189	0.201	**0.195**	0.192	0.203	**0.198**
T_7 (100%S)	0.113	0.125	**0.119**	0.111	0.121	**0.116**	0.119	0.120	**0.115**	0.111	0.122	**0.117**
Mean	**0.262**	**0.273**	**0.267**	**0.260**	**0.270**	**0.265**	**0.256**	**0.266**	**0.261**	**0.259**	**0.270**	**0.265**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.004	0.006	0.003	0.010	0.005	0.008	0.014

***Table 4.34* Effect of effluent and biosludge on exchangeable sodium per cent (ESP) of soil**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	14.70	15.27	**14.99**	15.68	17.14	**16.41**	16.89	18.72	**17.81**	15.76	17.04	**16.40**
T_2 (S_{50})	14.11	14.67	**14.39**	15.38	16.70	**16.04**	16.61	18.08	**17.35**	15.37	16.48	**15.93**
T_3 (S_{100})	13.77	14.39	**14.08**	14.55	16.20	**15.38**	15.80	17.70	**16.75**	14.71	16.10	**15.40**
T_4 (S_{200})	13.21	13.76	**13.49**	14.05	15.40	**14.73**	15.22	16.78	**16.00**	14.16	15.31	**14.74**
T_5 (S_{400})	12.28	12.86	**12.57**	13.11	14.40	**13.76**	14.17	15.74	**14.96**	13.19	14.33	**13.76**
T_6 (50% S)	10.90	11.33	**11.12**	11.48	12.66	**12.07**	12.28	13.82	**13.05**	11.55	12.60	**12.08**
T_7 (100%S)	6.89	7.20	**7.05**	7.29	8.00	**7.65**	7.75	8.67	**8.21**	7.31	7.96	**7.63**
Mean	**12.27**	**12.78**	**12.52**	**13.08**	**14.36**	**13.72**	**14.10**	**15.64**	**14.87**	**13.15**	**14.26**	**13.71**

CD (p=0.05)

I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.185	0.283	0.151	0.491	0.262	0.401	0.694

Hundred per cent biosludge application recorded low ESP at all stages than rest of the treatments.

Among the treatments, 100 per cent biosludge registered the lowest ESP of 7.63 which was significantly different from the rest. The highest ESP was recorded in NPK treatment (16.40).

4.8.4.1.17. Sodium adsorption ratio (SAR) (Table 4.35)

SAR in soil increased under cent per cent effluent than 50 per cent effluent irrigation at all critical stages of crop growth. The SAR increased from 1.22 at vegetative stage to 1.50 at harvest stage irrespective of irrigation sources.

Among the treatments/ 100 per cent biosludge registered lower SAR (1.08) which was significantly different from the rest. The highest SAR was recorded both in 50 and 100 t ha^{-1} biosludge application (1.44) which was on par with control and rest of the graded levels of biosludge applications.

4.8.5. Soil enzymes as influenced by biosludge and effluent irrigation

4.8.5.1. Amylase (4.36a)

The amylase activity ranged between 0.073 and 0.400 mg of glucose g^{-1} of soil. The least was registered in interaction between 100 per cent biosludge and 100 per cent effluent irrigation at vegetative stage of the crop. During flowering stage of the crop, interaction between 200 t ha^{-1} biosludge and 50 per cent effluent irrigation had registered the highest amylase activity.

Table 4.35 Effect of effluent and biosludge on sodium adsorption ratio (SAR) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	1.25	1.31	**1.28**	1.35	1.51	**1.43**	1.48	1.70	**1.59**	1.36	1.51	**1.43**
T_2 (S_{50})	1.24	1.30	**1.27**	1.37	1.52	**1.45**	1.51	1.70	**1.61**	1.37	1.51	**1.44**
T_3 (S_{100})	1.25	1.32	**1.29**	1.36	1.53	**1.45**	1.48	1.72	**1.60**	1.36	1.52	**1.44**
T_4 (S_{200})	1.23	1.30	**1.27**	1.33	1.49	**1.41**	1.46	1.68	**1.57**	1.34	1.49	**1.42**
T_5 (S_{400})	1.21	1.27	**1.24**	1.30	1.46	**1.38**	1.43	1.63	**1.53**	1.31	1.45	**1.38**
T_6 (50% S)	1.16	1.21	**1.19**	1.24	1.38	**1.31**	1.34	1.53	**1.44**	1.25	1.37	**1.31**
T_7 (100%S)	0.96	1.04	**1.00**	1.03	1.13	**1.08**	1.10	1.24	**1.17**	1.03	1.34	**1.08**
Mean	**1.19**	**1.25**	**1.22**	**1.28**	**1.43**	**1.36**	**1.40**	**1.60**	**1.50**	**1.29**	**1.43**	**1.36**

CD (p=0.05)

I_1 -50% Effluent I_2 - 100% Effluent

S	T	I	S X T	S X I	T X I	S X T X I
0.019	0.029	0.015	0.050	0.027	0.041	0.071

Table 4.36a Effect of effluent and bio-sludge on amylase (mg of glucose g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.132	0.120	**0.126**	0.260	0.220	**0.240**	0.220	0.188	**0.204**	0.204	0.176	**0.190**
T_2 (S_{50})	0.175	0.150	**0.163**	0.312	0.280	**0.296**	0.285	0.250	**0.268**	0.257	0.227	**0.242**
T_3 (S_{100})	0.185	0.166	**0.176**	0.356	0.320	**0.338**	0.330	0.276	**0.303**	0.290	0.254	**0.272**
T_4 (S_{200})	0.210	0.180	**0.195**	0.400	0.375	**0.388**	0.367	0.323	**0.345**	0.326	0.293	**0.309**
T_5 (S_{400})	0.140	0.130	**0.135**	0.295	0.250	**0.273**	0.292	0.210	**0.251**	0.242	0.197	**0.220**
T_6 (50% S)	0.101	0.095	**0.098**	0.210	0.180	**0.195**	0.198	0.165	**0.182**	0.170	0.147	**0.158**
T_7 (100%S)	0.096	0.073	**0.085**	0.175	0.145	**0.160**	0.155	0.081	**0.118**	0.142	0.100	**0.121**
Mean	**0.148**	**0.131**	**0.140**	**0.287**	**0.253**	**0.270**	**0.264**	**0.213**	**0.239**	**0.233**	**0.199**	**0.216**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.011	0.006	0.020	0.011	0.016	0.028

During the flowering stage, the amylase activity reached the highest (0.270 mg of glucose g^{-1} of soil). In general, 50 per cent effluent irrigation has showed higher amylase activity. Invariably, biosludge @ 200 t ha^{-1} registered higher amylase activity.

4.8.5.2. Invertase (Table 4.36b)

The interaction between 100 per cent biosludge and 100 per cent effluent irrigation at vegetative stage registered the least soil invertase activity (6.94 mg of glucose g^{-1} of soil). The highest activity of invertase (22.89 mg of glucose g^{-1} of soil) was caused by interaction between biosludge @ 200 t ha^{-1} and 50 per cent effluent irrigation at harvesting stage of the crop.

The activity of invertase continued to increase from 12.83 to 16.40 mg of glucose g^{-1} of soil during the cropping stage and reached the maximum during harvesting stage. In general, 50 per cent effluent irrigation increased the invertase activity. Regardless of the stages of crop growth and nature of irrigation, treatment with 200 t ha^{-1} biosludge caused higher invertase activity.

4.8.5.3. Catalase (Table 4.36c)

The catalase activity ranged between 2.213 and 25.14 μ mol H_2O_2 g^{-1} of soil. The interaction between 100 per cent biosludge and 100 per cent effluent at vegetative stage registered the least activity. The highest was noticed in biosludge @ 200 t ha^{-1} under 50 per cent effluent irrigation.

The highest catalase activity was registered at flowering stage of the crop (16.04 μ mol H_2O_2 g^{-1} of soil). In general, 50 per cent effluent irrigation

Table 4.36b Effect of effluent and bio-sludge on invertase(mg of glucose g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	14.13	13.21	**13.67**	15.25	14.86	**15.05**	17.93	16.10	**17.02**	15.77	14.72	**15.25**
T_2 (S_{50})	14.96	11.25	**13.11**	16.33	15.95	**16.14**	18.65	17.53	**18.09**	16.65	14.91	**15.78**
T_3 (S_{100})	15.01	12.33	**13.67**	17.85	14.86	**16.35**	19.43	18.32	**18.88**	17.43	15.17	**16.30**
T_4 (S_{200})	18.25	16.12	**17.19**	20.93	17.97	**19.45**	22.89	20.86	**21.87**	20.69	18.32	**19.50**
T_5 (S_{400})	13.75	11.55	**12.65**	14.95	13.25	**14.10**	16.05	14.98	**15.52**	14.92	13.26	**14.09**
T_6 (50% S)	12.69	10.73	**11.71**	13.01	12.63	**12.82**	14.25	13.99	**14.12**	13.32	12.45	**12.88**
T_7 (100%S)	8.75	6.94	**7.85**	9.69	7.25	**8.47**	11.54	7.11	**9.32**	9.99	7.05	**8.55**
Mean	**13.93**	**11.73**	**12.83**	**15.43**	**13.82**	**14.63**	**17.25**	**15.56**	**16.40**	**15.54**	**13.70**	**14.62**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.196	0.300	0.160	0.519	0.278	0.424	0.735

Table 4.36c Effect of effluent and bio-sludge on catalase (μ mol of H_2O_2 g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	5.21	4.01	**4.61**	17.81	15.18	**16.50**	16.08	14.97	**15.53**	13.03	11.39	**12.21**
T_2 (S_{50})	6.95	3.97	**5.46**	18.65	13.86	**16.26**	15.75	13.14	**14.45**	13.78	10.32	**12.05**
T_3 (S_{100})	5.63	4.85	**5.24**	21.93	18.59	**20.26**	19.78	15.98	**17.88**	15.78	13.14	**14.46**
T_4 (S_{200})	8.12	6.24	**7.18**	25.14	24.40	**24.77**	22.65	20.13	**21.39**	18.64	16.92	**17.78**
T_5 (S_{400})	4.39	3.02	**3.71**	14.96	13.20	**14.08**	12.98	11.08	**12.03**	10.78	9.10	**9.94**
T_6 (50% S)	3.17	2.73	**2.95**	12.75	9.39	**11.07**	11.33	8.43	**9.88**	9.08	6.85	**7.97**
T_7 (100%S)	2.89	2.213	**2.55**	10.69	8.01	**9.35**	8.89	7.65	**8.27**	7.49	5.96	**6.72**
Mean	**5.19**	**3.86**	**4.53**	**17.42**	**14.66**	**16.04**	**15.35**	**13.05**	**14.20**	**12.66**	**10.53**	**11.59**

CD (p=0.05) **I_1 -50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.319	0.487	0.26	0.843	0.451	0.688	0.599

had shown higher amylase activity. Invariably, biosludge @ 200 t ha^{-1} had registered higher activity of catalase.

4.8.5.4. Phosphatase (Table 4.36d)

The interaction between 100 per cent biosludge and 100 per cent effluent irrigation at vegetative stage registered the least phosphatase activity (9.79 μg PNP g^{-1} of soil). The interaction between biosludge @ 200 t ha^{-1} and 50 per cent effluent at flowering stage had registered the highest activity of phosphatase (37.05 μg PNP g^{-1} of soil).

During flowering stage of the crop the soil phosphatase activity was higher. Invariably 50 per cent effluent irrigation registered higher phosphatase activity. Irrespective of stages of crop growth and nature of irrigation, biosludge @ 200 t ha^{-1} had registered higher phosphatase activity than the rest.

4.8.6. Influence of effluent and biosludge on residual blackgram

4.8.6.1. Growth and yield attributes

4.8.6.1.1. Dry matter production (Table 4.37)

The highest DMP was recorded under 50 per cent effluent (7.34 g pot^{-1}) compared to the 100 per cent effluent irrigation (7.17 g pot^{-1}) which was similar to the results of the DMP of maize.

Among the different graded levels of biosludge application, biosludge @ 200 t ha^{-1} recorded the maximum DMP of 8.05 g pot^{-1} which was in contrast to the results of maize wherein the maximum DMP was registered in biosludge @ 400 t ha^{-1}. The DMP was minimum at 100 per cent biosludge

Table 4.36d Effect of effluent and bio-sludge on phosphatase (μg PNP g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	13.45	12.96	**13.21**	19.40	18.15	**18.78**	16.58	14.53	**15.56**	16.48	15.21	**15.85**
T_2 (S_{50})	18.07	16.45	**17.26**	31.12	29.50	**30.11**	28.20	22.56	**25.38**	25.80	22.84	**24.32**
T_3 (S_{100})	19.55	17.97	**18.76**	34.30	32.17	**32.24**	30.15	27.73	**28.94**	28.00	25.96	**26.98**
T_4 (S_{200})	22.98	21.43	**22.21**	37.95	36.56	**37.26**	33.63	30.98	**32.31**	31.52	29.66	**30.59**
T_5 (S_{400})	16.39	15.47	**15.93**	30.75	28.05	**29.40**	25.97	23.75	**24.86**	24.37	22.42	**23.40**
T_6 (50% S)	12.63	11.08	**11.86**	25.93	20.70	**23.32**	19.85	17.63	**18.74**	19.47	16.47	**17.97**
T_7 (100%S)	10.87	9.79	**10.33**	18.45	17.65	**18.05**	16.76	13.50	**15.13**	15.36	13.65	**14.50**
Mean	**16.28**	**15.02**	**15.65**	**28.27**	**26.11**	**27.19**	**24.45**	**21.53**	**22.99**	**23.00**	**20.89**	**21.94**

CD (p=0.05) **I_1-50% Effluent** **I_2 - 100% Effluent**

S	T	I	S X T	S X I	T X I	S X T X I
0.520	0.795	0.425	1.38	0.736	1.24	1.95

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application (5.16 g pot^{-1}) which was significantly different from the rest of the treatments.

4.8.6.1.2. Grain yield (Table 4.37)

Fifty per cent effluent irrigation had registered higher grain yield (5.57 g pot^{-1}) compared to 100 per cent effluent irrigation. (5.07 g pot^{-1}).

Among the treatments, similar to the grain yield of maize, in blackgram also the mean yield was the highest in biosludge @ 200 t ha^{-1} followed by NPK and biosludge @ 100 t ha^{-1} (5.86 g pot^{-1}) which were on par with each other. The lowest grain yield of 3.55 g was recorded in 100 per cent biosludge which was significantly different from other treatments.

4.8.6.2. Soil characteristics

4.8.6.2.1. Available N, P and water extractable K (Table 4.38)

The available NPK of the residual blackgram soils decreased from post harvest soils of maize crop due to continuous effluent irrigation irrespective of the dilution.

Among the graded levels of biosludge application, the N and P availability was maximum in 100 per cent biosludge (249.56 and 12.20 m Eq/100 g of soil respectively), the least availability of N was in control (90.03 m Eq/100 g of soil) and the least availability of P was in biosludge @ 50 t ha^{-1} (7.10 m Eq/100 g of soil). Regarding the available K, the maximum was registered in the control (0.083 m Eq/100 g of soil) and least availability was in 100 per cent biosludge (0.050 m Eq/100 g of soil) which was significantly different than the rest.

Table 4.37 Effect of effluent and biosludge on dry matter production (g pot^{-1}) and yield (g pot^{-1}) of residual crop

Treatments	DMP			YIELD		
	I_1	I_2	Mean	I_1	I_2	Mean
T_1	7.75	7.59	**7.67**	6.00	5.72	**5.86**
T_2	7.42	7.23	**7.33**	5.64	5.31	**5.48**
T_3	8.04	7.91	**7.98**	6.12	5.61	**5.86**
T_4	8.09	8.00	**8.05**	6.13	5.63	**5.88**
T_5	7.52	7.32	**7.42**	5.91	5.11	**5.51**
T_6	7.28	7.11	**7.20**	5.32	4.81	**5.07**
T_7	5.31	5.01	**5.16**	3.84	3.25	**3.55**
Mean	**7.34**	**7.17**	**7.26**	**5.57**	**5.07**	**5.32**

CD (p=0.05)	I	T	I X T	I	T	I X T
	0.137	0.256	0.362	0.101	0.190	0.268

I_1 -50% Effluent I_2 - 100% Effluent

Table 4.38 Effect of effluent and bio-sludge on available nitrogen and phosphorus and water extractable potassium (m Eq 100 g^{-1}) content of post harvest soil (residual crop)

Treatments	Nitrogen			Phosphorus			Potassium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1	90.47	89.60	**90.03**	7.30	7.39	**7.35**	0.079	0.083	**0.081**
T_2	91.60	89.80	**90.70**	7.20	7.10	**7.15**	0.068	0.069	**0.069**
T_3	91.87	90.90	**91.38**	7.39	7.28	**7.34**	0.071	0.073	**0.072**
T_4	93.30	93.50	**93.40**	7.90	8.00	**7.95**	0.065	0.064	**0.065**
T_5	98.50	97.80	**98.15**	8.00	8.10	**8.05**	0.063	0.064	**0.064**
T_6	104.30	103.20	**103.75**	8.20	8.10	**8.15**	0.069	0.072	**0.071**
T_7	250.20	248.91	**249.56**	12.30	12.10	**12.20**	0.051	0.048	**0.050**
Mean	**117.18**	**116.25**	**116.71**	**8.33**	**8.30**	**8.31**	**0.067**	**0.068**	**0.067**

CD (p=0.05) I_1 -50% Effluent I_2 - 100% Effluent

	I	T	I X T	I	T	I X T	I	T	I X T
	2.45	**4.58**	**6.48**	**0.161**	**0.301**	**0.426**	**0.001**	**0.002**	**0.003**

4.8.6.2.2. Water extractable cations (Table 4.39)

Except the water extractable Mg the water extractable Ca and Na increased gradually due to the continuous effluent irrigation irrespective of the dilution. Generally the water extractable cations were higher in 100 per cent effluent irrigation than 50 per cent effluent irrigation.

Among the graded levels of biosludge application, the mean content of these cations (Ca, Mg and Na) were maximum in 100 per cent biosludge application (1.218, 0.635, 1.642 m Eq/100 g of soil respectively). The least content was registered in standard NPK treatment which was 0.954, 0.315 and 1.440 m Eq/100 g of soil for Ca, Mg and Na respectively.

4.8.6.2.3. Water extractable anions (Table 4.40)

The water extractable chloride, sulphate and bicarbonate increased gradually due to the continuous effluent irrigation irrespective of the dilution factor. But these cations were higher in 100 per cent effluent irrigation than 50 per cent effluent irrigation.

Regarding the graded levels of biosludge application the maximum mean water extractable chloride (0.698 m Eq/100 g of soil) sulphate (0.530 m Eq/100 g of soil) and bicarbonate (1.73 m Eq/100 g of soil) were recorded in the 100 per cent biosludge application. The least content of all these cations were registered in the NPK application with the values of 0.524, 0.230 and 1.56 m Eq/100 g of soil for chlorides, sulphates and bicarbonates respectively.

4.8.6.2.4. Exchangeable cations (Table 4.41)

In the residual blackgram the exchangeable cations *viz.*, Na, Ca, Mg and K increased gradually due to continuous effluent irrigation

Table 4.39 Effect of effluent and biosludge on water extractable cations (m Eq 100 g^{-1}) content of post harvest soil (residual crop)

Treatments	Calcium			Magnesium			Sodium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.936	0.971	**0.954**	0.308	0.322	**0.315**	1.358	1.521	**1.440**
T_2 (S_{50})	0.958	0.998	**0.978**	0.382	0.393	**0.388**	1.429	1.601	**1.515**
T_3 (S_{100})	0.985	1.056	**1.021**	0.419	0.421	**0.420**	1.493	1.643	**1.568**
T_4 (S_{200})	1.032	1.117	**1.075**	0.473	0.482	**0.478**	1.498	1.663	**1.581**
T_5 (S_{400})	1.093	1.157	**1.125**	0.491	0.503	**0.497**	1.532	1.685	**1.609**
T_6 (50% S)	1.136	1.211	**1.174**	0.551	0.562	**0.557**	1.547	1.706	**1.627**
T_7 (100%S)	1.181	1.255	**1.218**	0.629	0.641	**0.635**	1.563	1.721	**1.642**
Mean	**1.046**	**1.109**	**1.078**	**0.465**	**0.475**	**0.470**	**1.489**	**1.649**	**1.569**

I_1 -50% Effluent I_2 - 100% Effluent

CD (p=0.05)	I	T	I X T	I	T	I X T	I	T	I X T
	0.020	0.038	0.054	0.009	0.016	0.023	0.030	0.056	0.079

Table 4.40 Effect of effluent and biosludge on water extractable anions (m Eq 100 g^{-1}) content of post harvest soil (residual crop)

Treatments	Chloride			Sulphate			Bicarbonate		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.515	0.533	**0.524**	0.218	0.241	**0.230**	1.54	1.58	**1.56**
T_2 (S_{50})	0.531	0.550	**0.541**	0.231	0.249	**0.240**	1.56	1.59	**1.58**
T_3 (S_{100})	0.533	0.548	**0.541**	0.247	0.265	**0.256**	1.57	1.61	**1.59**
T_4 (S_{200})	0.539	0.543	**0.541**	0.258	0.273	**0.266**	1.61	1.65	**1.63**
T_5 (S_{400})	0.574	0.589	**0.582**	0.298	0.315	**0.306**	1.64	1.68	**1.66**
T_6 (50% S)	0.650	0.665	**0.658**	0.393	0.408	**0.401**	1.64	1.68	**1.66**
T_7 (100%S)	0.691	0.704	**0.698**	0.521	0.540	**0.530**	1.70	1.75	**1.73**
Mean	**0.576**	**0.590**	**0.583**	**0.309**	**0.327**	**0.318**	**1.61**	**1.65**	**1.63**

I_1 -50% Effluent I_2 - 100% Effluent

CD (p=0.05)	I	T	I X T	I	T	I X T	I	T	I X T
	0.011	0.021	0.029	0.006	0.012	0.017	0.031	0.058	0.081

Table 4.41 Effect of effluent and biosludge on exchangeable cations content (cmol(p^+)kg^{-1}) of post harvest soil (residual crop)

Treatments	Calcium			Magnesium			Sodium			Potassium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	18.80	19.80	**19.30**	7.14	7.19	**7.17**	5.81	6.68	**6.25**	0.346	0.357	**0.352**
T_2 (S_{50})	20.60	21.30	**20.95**	7.66	7.71	**7.69**	6.17	6.93	**6.55**	0.314	0.313	**0.314**
T_3 (S_{100})	22.70	23.70	**23.20**	7.96	8.02	**7.99**	6.35	7.32	**6.84**	0.308	0.320	**0.314**
T_4 (S_{200})	24.20	25.00	**24.60**	8.80	8.85	**8.83**	6.47	7.39	**6.93**	0.275	0.289	**0.282**
T_5 (S_{400})	27.90	28.44	**28.17**	9.34	9.40	**9.37**	6.96	7.56	**7.26**	0.244	0.255	**0.250**
T_6 (50% S)	35.30	35.50	**35.40**	10.16	10.22	**10.19**	6.87	7.82	**7.35**	0.188	0.199	**0.194**
T_7 (100%S)	66.80	67.00	**66.90**	18.54	18.58	**18.56**	7.67	8.60	**8.14**	0.108	0.178	**0.143**
Mean	**30.90**	**31.53**	**31.22**	**9.94**	**10.00**	9.97	**6.15**	7.47	7.04	**0.255**	**0.273**	**0.264**

CD (p=0.05) I_1 -50% Effluent I_2 - 100% Effluent

	I	T	I X T	I	T	I X T	I	T	I X T	I	T	I X T
	0.660	**1.235**	**1.747**	**0.201**	**0.377**	**0.533**	**0.134**	**0.252**	**0.356**	**0.005**	**0.010**	**0.014**

irrespective of dilution. These exchangeable cations were higher in 100 per cent effluent irrigation than that of 50 per cent effluent irrigation.

Regarding the graded levels of biosludge application the exchangeable cations *viz.,* Na, Ca and Mg were maximum in 100 per cent biosludge application. (8.14, 66.90 and 18.56 C mol (P^+) kg ha^{-1} of soil respectively) whereas the exchangeable K was maximum in NPK treatment (0.352 C mol (P^+) kg ha^{-1}) and the least in 100 per cent biosludge with the value of 0.143 C mol (P^+) kg ha^{-1}.

4.8.6.2.5. Exchangeable sodium per cent (ESP) (Table 4.42)

In the residual soils of blackgram, ESP was higher under 100 per cent effluent than 50 per cent effluent irrigation.

ESP increased to 15.82 in the residual crop soils from 14.87 in the post harvest soils of maize due to continuous effluent irrigation irrespective of the dilution.

Among the treatments, the lowest ESP of 8.68 was recorded in 100 per cent biosludge. The highest ESP was found in the NPK treatment (18.87).

4.8.6.2.6. Sodium adsorption ratio (SAR) (Table 4.42)

SAR in the residual soils of blackgram increased in 100 per cent effluent irrigation than 50 per cent effluent irrigation.

Table 4.42 Effect of effluent and biosludge on exchangeable sodium per cent (ESP) and sodium adsorption ratio (SAR) of post harvest soil (residual crop)

Treatments	ESP			SAR		
	I_1	I_2	Mean	I_1	I_2	Mean
T_1	18.10	19.63	**18.87**	1.61	1.82	**1.72**
T_2	17.76	19.12	**18.44**	1.64	1.82	**1.73**
T_3	17.02	18.60	**17.81**	1.63	1.84	**1.73**
T_4	16.20	17.79	**16.70**	1.59	1.80	**1.70**
T_5	15.66	16.56	**16.11**	1.61	1.73	**1.67**
T_6	13.08	14.55	**13.82**	1.44	1.64	**1.54**
T_7	8.24	9.11	**8.68**	1.18	1.31	**1.24**
Mean	**15.15**	**16.48**	**15.82**	**1.53**	**1.71**	**1.62**

CD (p=0.05) I_1 -50% Effluent I_2 - 100% Effluent

	I	T	I X T	I	T	I X T
	0.306	**0.573**	**0.810**	**0.032**	**0.059**	**0.084**

SAR increased to the level of 1.62 in residual soils from 1.50 of the post harvest soil of maize due to continuous effluent irrigation irrespective of dilution.

Among the graded levels of biosludge application, 100 per cent biosludge registered low SAR of 1.24 which was significantly different from the rest. The highest SAR was recorded both in 50 and 100 t ha^{-1} biosludge application (1.73) which was on par with control (1.72).

4.9. Influence of biosludge with amendments under effluent irrigation on crop growth and soil characteristics

4.9.1. Growth characters

4.9.1.1. Plant height (Table 4.43)

The plants were taller under effluent irrigation compared to that of siruvani water at all critical stages of crop growth.

Among the amendments, poultry manure application recorded taller plants at vegetative (88.50 cm) and flowering stage (131.50 cm) and the maximum height of 150.50 cm was recorded at harvesting stage under pressmud application.

Among the organic wastes, poultry manure recorded increased plant height (122.67 cm) followed by pressmud (120.68 cm), NPK treatment (117.85 cm) and fly ash (115.50 cm). The least plant height was recorded in biosludge (104.67 cm) followed by FYM (105.50 cm) and gypsum (109.00 cm) which were on par with each other.

Table 4.43 Effect of effluent, biosludge and amendments on plant height (cm) of maize

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	81.10	83.00	**82.05**	127.00	129.00	**128.00**	142.00	145.00	**143.50**	116.70	119.00	**117.85**
T_2 (FYM)	68.00	72.00	**70.00**	117.00	121.00	**119.00**	125.00	130.00	**127.50**	103.33	107.67	**105.50**
T_3 (S_{50})	70.00	72.00	**71.00**	115.00	117.00	**116.00**	126.00	128.00	**127.00**	103.67	105.67	**104.67**
T_4 (S_{50}+Gyp)	76.00	81.00	**78.50**	116.00	120.00	**118.00**	129.00	132.00	**130.50**	107.00	111.00	**109.00**
T_5 (S_{50}+Pr.M)	81.10	87.00	**84.05**	125.00	130.00	**127.00**	153.00	148.00	**150.50**	119.70	121.67	**120.68**
T_6 (S_{50}+Pl.M)	85.00	92.00	**88.50**	129.00	134.00	**131.50**	146.00	150.00	**148.00**	120.00	125.33	**122.67**
T_7 (S_{50}+FA)	79.00	83.00	**81.00**	119.00	122.00	**120.50**	131.00	135.00	**133.00**	109.67	113.33	**111.50**
Mean	**77.17**	**81.43**	**79.30**	**121.14**	**124.71**	**122.93**	**136.00**	**138.29**	**137.14**	**111.44**	**114.81**	**113.12**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
1.997	3.050	1.631	5.283	2.824	4.314	7.472

4.9.1.2. Dry matter production (DMP) (Table 4.44)

The increased DMP was recorded under effluent irrigation compared to that of siruvani water irrigation at all critical stages of crop growth.

Among the amendments, poultry manure application recorded the maximum DMP at vegetative (12.50 g pot^{-1}), flowering (35.32 g pot^{-1}) and harvesting (53.10 g pot^{-1}) stage of crop growth followed by pressmud application.

Among the organic wastes, poultry manure recorded maximum DMP (33.56 g pot^{-1}) followed by pressmud (32.98 g pot^{-1}), flyash (32.02 g pot^{-1}) and NPK (32.72 g pot^{-1}). The minimum DMP was recorded in biosludge (29.22 g pot^{-1}) followed by FYM (29.60 g pot^{-1}) which were on par with each other.

4.9.2. Grain yield (Table 4.45)

Effluent irrigation recorded higher grain yield (56.06 g pot^{-1}) compared to siruvani water irrigation (54.08 g pot^{-1}). The yield of maize ranged between 47.60 and 61.20 g pot^{-1}. The interaction between FYM application and siruvani water irrigation had registered the lowest yield (47.60 g pot^{-1}). The interaction between poultry manure application and effluent irrigation had registered the highest yield (61.20 g pot^{-1}).

Among the treatments, the poultry manure recorded higher grain yield (60.27 g pot^{-1}) followed by pressmud (58.40 g pot^{-1}) and NPK (57.53 g pot^{-1}) which were on par with each other. The lowest yield was recorded in FYM (48.60 g pot^{-1}) which was on par with biosludge (51.47 g pot^{-1}).

Table 4.44 **Effect of effluent, biosludge and amendments on dry matter production (g pot^{-1}) of maize**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	11.60	12.00	**11.80**	33.50	34.20	**33.85**	49.20	49.80	**49.50**	31.43	32.00	**31.72**
T_2 (FYM)	10.40	10.60	**10.50**	31.30	32.40	**31.85**	46.10	46.80	**46.45**	29.27	29.93	**29.60**
T_3 (S_{50})	9.93	10.50	**10.22**	31.60	31.10	**31.85**	45.30	45.90	**45.90**	28.94	29.50	**29.22**
T_4 (S_{50}+Gyp)	10.50	11.20	**10.85**	33.80	34.00	**33.90**	49.90	50.70	**50.70**	31.40	31.97	**31.68**
T_5 (S_{50}+Pr.M)	12.00	12.50	**12.25**	34.30	35.00	**34.65**	51.80	52.30	**52.30**	32.70	33.27	**32.98**
T_6 (S_{50}+Pl.M)	12.20	12.80	**12.50**	35.10	35.53	**35.32**	52.60	53.10	**53.10**	33.30	33.81	**33.56**
T_7 (S_{50}+FA)	11.50	11.80	**11.65**	33.40	34.50	**33.95**	50.00	50.90	**50.90**	31.63	32.40	**32.02**
Mean	**11.16**	**11.63**	11.40	**33.29**	**33.96**	33.62	**49.27**	**49.93**	49.60	**31.24**	**31.84**	31.54

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.420	0.651	0.348	1.128	0.603	0.921	1.595

Table 4.45 Effect of effluent, biosludge and amendments on grain yield (g pot^{-1}) of maize

Treatments	Grain Yield (g pot^{-1})		
	I_1	I_2	MEAN
T_1 (Control)	56.90	58.17	57.53
T_2 (FYM)	47.60	49.60	48.60
T_3 (S_{50})	50.37	52.57	51.47
T_4 (S_{50}+Gyp)	51.80	54.30	53.05
T_5 (S_{50}+Pr.M)	57.30	59.50	58.40
T_6 (S_{50}+Pl.M)	59.33	61.20	60.27
T_7 (S_{50}+FA)	55.27	57.10	56.18
Mean	54.08	56.06	55.07

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

	I	T	I X T
	1.132	2.118	2.996

4.9.3. Plant nutrient uptake

4.9.3.1. Uptake by stalk

4.9.3.1.1. Nitrogen uptake (Table 4.46)

The N uptake of the maize crop which ranged from 0.163 to 0.493 g pot^{-1} varied significantly among the different amendments, irrigation water and different growth stages.

The N uptake of maize stalk significantly increased from vegetative stage (0.189 g pot^{-1}) to flowering stage (0.463 g pot^{-1}) and then decreased at harvest (0.251 g pot^{-1}).

Irrespective of stages, the N uptake was found to be enhanced by the effluent irrigation (0.305 g pot^{-1}) over siruvani water irrigation (0.297 g pot^{-1}).

Regarding various amendments, application of poultry manure @ 5 t ha^{-1} along with biosludge @ 50 t ha^{-1} recorded the highest value (0.324 g pot^{-1}) followed by pressmud @ 10 t ha^{-1} along with biosludge @ 50 t ha^{-1} (0.317 g pot^{-1}). However, the combined application of pressmud and biosludge was on par with NPK fertilizer application (0.307 g pot^{-1}). This was followed by biosludge plus flyash (0.304 g pot^{-1}) which was comparable with biosludge plus gypsum (0.298 g pot^{-1}).

It was also observed that application of FYM @ 12.5 t ha^{-1} (0.280 g pot^{-1}) was comparable with biosludge application @ 50 t ha^{-1} (0.276 g pot^{-1}).

The interaction effect of effluent irrigation, amendments and different growth stages was statistically significant which showed that combined

Table 4.46 Effect of effluent, biosludge and amendments on nitrogen uptake(g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.193	.200	**0.197**	0.467	0.480	**0.473**	0.250	0.253	**0.252**	0.303	0.311	**0.307**
T_2 (FYM)	0.178	0.177	**0.177**	0.430	0.440	**0.435**	0.223	0.233	**0.228**	0.277	0.283	**0.280**
T_3 (S_{50})	0.163	0.170	**0.167**	0.430	0.440	**0.435**	0.223	0.227	**0.225**	0.272	0.279	**0.276**
T_4 (S_{50}+Gyp)	0.173	0.183	**0.178**	0.463	0.467	**0.465**	0.250	0.253	**0.252**	0.296	0.301	**0.298**
T_5 (S_{50}+Pr.M)	0.200	0.210	**0.205**	0.473	0.487	**0.480**	0.263	0.270	**0.267**	0.312	0.322	**0.317**
T_6 (S_{50}+Pl.M)	0.207	0.210	**0.208**	0.487	0.493	**0.490**	0.273	0.277	**0.275**	0.322	0.327	**0.324**
T_7 (S_{50}+FA)	0.190	0.193	**0.192**	0.457	0.473	**0.465**	0.250	0.260	**0.255**	0.299	0.309	**0.304**
Mean	**0.186**	**0.192**	**0.189**	**0.458**	**0.469**	**0.463**	**0.248**	**0.253**	**0.251**	**0.297**	**0.305**	**0.301**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.010	0.005	0.018	0.010	0.015	0.025

application of biosludge @ 50 t ha^{-1} and poultry manure @ 5 t ha^{-1} along with effluent irrigation recorded the N uptake (0.493 g pot^{-1}) at flowering stage followed by the application of biosludge plus pressmud with effluent irrigation.

4.9.3.1.2. Phosphorus uptake (Table 4.47)

Uptake of phosphorus by maize crop ranged from 0.077 g pot^{-1} at vegetative stage to 0.193 g pot^{-1} at flowering stage. The uptake pattern of phosphorus varied significantly among the different amendments and sources of irrigation at different growth stages.

The mean uptake of phosphorus by maize was 0.088 g pot^{-1} at vegetative stage, increased to 0.182 g pot^{-1} at flowering stage and decreased to 0.088 g pot^{-1} at the harvesting stage of the crop.

The overall mean uptake of phosphorus was higher (0.129 g pot^{-1}) under poultry manure amended treatment. It was on par with the effects produced by various amendments namely NPK fertilizers (0.125 g pot^{-1}), gypsum (0.117 g pot^{-1}) pressmud (0.124 g pot^{-1}) and flyash (0.122 g pot^{-1}). The least uptake of phosphorus (0.108 g pot^{-1}) was noticed in biosludge amended treatment.

4.9.3.1.3. Potassium uptake (Table 4.48)

The uptake of potassium by maize crop ranged from 0.203 g pot^{-1} at vegetative stage and increased to 0.483 g pot^{-1} at flowering stage and continued to increase at harvesting stage (0.780 g pot^{-1}). The uptake pattern

Table 4.47 Effect of effluent, biosludge and amendments on phosphorus uptake(g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.090	0.097	**0.093**	0.183	0.187	**0.185**	0.093	0.100	**0.097**	0.122	0.128	**0.125**
T_2 (FYM)	0.083	0.080	**0.082**	0.170	0.183	**0.177**	0.077	0.080	**0.078**	0.110	0.114	**0.112**
T_3 (S_{50})	0.077	0.080	**0.078**	0.170	0.170	**0.170**	0.073	0.077	**0.075**	0.107	0.109	**0.108**
T_4 (S_{50}+Gyp)	0.080	0.083	**0.082**	0.183	0.180	**0.182**	0.083	0.090	**0.087**	0.116	0.118	**0.117**
T_5 (S_{50}+Pr.M)	0.093	0.100	**0.097**	0.183	0.190	**0.187**	0.090	0.090	**0.090**	0.122	0.127	**0.124**
T_6 (S_{50}+Pl.M)	0.093	0.097	**0.095**	0.193	0.190	**0.192**	0.100	0.100	**0.100**	0.129	0.129	**0.129**
T_7 (S_{50}+FA)	0.090	0.093	**0.092**	0.180	0.187	**0.183**	0.090	0.090	**0.090**	0.120	0.123	**0.122**
Mean	**0.087**	**0.090**	**0.088**	**0.181**	**0.184**	**0.182**	**0.087**	**0.090**	**0.088**	**0.118**	**0.121**	**0.120**

CD (p=0.05)

I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.004	0.006	0.003	0.010	0.005	0.008	0.014

Table 4.48 Effect of effluent, biosludge and amendments on potassium uptake (g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.240	0.253	**0.247**	0.467	0.473	**0.470**	0.733	0.750	**0.742**	0.480	0.492	**0.486**
T_2 (FYM)	0.223	0.220	**0.222**	0.427	0.443	**0.435**	0.673	0.680	**0.677**	0.441	0.448	**0.444**
T_3 (S_{50})	0.203	0.217	**0.210**	0.430	0.437	**0.433**	0.660	0.667	**0.663**	0.431	0.440	**0.436**
T_4 (S_{50}+Gyp)	0.220	0.230	**0.225**	0.460	0.463	**0.462**	0.733	0.747	**0.740**	0.471	0.480	**0.476**
T_5 (S_{50}+Pr.M)	0.250	0.260	**0.255**	0.470	0.483	**0.477**	0.757	0.767	**0.762**	0.492	0.503	**0.498**
T_6 (S_{50}+Pl.M)	0.253	0.267	**0.260**	0.483	0.473	**0.478**	0.773	0.780	**0.777**	0.503	0.507	**0.505**
T_7 (S_{50}+FA)	0.240	0.247	**0.243**	0.463	0.477	**0.470**	0.740	0.750	**0.745**	0.481	0.491	**0.486**
Mean	**0.233**	**0.242**	0.237	**0.457**	**0.464**	0.461	**0.724**	**0.734**	0.729	**0.471**	**0.480**	0.476

CD (p=0.05)

I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.009	0.013	0.007	0.023	0.012	0.018	0.032

of potassium differed significantly among the treatments and their interactions.

The mean uptake of potassium showed an increasing trend throughout the crop growth. The mean uptake was 0.237 g pot^{-1} at vegetative stage; 0.461 g pot^{-1} at flowering stage and 0.729 g pot^{-1} at harvesting stage.

Regardless of the stages of plant growth, the overall mean potassium uptake was higher in effluent irrigation (0.480 g pot^{-1}) than under siruvani water irrigation (0.471 g pot^{-1}).

With respect to various amendments, application of poultry manure @ 5 t ha^{-1} significantly increased the potassium uptake (0.505 g pot^{-1}) and it was on par with other amendments and NPK application. Application of sludge alone @ 50 t ha^{-1} exerted a steep decline in potassium uptake (0.436 g pot^{-1}) and it was on par with application of FYM @ 12.5 t/ha that caused the potassium uptake of 0.444 g pot^{-1}.

4.9.3.1.4. Calcium uptake (Table 4.49)

The uptake of calcium by maize crop ranged between 0.027 g pot^{-1} and 0.220 g pot^{-1}. At the vegetative stage, uptake was the least 0.027 g pot^{-1}; in the flowering stage it was 0.083 g pot^{-1} and during harvesting stage the uptake was maximum 0.220 g pot^{-1}. The uptake pattern of calcium differed significantly among the treatments, stages of crop and irrigation sources.

The mean uptake of calcium showed an increasing trend throughout the crop growth from vegetative to harvesting stage. At the vegetative,

Table 4.49 Effect of effluent, biosludge and amendments on calcium uptake(g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.030	0.033	**0.032**	0.093	0.103	**0.098**	0.197	0.203	**0.200**	0.107	0.113	**0.110**
T_2 (FYM)	0.030	0.030	**0.030**	0.083	0.090	**0.087**	0.177	0.177	**0.177**	0.097	0.099	**0.098**
T_3 (S_{50})	0.027	0.030	**0.028**	0.093	0.093	**0.093**	0.177	0.193	**0.185**	0.099	0.107	**0.102**
T_4 (S_{50}+Gyp)	0.033	0.033	**0.033**	0.103	0.107	**0.105**	0.207	0.207	**0.207**	0.114	0.116	**0.115**
T_5 (S_{50}+Pr.M)	0.037	0.037	**0.037**	0.107	0.107	**0.107**	0.213	0.217	**0.215**	0.119	0.120	**0.119**
T_6 (S_{50}+Pl.M)	0.033	0.040	**0.037**	0.107	0.110	**0.108**	0.220	0.217	**0.218**	0.120	0.122	**0.121**
T_7 (S_{50}+FA)	0.033	0.033	**0.033**	0.107	0.113	**0.110**	0.213	0.220	**0.217**	0.118	0.122	**0.120**
Mean	**0.032**	**0.034**	**0.033**	**0.099**	**0.103**	**0.101**	**0.201**	**0.205**	**0.203**	**0.111**	**0.114**	**0.112**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.004	0.006	0.003	0.010	0.005	0.008	0.014

flowering and harvesting stages of the crop, the mean uptake of calcium was 0.033, 0.101 and 0.203 g pot^{-1} respectively.

Irrespective of stages of crop growth, effluent irrigation registered higher calcium uptake (0.114 g pot^{-1}) than the siruvani water (0.111 g pot^{-1}).

With regard to various amendments, addition of poultry manure @ 5 t ha^{-1} along with biosludge @ 50 t ha^{-1} had increased the overall calcium uptake to 0.121 g pot^{-1} and it was on par with other amendments and NPK application. Application of FYM @ 12.5 t ha^{-1} had little impact on calcium uptake (0.098 g pot^{-1}) and it was on par with biosludge application that caused the calcium uptake of 0.102 g pot^{-1}.

4.9.3.1.5. Magnesium uptake (Table 4.50)

The magnesium uptake by maize crop ranged between 0.010 and 0.080 g pot^{-1}. The maximum uptake of magnesium at vegetative, flowering and harvesting stages of maize was 0.020 g pot^{-1}, 0.080 g pot^{-1} and 0.067 g pot^{-1} respectively. The uptake of calcium increased upto flowering stage and thereafter showed a decreased trend. The overall uptake of magnesium during the aforesaid stages of crop was 0.017, 0.067 and 0.053 g pot^{-1} respectively.

Irrespective of stages of crop growth, effluent irrigation had maximum magnesium uptake of 0.047 g pot^{-1} than siruvani water irrigation (0.044 g pot^{-1}).

Table 4.50 Effect of effluent, biosludge and amendments on magnesium uptake(g pot^{-1}) by maize stalk

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.017	0.017	**0.017**	0.063	0.070	**0.067**	0.047	0.053	**0.050**	0.042	0.047	**0.044**
T_2 (FYM)	0.013	0.013	**0.013**	0.057	0.057	**0.060**	0.043	0.047	**0.045**	0.038	0.039	**0.038**
T_3 (S_{50})	0.010	0.013	**0.012**	0.057	0.063	**0.060**	0.047	0.047	**0.047**	0.038	0.041	**0.039**
T_4 (S_{50}+Gyp)	0.013	0.020	**0.017**	0.063	0.067	**0.065**	0.047	0.053	**0.050**	0.041	0.047	**0.044**
T_5 (S_{50}+Pr.M)	0.020	0.020	**0.020**	0.070	0.070	**0.070**	0.057	0.053	**0.055**	0.049	0.048	**0.048**
T_6 (S_{50}+Pl.M)	0.020	0.020	**0.020**	0.073	0.080	**0.077**	0.063	0.063	**0.063**	0.052	0.054	**0.053**
T_7 (S_{50}+FA)	0.020	0.020	**0.020**	0.070	0.073	**0.072**	0.060	0.067	**0.063**	0.050	0.053	**0.052**
Mean	**0.016**	**0.018**	**0.017**	**0.065**	**0.069**	**0.067**	**0.052**	**0.055**	**0.053**	**0.044**	**0.047**	**0.046**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.003	0.004	0.002	0.007	0.004	0.006	0.010

With respect to various amendments, addition of poultry manure @ 5 t ha^{-1} along with biosludge @ 50 t ha^{-1} has increased the magnesium uptake to 0.053 g pot^{-1} and it was on par with other amendments and NPK application. The least magnesium uptake was observed in FYM treatment with 0.038 g pot^{-1}.

4.9.3.1.6. Sodium uptake (Table 4.51)

The uptake of sodium by maize crop ranged from 0.01 g pot^{-1} at vegetative stage to 0.07 g pot^{-1} at harvesting stage.

The mean uptake of sodium showed an increasing trend throughout the crop growth. The uptake was 0.012 g pot^{-1} at vegetative stage; 0.045 g pot^{-1} at flowering stage and 0.058 g pot^{-1} at harvesting stage of crop growth.

Regardless of the stages of plant growth, the sodium uptake was higher 0.046 g pot^{-1} in effluent irrigation than siruvani water irrigation (0.030 g pot^{-1}).

Regarding the various amendments, application of poultry manure significantly increased the sodium uptake of 0.039 g pot^{-1} followed by pressmud (0.038 g pot^{-1}) and flyash (0.038 g pot^{-1}) which were on par with each other.

The least uptake was registered in the FYM @ 12.5 t ha^{-1} (0.031 g pot^{-1}).

4.9.3.2. Grain uptake

4.9.3.2.1. Nitrogen uptake (Table 4.52)

In general effluent irrigation has increased the nitrogen uptake by grains (0.353 g pot^{-1}) to a greater extent than siruvani water irrigation (0.323 g pot^{-1}).

Table 4.51 Effect of effluent, biosludge and amendments on sodium uptake(g pot^{-1}) by maize stalk

Treatments	calcium			Magnesium			Sodium			Potassium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.011	0.012	**0.012**	0.031	0.041	**0.036**	0.046	0.068	**0.057**	0.029	0.040	**0.035**
T_2 (FYM)	0.010	0.010	**0.010**	0.028	0.038	**0.033**	0.042	0.059	**0.051**	0.027	0.036	**0.031**
T_3 (S_{50})	0.011	0.011	**0.011**	0.032	0.036	**0.034**	0.044	0.065	**0.055**	0.029	0.037	**0.033**
T_4 (S_{50}+Gyp)	0.010	0.011	**0.011**	0.034	0.041	**0.038**	0.048	0.070	**0.059**	0.031	0.041	**0.036**
T_5 (S_{50}+Pr.M)	0.012	0.013	**0.013**	0.034	0.043	**0.039**	0.050	0.073	**0.062**	0.032	0.043	**0.038**
T_6 (S_{50}+Pl.M)	0.012	0.014	**0.013**	0.035	0.044	**0.040**	0.051	0.074	**0.063**	0.029	0.044	**0.039**
T_7 (S_{50}+FA)	0.012	0.013	**0.013**	0.034	0.045	**0.040**	0.050	0.073	**0.062**	0.032	0.044	**0.038**
Mean	**0.011**	**0.012**	**0.012**	**0.031**	**0.041**	**0.037**	**0.047**	**0.069**	**0.058**	**0.030**	**0.046**	**0.036**

CD (p=0.05) I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.001	**0.001**	**0.001**	**0.002**	**0.001**	**0.002**	**0.003**

The overall mean uptake of nitrogen by grains under siruvani water irrigation was 0.300 pot^{-1} and same was 0.319 g pot^{-1} in effluent irrigation.

Application of pressmud @ 10 t ha^{-1} along with biosludge @ 50 t ha^{-1} had increased the nitrogen uptake of maize grains to 0.333 g pot^{-1} and it was on par with other treatments and NPK application. The treatment with FYM @ 12.5 t ha^{-1} had registered the least uptake of nitrogen (0.275 g pot^{-1}) and it was on par with biosludge application that had the nitrogen uptake of 0.287 g pot^{-1}.

4.9.3.2.2. Phosphorus uptake (Table 4.52)

The effluent irrigation, in general, has increased the phosphorus uptake by grain (0.170 g pot^{-1}) to a greater extent than siruvani water irrigation that showed an uptake upto the level of 0.160 g pot^{-1}.

The overall mean uptake of phosphorus under grain in siruvani water irrigation was 0.143 g pot^{-1} and same was 0.153 g pot^{-1} in effluent irrigation.

Application of NPK fertilizer had increased the phosphorus uptake of maize grains by 0.162 g pot^{-1} and it was on par with other treatments except application of biosludge alone (0.133 g pot^{-1}) and FYM application that showed the least uptake (0.128 g pot^{-1}) which were on par with each other.

4.9.3.2.3. Potassium uptake (Table 4.52)

The potassium uptake of maize grain ranged between 0.200 g pot^{-1} and 0.230 g pot^{-1}. In general effluent irrigation had registered high potassium uptake in all the treatments except biosludge along with poultry manure.

Table 4.52 Effect of effluent, biosludge and amendments on nitrogen, phosphorus and potassium uptake (g pot^{-1}) by maize grain

Treatments	N uptake			P uptake			K uptake		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.323	0.337	**0.330**	0.160	0.163	**0.162**	0.200	0.210	**0.205**
T_2 (FYM)	0.270	0.280	**0.275**	0.123	0.133	**0.128**	0.200	0.200	**0.200**
T_3 (S_{50})	0.280	0.293	**0.287**	0.130	0.137	**0.133**	0.210	0.220	**0.215**
T_4 (S_{50}+Gyp)	0.287	0.303	**0.295**	0.140	0.143	**0.142**	0.230	0.230	**0.230**
T_5 (S_{50}+Pr.M)	0.323	0.343	**0.333**	0.147	0.163	**0.155**	0.210	0.210	**0.210**
T_6 (S_{50}+Pl.M)	0.307	0.353	**0.330**	0.150	0.170	**0.160**	0.220	0.210	**0.215**
T_7 (S_{50}+FA)	0.307	0.320	**0.313**	0.153	0.160	**0.157**	0.220	0.220	**0.220**
Mean	**0.300**	**0.319**	**0.309**	**0.143**	**0.153**	**0.148**	**0.213**	**0.214**	**0.214**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

	I	T	I X T	I	T	I X T	I	T	I X T
	0.015	0.027	0.039	0.010	0.018	0.025	0.010	0.018	0.025

Overall mean potassium uptake by maize grain was 0.213 g pot^{-1} in siruvani water irrigated treatment whereas it was 0.214 g pot^{-1} in effluent irrigation.

The maximum uptake of potassium (0.230 g pot^{-1}) was noted in treatment having biosludge with gypsum amendment. The other treatments except FYM were on par with each other. Application of FYM @ 12.5 t ha^{-1} had registered the potassium uptake of maize grain to the extent of 0.200 g pot^{-1}.

4.9.3.2.4. Calcium uptake (Table 4.53)

The calcium uptake ranged between 0.093 g pot^{-1} and 0.127 g pot^{-1}. The mean uptake of calcium by maize grain under siruvani water irrigation was 0.112 g pot^{-1} and it was lesser than effluent irrigation that registered a mean uptake of 0.118 g pot^{-1}.

In general, biosludge with poultry manure had registered the highest uptake of calcium (0.123 g pot^{-1}). The least uptake of calcium was noticed in FYM @ 12.5 t ha^{-1}.

4.9.3.2.5. Magnesium uptake (Table 4.53)

The magnesium uptake by maize grain ranged from 0.083 g pot^{-1} to 0.150 g pot^{-1}. In general uptake of magnesium was higher in effluent irrigated soils than siruvani water irrigated soils. The overall mean uptake of magnesium in these two were 0.106 and 0.104 g pot^{-1} respectively.

Irrespective of irrigation sources, the mean uptake of magnesium was the highest in poultry manure amended soils (0.137 g pot^{-1}) and it was on par

Table 4.53 Effect of effluent, biosludge and amendments on calcium, magnesium and sodium uptake (g pot^{-1}) by maize grain

Treatments	Ca uptake			Mg uptake			Na uptake		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.110	0.120	**0.115**	0.097	0.100	**0.098**	0.010	0.013	**0.012**
T_2 (FYM)	0.093	0.097	**0.095**	0.083	0.093	**0.088**	0.008	0.010	**0.009**
T_3 (S_{50})	0.103	0.113	**0.108**	0.090	0.093	**0.092**	0.009	0.012	**0.011**
T_4 (S_{50}+Gyp)	0.117	0.123	**0.120**	0.093	0.103	**0.098**	0.009	0.011	**0.010**
T_5 (S_{50}+Pr.M)	0.120	0.120	**0.120**	0.107	0.113	**0.110**	0.010	0.013	**0.012**
T_6 (S_{50}+Pl.M)	0.117	0.127	**0.123**	0.150	0.123	**0.137**	0.011	0.014	**0.013**
T_7 (S_{50}+FA)	0.123	0.123	**0.122**	0.110	0.117	**0.113**	0.010	0.014	**0.012**
Mean	**0.112**	**0.118**	**0.115**	**0.104**	**0.106**	**0.105**	**0.010**	**0.012**	**0.011**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

	I	T	I X T	I	T	I X T	I	T	I X T
CD (p=0.05)	0.008	0.016	0.022	0.007	0.012	0.018	0.0004	0.0008	0.0011

with fly ash. The least uptake was noticed in FYM (0.088 g pot^{-1}) that was on par with NPK application (0.098 g pot^{-1}), biosludge application (0.092 g pot^{-1}) and gypsum amendment (0.098 g pot^{-1}).

4.9.3.2.6. Sodium uptake (Table 4.53)

The sodium uptake ranged between 0.008 and 0.014 g pot^{-1}. The mean uptake of sodium by maize grains in siruvani water was 0.010 g pot^{-1} compared with effluent 0.012 g pot^{-1} with no significant difference.

In general, biosludge with poultry manure had registered the highest uptake of sodium (0.013 g pot^{-1}) which was on par with other treatments. The least uptake of sodium was noticed in FYM @ 12.5 t ha^{-1}.

4.9.4. Soil characteristics as influenced by biosludge, amendments and effluent

4.9.4.1. Chemical properties

4.9.4.1.1. Soil reaction (Table 4.54)

The data on soil reaction revealed that it was high under effluent irrigation compared to that of siruvani water. The soil reaction increased gradually from vegetative to harvest stages of crop growth.

Among the treatments, the mean soil reaction was high in fly ash (7.82) and under NPK (7.82) followed by biosludge (7.80) which were on par with each other and rest of the treatments. Poultry manure either with effluent or siruvani water irrigation was best, recording near neutral soil reaction (7.75).

Table 4.54 Effect of effluent, biosludge and amendments on pH of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	7.80	7.82	**7.81**	7.80	7.85	**7.83**	7.81	7.86	**7.84**	7.80	7.84	**7.82**
T_2 (FYM)	7.77	7.79	**7.78**	7.76	7.80	**7.78**	7.80	7.80	**7.80**	7.78	7.80	**7.79**
T_3 (S_{50})	7.79	7.80	**7.80**	7.79	7.81	**7.80**	7.80	7.82	**7.81**	7.79	7.81	**7.80**
T_4 (S_{50}+Gyp)	7.78	7.79	**7.79**	7.79	7.80	**7.80**	7.79	7.81	**7.80**	7.79	7.80	**7.79**
T_5 (S_{50}+Pr.M)	7.76	7.77	**7.77**	7.76	7.78	**7.77**	7.75	7.79	**7.77**	7.76	7.78	**7.77**
T_6 (S_{50}+Pl.M)	7.74	7.74	**7.74**	7.75	7.75	**7.75**	7.74	7.76	**7.75**	7.74	7.75	**7.75**
T_7 (S_{50}+FA)	7.81	7.83	**7.82**	7.81	7.76	**7.79**	7.80	7.88	**7.84**	7.81	7.82	**7.82**
Mean	**7.78**	**7.79**	**7.79**	**7.78**	**7.79**	**7.79**	**7.78**	**7.82**	**7.80**	**7.78**	**7.80**	**7.79**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.100	0.153	0.082	0.264	0.141	0.216	0.374

4.9.4.1.2. EC (Table 4.55)

The EC of the soil samples revealed that it was high under effluent irrigation than under siruvani water irrigation. The soil EC increased gradually from vegetative to harvest stages of crop growth.

Among the amendments, the mean EC value was high in gypsum (0.48 dSm^{-1}) followed by biosludge (0.47 dSm^{-1}) as well as fly ash (0.47 dSm^{-1}) which were on par with each other and other amendments except the FYM and NPK. FYM either with effluent or siruvani water recorded lower soil EC (0.42 dSm^{-1}).

4.9.4.1.3. Available N (Table 4.56)

The highest availability of nitrogen was in control (98.70 m Eq/100 g of soil) under siruvani water irrigation at vegetative stage and the lowest availability was in gypsum (87.20 m Eq/100 g of soil) under effluent irrigation at the harvesting stage.

The mean availability of nitrogen during vegetative, flowering and harvesting stage of the crop were 95.30, 94.78 and 89.72 m Eq/100 g of soil respectively. There was no significant difference between siruvani water and effluent irrigation.

The overall availability of nitrogen was the highest in poultry manure amended biosludge (95.76 m Eq/100 g of soil) followed by pressmud (94.66 m Eq/100 g of soil) and NPK (94.60 m Eq/100 g of soil) which were on par with each other. The least overall availability of nitrogen was recorded in FYM (90.91 m Eq/100 g of soil) treatment.

Table 4.55 Effect of effluent, biosludge and amendments on electrical conductivity (dSm^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.39	0.45	**0.42**	0.38	0.48	**0.43**	0.38	0.51	**0.46**	0.38	0.48	**0.43**
T_2 (FYM)	0.38	0.44	**0.41**	0.38	0.46	**0.42**	0.39	0.49	**0.44**	0.38	0.46	**0.42**
T_3 (S_{50})	0.41	0.49	**0.45**	0.41	0.52	**0.47**	0.41	0.57	**0.49**	0.41	0.53	**0.47**
T_4 (S_{50}+Gyp)	0.43	0.51	**0.47**	0.42	0.54	**0.48**	0.40	0.59	**0.50**	0.42	0.55	**0.48**
T_5 (S_{50}+Pr.M)	0.40	0.47	**0.44**	0.41	0.49	**0.45**	0.40	0.54	**0.47**	0.40	0.50	**0.45**
T_6 (S_{50}+Pl.M)	0.41	0.45	**0.43**	0.41	0.47	**0.44**	0.41	0.52	**0.47**	0.41	0.48	**0.45**
T_7 (S_{50}+FA)	0.44	0.47	**0.46**	0.43	0.49	**0.46**	0.42	0.55	**0.49**	0.43	0.50	**0.47**
Mean	**0.41**	**0.47**	**0.44**	**0.41**	**0.49**	**0.45**	**0.40**	**0.54**	**0.47**	**0.41**	**0.50**	**0.45**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.006	0.009	0.005	0.015	0.008	0.012	0.021

Table 4.56 Effect of effluent, biosludge and amendments on available nitrogen content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	98.70	98.30	**98.50**	96.30	95.80	**96.05**	89.37	89.10	**89.23**	94.79	94.40	**94.60**
T_2 (FYM)	93.32	91.90	**92.61**	91.80	91.20	**91.50**	88.80	88.45	**88.63**	91.31	90.52	**90.91**
T_3 (S_{50})	94.42	94.10	**94.26**	94.00	93.80	**93.90**	89.87	89.60	**89.73**	92.76	92.50	**92.63**
T_4 (S_{50}+Gyp)	94.10	93.80	**93.95**	93.80	93.50	**93.65**	89.20	87.20	**88.20**	92.37	91.50	**91.93**
T_5 (S_{50}+Pr.M)	96.88	96.30	**96.59**	96.30	96.00	**96.15**	92.29	90.20	**91.25**	95.16	94.17	**94.66**
T_6 (S_{50}+Pl.M)	96.87	97.83	**97.35**	98.10	97.83	**97.97**	91.63	92.30	**91.97**	95.53	95.99	**95.76**
T_7 (S_{50}+FA)	94.00	93.70	**93.85**	95.40	93.10	**94.25**	89.20	88.90	**89.05**	92.87	91.90	**92.38**
Mean	**95.47**	**95.13**	95.30	**95.10**	**94.46**	94.78	90.05	**89.39**	89.72	**93.54**	**93.00**	93.27

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
1.295	1.978	1.057	3.426	1.831	2.798	4.846

4.9.4.1.4. Available P (Table 4.57)

The highest availability of phosphorus was in control (9.30 m Eq/100 g of soil) under effluent irrigation at vegetative stage and gypsum recorded the lowest available P (7.30 m Eq/100 g of soil) under siruvani water irrigation at harvesting stage of crop growth.

The mean availability of phosphorus decreased from 8.62 m Eq/100 g of soil at vegetative stage to 7.61 m Eq/100 g of soil at the harvesting stage.

The overall availability of phosphorus was the highest in control (8.50 m Eq/100 g of soil), followed by poultry manure (8.35 m Eq/100 g of soil) and pressmud (8.32 m Eq/100 g of soil) which were on par with each other. The least availability was in FYM (7.87 m Eq/100 g of soil) followed by biosludge @ 50 t ha^{-1} (7.88 m Eq/100 g of soil) and gypsum (7.94 m Eq/100 g of soil) which were on par with each other.

4.9.4.1.5. Water extractable K (Table 4.58)

The least and highest limit of water extractable potassium in this experiment were 0.073 and 0.094 m Eq/100 g of soil respectively. In pressmud amended biosludge treatment, the interaction between siruvani water irrigation and flowering stage resulted in least availability. The interaction between vegetative stage and effluent irrigation had caused the highest availability.

The mean water extractable potassium during vegetative, flowering and harvesting stage of the crop were 0.086, 0.080 and 0.081 m Eq/100 g of

Table 4.57 Effect of effluent, biosludge and amendments on available phosphorus content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	9.20	9.30	**9.25**	8.50	8.60	**8.55**	7.60	7.80	**7.70**	8.43	8.57	**8.50**
T_2 (FYM)	8.30	8.40	**8.35**	7.80	8.00	**7.90**	7.32	7.40	**7.35**	7.80	7.93	**7.87**
T_3 (S_{50})	8.20	8.20	**8.20**	7.90	8.00	**7.95**	7.40	7.60	**7.50**	7.83	7.93	**7.88**
T_4 (S_{50}+Gyp)	8.30	8.50	**8.40**	7.80	8.17	**7.98**	7.30	7.60	**7.45**	7.80	8.09	**7.94**
T_5 (S_{50}+Pr.M)	8.90	8.80	**8.85**	8.20	8.50	**8.35**	7.70	7.80	**7.75**	8.27	8.37	**8.32**
T_6 (S_{50}+Pl.M)	8.70	8.80	**8.75**	8.40	8.50	**8.45**	7.90	7.80	**7.85**	8.33	8.37	**8.35**
T_7 (S_{50}+FA)	8.50	8.60	**8.55**	8.10	8.30	**8.20**	7.60	7.70	**7.65**	8.07	8.20	**8.13**
Mean	**8.59**	**8.66**	**8.62**	**8.10**	**8.30**	**8.20**	**7.54**	**7.67**	**7.61**	**8.08**	**8.21**	**8.14**

CD (p=0.05)

I_1 - Fresh water **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.104	0.159	0.085	0.275	0.147	0.224	0.388

Table 4.58 Effect of effluent, biosludge and amendments on available potassium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.088	0.089	**0.089**	0.085	0.086	**0.086**	0.084	0.082	**0.082**	0.085	0.086	**0.086**
T_2 (FYM)	0.085	0.084	**0.085**	0.080	0.079	**0.080**	0.079	0.080	**0.080**	0.081	0.081	**0.081**
T_3 (S_{50})	0.080	0.079	**0.080**	0.075	0.074	**0.075**	0.077	0.076	**0.077**	0.077	0.076	**0.077**
T_4 (S_{50}+Gyp)	0.079	0.081	**0.080**	0.074	0.075	**0.075**	0.077	0.076	**0.077**	0.077	0.077	**0.077**
T_5 (S_{50}+Pr.M)	0.092	0.094	**0.093**	0.073	0.074	**0.074**	0.086	0.088	**0.087**	0.084	0.085	**0.085**
T_6 (S_{50}+Pl.M)	0.091	0.092	**0.087**	0.087	0.086	**0.087**	0.085	0.086	**0.086**	0.088	0.088	**0.088**
T_7 (S_{50}+FA)	0.082	0.082	**0.092**	0.086	0.086	**0.086**	0.080	0.079	**0.080**	0.083	0.082	**0.083**
Mean	**0.085**	**0.086**	**0.086**	**0.080**	**0.080**	**0.080**	**0.081**	**0.081**	**0.081**	**0.082**	**0.082**	**0.082**

CD (p=0.05)

I_1 - Fresh water **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.001	0.002	0.009	0.003	0.002	0.002	0.004

soil respectively. There was no significant difference between siruvani water irrigation and effluent irrigation.

The overall water extractable potassium was the highest in poultry manure amended biosludge followed by NPK application (0.088 and 0.86 m Eq/100 g of soil) and it was on par with pressmud amended biosludge and fly ash amended biosludge (0.085 and 0.083 m Eq/100 g of soil respectively). The lowest water extractable potassium was recorded in biosludge alone and gypsum with biosludge (0.077 m Eq/100 g of soil).

4.9.4.1.6. Water extractable Ca (Table 4.59)

The water extractable range of calcium in soil solution was between 0.856 and 1.380 m Eq/100 g of soil. The least value was registered in vegetative stage of crop at the interaction between NPK fertilizer application and siruvani water irrigation; the highest water extractable calcium was registered at harvesting stage of the crop at the interaction between biosludge plus gypsum application with siruvani water irrigation.

The mean water extractable calcium showed an increasing trend. In all stages of crop growth, treatment with biosludge plus gypsum application on irrigation with siruvani water showed higher water extractable calcium. In other treatments effluent irrigation showed higher water extractable calcium.

Regardless of crop growth and source of irrigation, treatment with biosludge plus gypsum showed higher water extractable calcium (1.212 m Eq/100 g of soil). Flyash ranked next (0.986 m Eq/100 g of soil) and other amendments *viz.*, pressmud and poultry manure were on par (0.974 and

Table 4.59 Effect of effluent, biosludge and amendments on water extractable calcium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.865	0.903	**0.884**	0.861	0.916	**0.889**	0.856	0.940	**0.898**	0.861	0.920	**0.890**
T_2 (FYM)	0.879	0.915	**0.897**	0.873	0.920	**0.897**	0.865	0.946	**0.906**	0.872	0.927	**0.900**
T_3 (S_{50})	0.903	0.935	**0.919**	0.905	0.938	**0.922**	0.893	0.956	**0.925**	0.900	0.943	**0.922**
T_4 (S_{50}+Gyp)	1.375	1.035	**1.205**	1.380	1.049	**1.215**	1.375	1.056	**1.216**	1.377	1.047	**1.212**
T_5 (S_{50}+Pr.M)	0.945	0.985	**0.965**	0.947	0.995	**0.971**	0.944	1.025	**0.985**	0.945	1.002	**0.974**
T_6 (S_{50}+Pl.M)	0.943	0.982	**0.963**	0.945	0.982	**0.964**	0.942	0.993	**0.968**	0.943	0.986	**0.965**
T_7 (S_{50}+FA)	0.957	0.995	**0.976**	0.969	1.010	**0.988**	0.963	1.022	**0.993**	0.962	1.009	**0.986**
Mean	**0.981**	**0.964**	**0.973**	**0.982**	**0.973**	**0.978**	**0.977**	**0.991**	**0.984**	**0.980**	**0.976**	**0.978**

CD (p=0.05) I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.013	0.020	0.011	0.034	0.018	0.028	0.049

0.965 m Eq/100 g of soil). The least water extractable calcium (0.890 m Eq/100 g of soil) was noticed in NPK fertilizer application.

4.9.4.1.7. Water extractable Mg (Table 4.60)

The water extractable magnesium ranged between 0.356 and 0.535 m Eq/100 g of soil. The least was observed in harvesting stage of the crop at the interaction between siruvani water irrigation and NPK fertilizer application. The highest was observed in vegetative stage of the crop at the interaction between effluent irrigation and fly ash and biosludge application.

In general, the mean water extractable magnesium showed a decreasing trend from 0.466 to 0.430 m Eq/100 g of soil from vegetative to harvesting stage of the crop. The mean water extractable magnesium as influenced by source of irrigation showed that effluent increased the water extractable magnesium to higher extent.

Regardless of the stages of crop growth and source of irrigation, biosludge plus flyash had increased the water extractable magnesium (0.505 m Eq/100 g of soil) significantly. Treatments, biosludge plus pressmud registered the water extractable magnesium 0.468 m Eq/100 g of soil stood next and it was on par with biosludge alone and its combination with poultry manure as well as gypsum (0.459, 0.466 and 0.459 m Eq/100 g of soil respectively). NPK application had the least effect on water extractable magnesium (0.388 m Eq/100 g of soil).

4.9.4.1.8. Water extractable Na (Table 4.61)

The water extractable sodium in soil, as influenced by amendments of biosludge, stage of the crop and source of irrigation ranged between 0.319

Table 4.60 Effect of effluent, biosludge and amendments on water extractable magnesium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.400	0.415	**0.408**	0.368	0.405	**0.387**	0.356	0.379	**0.368**	0.375	0.400	**0.388**
T_2 (FYM)	0.404	0.428	**0.416**	0.381	0.417	**0.399**	0.365	0.393	**0.379**	0.383	0.413	**0.390**
T_3 (S_{50})	0.462	0.486	**0.474**	0.442	0.478	**0.460**	0.425	0.459	**0.442**	0.443	0.474	**0.459**
T_4 (S_{50}+Gyp)	0.466	0.489	**0.478**	0.449	0.477	**0.446**	0.423	0.451	**0.437**	0.446	0.472	**0.459**
T_5 (S_{50}+Pr.M)	0.473	0.495	**0.484**	0.452	0.486	**0.468**	0.437	0.461	**0.449**	0.454	0.481	**0.468**
T_6 (S_{50}+Pl.M)	0.472	0.493	**0.483**	0.450	0.484	**0.467**	0.435	0.459	**0.447**	0.452	0.479	**0.466**
T_7 (S_{50}+FA)	0.508	0.535	**0.522**	0.489	0.523	**0.506**	0.474	0.502	**0.488**	0.490	0.520	**0.505**
Mean	**0.455**	**0.477**	**0.466**	**0.433**	**0.467**	**0.448**	**0.416**	**0.443**	**0.430**	**0.435**	**0.463**	**0.449**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.011	0.006	0.018	0.010	0.015	0.026

Table 4.61 Effect of effluent, biosludge and amendments on water extractable sodium content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.319	0.634	**0.477**	0.315	0.983	**0.649**	0.312	1.208	**0.760**	0.315	0.942	**0.629**
T_2 (FYM)	0.322	0.640	**0.481**	0.320	0.981	**0.651**	0.316	1.204	**0.760**	0.319	0.942	**0.631**
T_3 (S_{50})	0.358	0.678	**0.518**	0.353	0.915	**0.634**	0.351	1.227	**0.789**	0.354	0.940	**0.647**
T_4 (S_{50}+Gyp)	0.351	0.671	**0.511**	0.349	1.005	**0.677**	0.346	1.273	**0.810**	0.349	0.983	**0.666**
T_5 (S_{50}+Pr.M)	0.362	0.680	**0.521**	0.360	1.019	**0.690**	0.358	1.239	**0.799**	0.360	0.979	**0.670**
T_6 (S_{50}+Pl.M)	0.370	0.689	**0.530**	0.367	1.024	**0.696**	0.363	1.225	**0.794**	0.367	0.979	**0.673**
T_7 (S_{50}+FA)	0.397	0.705	**0.551**	0.394	1.037	**0.716**	0.390	1.235	**0.813**	0.394	0.992	**0.693**
Mean	**0.354**	**0.671**	**0.513**	**0.351**	**0.995**	**0.673**	**0.348**	**1.230**	**0.789**	**0.351**	**0.965**	**0.658**

CD (p=0.05) I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.027	0.042	0.022	0.072	0.039	0.059	0.103

and 1.273 m Eq/100 g of soil. Both the extremes were recorded under NPK; least was at vegetative stage and the highest was at harvesting stage of the crop.

The mean water extractable sodium during vegetative, flowering and harvesting of the crop was (0.513, 0.673 and 0.789 m Eq/100 g of soil respectively and showed an increasing trend throughout the crop growth. In general, effluent irrigation showed higher water extractable sodium during all stages of crop growth and in all treatments.

Regardless of crop growth and source of irrigation, the treatment biosludge plus flyash showed the highest overall mean water extractable sodium (0.693 m Eq/100 g of soil) and it was on par with other treatments. The least was noticed in NPK (0.629 m Eq/100 g of soil).

4.9.4.1.9. Water extractable chloride (Table 4.62)

The least water extractable chloride (0.443 m Eq/100 g of soil) was registered in NPK application with siruvani water irrigation at vegetative stage of the crop. The highest water extractable chloride was registered in the interaction between effluent irrigation and biosludge plus flyash at the harvesting stage of the crop (0.620 m Eq/100 g of soil).

The water extractable chloride showed an increasing trend from 0.489 to 0.563 m Eq/100 g of soil from vegetative to harvesting stage of the crop. The mean water extractable chloride showed that it increased due to effluent irrigation.

Table 4.62 Effect of effluent, biosludge and amendments on water extractable chloride content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.443	0.480	**0.462**	0.491	0.546	**0.519**	0.504	0.585	**0.545**	0.479	0.537	**0.508**
T_2 (FYM)	0.469	0.483	**0.475**	0.494	0.552	**0.523**	0.506	0.589	**0.548**	0.489	0.541	**0.515**
T_3 (S_{50})	0.485	0.499	**0.492**	0.508	0.566	**0.537**	0.522	0.615	**0.569**	0.505	0.560	**0.533**
T_4 (S_{50}+Gyp)	0.481	0.495	**0.488**	0.506	0.561	**0.534**	0.520	0.596	**0.558**	0.502	0.551	**0.527**
T_5 (S_{50}+Pr.M)	0.493	0.508	**0.501**	0.518	0.583	**0.551**	0.533	0.613	**0.573**	0.515	0.568	**0.542**
T_6 (S_{50}+Pl.M)	0.486	0.501	**0.494**	0.512	0.576	**0.544**	0.525	0.606	**0.566**	0.508	0.561	**0.535**
T_7 (S_{50}+FA)	0.502	0.518	**0.510**	0.529	0.582	**0.556**	0.544	0.620	**0.582**	0.525	0.573	**0.549**
Mean	**0.480**	**0.498**	**0.489**	**0.508**	**0.567**	**0.537**	**0.522**	**0.603**	**0.563**	**0.503**	**0.556**	**0.530**

CD (p=0.05)

I_1 - Fresh water **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.007	0.011	0.006	0.019	0.010	0.015	0.027

Irrespective of crop growth and source of irrigation, overall mean water extractable chloride was the highest in biosludge plus flyash amendment (0.549 m Eq/100 g of soil) and it was on par with various amendments *viz.*, gypsum, pressmud and poultry manure (0.527, 0.542 and 0.535 m Eq/100 g of soil respectively).

4.9.4.1.10. Water extractable sulphate (Table 4.63)

The least water extractable sulphate (0.075 m Eq/100 g of soil) was noticed at the interaction between NPK and siruvani water irrigation at harvesting stage of the crop. The highest water extractable sulphate (0.344 m Eq/100 g of soil) was noticed at the interaction between biosludge plus gypsum and effluent irrigation at harvesting stage of the crop. The mean water extractable sulphate during vegetative, flowering and harvesting stages of the crop were 0.178, 0.185 and 0.197 m Eq/100 g of soil respectively that showed the increasing trend throughout the crop growth.

In general, effluent irrigation increased the mean water extractable sulphate in soil. Irrespective of crop growth stages and source of irrigation, biosludge plus gypsum showed the highest water extractable sulphates (0.285 m Eq/100 g of soil). The least water extractable sulphates (0.119 m Eq/100 g of soil) was registered in NPK application.

4.9.4.1.11. Water extractable bicarbonate (Table 4.64)

The water extractable bicarbonate ranged between 1.11 and 1.71 m Eq/100 g of soil. The least was due to the interaction between NPK and siruvani water irrigation at vegetative stages of the crop. The highest was

Table 4.63 Effect of effluent, biosludge and amendments on water extractable sulphate content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.082	0.139	**0.111**	0.078	0.158	**0.118**	0.075	0.186	**0.129**	0.078	0.160	**0.119**
T_2 (FYM)	0.111	0.151	**0.131**	0.106	0.168	**0.137**	0.098	0.197	**0.148**	0.105	0.172	**0.139**
T_3 (S_{50})	0.124	0.165	**0.145**	0.126	0.183	**0.155**	0.120	0.210	**0.165**	0.123	0.186	**0.155**
T_4 (S_{50}+Gyp)	0.259	0.297	**0.278**	0.251	0.315	**0.283**	0.240	0.344	**0.292**	0.250	0.319	**0.285**
T_5 (S_{50}+Pr.M)	0.139	0.179	**0.159**	0.139	0.197	**0.168**	0.132	0.224	**0.178**	0.137	0.200	**0.169**
T_6 (S_{50}+Pl.M)	0.140	0.181	**0.161**	0.141	0.198	**0.170**	0.130	0.228	**0.179**	0.137	0.202	**0.170**
T_7 (S_{50}+FA)	0.240	0.280	**0.259**	0.229	0.298	**0.263**	0.235	0.325	**0.285**	0.235	0.304	**0.270**
Mean	**0.156**	**0.199**	**0.178**	**0.153**	**0.217**	**0.185**	**0.147**	**0.246**	**0.197**	**0.152**	**0.220**	**0.187**

CD (p=0.05)

I_1 - Fresh water **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.003	0.005	0.003	0.009	0.005	0.007	0.013

Table 4.64 Effect of effluent, biosludge and amendments on water extractable bicarbonate content (m Eq 100 g^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	1.12	1.53	**1.33**	1.11	1.56	**1.34**	1.12	1.57	**1.35**	1.12	1.55	**1.34**
T_2 (FYM)	1.15	1.53	**1.34**	1.14	1.57	**1.28**	1.14	1.64	**1.39**	1.14	1.58	**1.36**
T_3 (S_{50})	1.21	1.58	**1.40**	1.21	1.61	**1.41**	1.22	1.67	**1.45**	1.21	1.62	**1.42**
T_4 (S_{50}+Gyp)	1.20	1.58	**1.39**	1.20	1.62	**1.41**	1.26	1.67	**1.47**	1.22	1.62	**1.42**
T_5 (S_{50}+Pr.M)	1.25	1.62	**1.44**	1.25	1.65	**1.45**	1.26	1.71	**1.49**	1.25	1.66	**1.46**
T_6 (S_{50}+Pl.M)	1.25	1.62	**1.44**	1.26	1.65	**1.46**	1.25	1.71	**1.48**	1.25	1.66	**1.46**
T_7 (S_{50}+FA)	1.19	1.58	**1.39**	1.19	1.65	**1.42**	1.20	1.68	**1.44**	1.19	1.63	**1.41**
Mean	**1.20**	**1.58**	1.39	**1.19**	**1.61**	1.40	**1.21**	**1.66**	1.44	**1.20**	**1.62**	1.41

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.019	0.029	0.015	0.050	0.027	0.041	0.070

due to the interaction between biosludge plus poultry manure and effluent irrigation at harvesting stage of the crop.

The mean water extractable bicarbonate during vegetative, flowering and harvesting stages of the crop were 1.39, 1.40 and 1.44 m Eq/100 g of soil respectively. In general, effluent irrigation had registered higher water extractable bicarbonate.

Irrespective of the crop growth stages and source of irrigation, poultry manure and pressmud amended biosludge had registered higher overall mean water extractable bicarbonate (1.46 m Eq/100 g of soil) and it was on par with biosludge and its amendments namely gypsum, flyash with water extractable bicarbonate of 1.42, 1.42 and 1.41 m Eq/100 g of soil respectively. The standard recommended dose of NPK had registered the least water extractable bicarbonate (1.34 m Eq/100 g of soil) and it was on par with FYM application (1.36 m Eq/100 g of soil).

4.9.4.1.12. Exchangeable Na (Table 4.65)

The exchangeable Na content was higher under effluent irrigation than in fresh water irrigation. The exchangeable Na content increased due to continuous effluent irrigation while there was no such increasing trend in the case of fresh water irrigation from vegetative to harvest stage of crop growth.

The exchangeable Na content ranged between 4.07 C mol (P^+) kg ha^{-1} in NPK under fresh water irrigation and 6.51 C mol (P^+) kg ha^{-1} in poultry manure under effluent irrigation both at the harvesting stage of crop growth.

Table 4.65 Effect of effluent, biosludge and amendments on exchangeable sodium content (cmol(p^+)kg^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	4.13	4.68	**4.41**	4.10	5.46	**4.78**	4.07	6.16	**5.12**	4.10	5.43	**4.77**
T_2 (FYM)	4.14	4.72	**4.43**	4.11	5.56	**4.83**	4.11	6.25	**5.18**	4.12	5.51	**4.81**
T_3 (S_{50})	4.29	4.89	**4.59**	4.23	5.74	**4.99**	4.21	6.42	**5.32**	4.24	5.68	**4.96**
T_4 (S_{50}+Gyp)	4.27	4.86	**4.57**	4.24	5.71	**4.98**	4.21	6.36	**5.29**	4.24	5.64	**4.94**
T_5 (S_{50}+Pr.M)	4.33	4.94	**4.64**	4.30	5.81	**5.06**	4.28	6.49	**5.39**	4.30	5.75	**5.03**
T_6 (S_{50}+Pl.M)	4.35	4.97	**4.66**	4.31	5.84	**5.08**	4.28	6.51	**5.40**	4.31	5.77	**5.04**
T_7 (S_{50}+FA)	4.39	5.01	**4.70**	4.34	6.19	**5.26**	4.32	6.30	**5.31**	4.35	5.83	**5.09**
Mean	**4.27**	**4.87**	4.57	**4.23**	**5.76**	5.00	**4.21**	**6.36**	5.28	**4.24**	**5.66**	4.95

CD (p=0.05)

I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.071	0.108	0.058	0.187	0.010	0.152	0.264

Among the treatment combinations flyash recorded highest exchangeable Na in soil (5.09 C mol (P^+) kg ha^{-1}) and the lowest value was recorded in NPK (4.77 C mol (P^+) kg ha^{-1}).

4.9.4.1.13. Exchangeable Ca (Table 4.66)

The exchangeable Ca content was higher under effluent irrigation compared to fresh water irrigation.

The exchangeable Ca content increased due to continuous effluent irrigation while the trend was reverse in case of freshwater irrigation as the crop progressed towards harvesting stage.

It ranged between 17.90 (C mol (P^+) kg ha^{-1}) in NPK under siruvani water irrigation and 27.10 C mol (P^+) kg ha^{-1} in gypsum under effluent irrigation both at the harvest.

Among the treatments, gypsum recorded highest exchangeable Ca in soil (26.65 C mol (P^+) kg ha^{-1}) and NPK registered lowest exchangeable Ca in soil (18.42 C mol (P^+) kg ha^{-1}).

4.9.4.1.14. Exchangeable Mg (Table 4.67)

Effluent irrigation recorded higher exchangeable Mg in soil compared to fresh water. It increased due to continuous effluent irrigation while decreased due to fresh water irrigation as the crop growth advanced towards harvesting stage.

Table 4.66 Effect of effluent, biosludge and amendments on exchangeable calcium content ($cmol(p^+)kg^{-1}$) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	18.10	18.50	**18.30**	18.00	18.80	**18.40**	17.90	19.20	**18.55**	18	18.83	**18.42**
T_2 (FYM)	18.90	19.20	**19.05**	18.70	19.30	**19.00**	18.50	19.60	**19.05**	18.7	19.37	**19.03**
T_3 (S_{50})	20.20	20.60	**20.40**	19.90	20.70	**20.30**	19.63	20.90	**20.27**	19.91	20.73	**20.32**
T_4 (S_{50}+Gyp)	26.10	26.80	**26.45**	26.50	26.90	**26.70**	26.50	27.10	**26.80**	26.37	26.93	**26.65**
T_5 (S_{50}+Pr.M)	21.00	21.40	**21.20**	20.90	21.60	**21.25**	20.70	21.80	**21.25**	20.87	21.60	**21.23**
T_6 (S_{50}+Pl.M)	20.90	21.30	**21.10**	20.70	21.50	**21.10**	20.60	21.70	**21.15**	20.73	21.50	**21.12**
T_7 (S_{50}+FA)	22.77	23.00	**22.88**	22.60	24.40	**23.50**	22.50	23.80	**23.15**	22.62	23.73	**23.18**
Mean	**21.14**	**21.54**	**21.34**	**21.04**	**21.89**	**21.46**	**20.90**	**22.01**	**21.50**	**21.03**	**21.81**	**21.42**

CD (p=0.05) I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.319	0.487	0.260	0.843	0.450	0.688	1.192

Table 4.67 Effect of effluent, biosludge and amendments on exchangeable magnesium content (cmol(p^+)kg^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	7.02	7.13	**7.07**	7.00	7.15	**7.08**	6.97	7.18	**7.08**	7.00	7.15	**7.07**
T_2 (FYM)	7.09	7.20	**7.15**	7.03	7.23	**7.13**	7.02	7.22	**7.12**	7.05	7.22	**7.13**
T_3 (S_{50})	7.55	7.65	**7.60**	7.51	7.66	**7.58**	7.45	7.68	**7.57**	7.50	7.66	**7.58**
T_4 (S_{50}+Gyp)	7.46	7.65	**7.56**	7.50	7.68	**7.59**	7.47	7.70	**7.59**	7.48	7.68	**7.58**
T_5 (S_{50}+Pr.M)	7.60	7.73	**7.67**	7.56	7.75	**7.66**	7.53	7.77	**7.65**	7.56	7.75	**7.66**
T_6 (S_{50}+Pl.M)	7.58	7.72	**7.65**	7.53	7.74	**7.64**	7.49	7.75	**7.62**	7.53	7.74	**7.64**
T_7 (S_{50}+FA)	8.11	8.26	**8.19**	8.15	8.28	**8.22**	8.11	8.30	**8.21**	8.12	8.28	**8.20**
Mean	**7.49**	**7.62**	**7.55**	**7.47**	**7.64**	**7.55**	**7.43**	**7.66**	**7.55**	**7.46**	**7.64**	**7.55**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.096	0.147	0.078	0.254	0.136	0.207	0.359

The values ranged between 6.97 C mol (P^+) kg ha^{-1} in NPK under siruvani water irrigation and 8.30 C mol (P^+) kg ha^{-1} in flyash under effluent irrigation.

Among the treatments, flyash and recommended NPK registered the highest (8.20 C mol (P^+) kg ha^{-1}) and the least (7.07 C mol (P^+) kg ha^{-1}) exchangeable Mg respectively.

4.9.4.1.15. Exchangeable K (Table 4.68)

Effluent irrigation recorded higher exchangeable K than that of fresh water. Irrespective of irrigation, it decreased from the vegetative to harvesting stage of crop growth.

The values ranged between 0.315 C mol (P^+) kg ha^{-1} in biosludge under siruvani water irrigation at harvesting stage and 0.374 C mol (P^+) kg ha^{-1} in pressmud under effluent irrigation at vegetative stage of crop growth.

Among the treatments, pressmud registered the maximum exchangeable Mg (0.369 C mol (P^+) kg ha^{-1}) in soil while biosludge registered the minimum exchangeable Mg of 0.320 C mol (P^+) kg ha^{-1}.

4.9.4.1.16. Exchangeable sodium per cent (ESP) (Table 4.69)

ESP was high under effluent irrigation than that of fresh water at all critical stages of crop growth . ESP increased from 14.23 at vegetative to 17.64 at harvest stage, under effluent irrigation. On the other hand ESP gradually decreased as the crop growth advanced, due to fresh water irrigation.

Table 4.68 Effect of effluent, biosludge and amendments on exchangeable potassium content (cmol(p^+)kg^{-1}) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.362	0.364	**0.363**	0.360	0.361	**0.361**	0.354	0.357	**0.356**	0.359	0.361	**0.360**
T_2 (FYM)	0.344	0.347	**0.346**	0.343	0.345	**0.344**	0.334	0.339	**0.337**	0.340	0.344	**0.342**
T_3 (S_{50})	0.323	0.324	**0.324**	0.320	0.321	**0.321**	0.315	0.316	**0.316**	0.319	0.320	**0.320**
T_4 (S_{50}+Gyp)	0.335	0.344	**0.339**	0.331	0.335	**0.3333**	0.327	0.330	**0.329**	0.331	0.336	**0.334**
T_5 (S_{50}+Pr.M)	0.371	0.374	**0.373**	0.368	0.371	**0.370**	0.362	0.368	**0.365**	0.367	0.371	**0.369**
T_6 (S_{50}+Pl.M)	0.352	0.353	**0.353**	0.350	0.352	**0.351**	0.341	0.348	**0.345**	0.348	0.351	**0.349**
T_7 (S_{50}+FA)	0.344	0.346	**0.345**	0.343	0.344	**0.344**	0.335	0.339	**0.337**	0.341	0.343	**0.342**
Mean	**0.347**	**0.350**	**0.349**	**0.345**	**0.347**	**0.346**	**0.338**	**0.342**	**0.340**	**0.344**	**0.347**	**0.345**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.004	0.007	0.004	0.012	0.006	0.010	0.017

Table 4.69 Effect of effluent, biosludge and amendments on exchangeable sodium per cent (ESP) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	13.95	15.28	**14.62**	13.92	17.19	**15.56**	13.89	18.73	**16.31**	13.92	17.07	**15.49**
T_2 (FYM)	13.59	15.00	**14.30**	13.63	17.14	**15.39**	13.66	18.70	**16.18**	13.63	16.95	**15.29**
T_3 (S_{50})	13.26	14.64	**13.95**	13.24	16.68	**14.96**	13.24	18.00	**15.62**	13.25	16.44	**14.84**
T_4 (S_{50}+Gyp)	11.17	12.23	**11.70**	10.95	14.11	**12.53**	10.93	15.46	**13.20**	11.02	13.93	**12.47**
T_5 (S_{50}+Pr.M)	13.00	14.34	**13.67**	12.98	16.35	**14.67**	13.02	17.87	**15.45**	13.00	16.17	**14.59**
T_6 (S_{50}+Pl.M)	13.11	14.47	**13.79**	13.10	16.48	**14.79**	13.08	17.93	**15.51**	13.10	16.29	**14.70**
T_7 (S_{50}+FA)	12.31	13.68	**13.00**	12.25	15.49	**13.87**	12.25	16.80	**14.53**	12.27	15.32	**13.80**
Mean	**12.91**	**14.23**	**13.57**	**12.89**	**16.21**	**14.54**	**12.87**	**17.64**	**15.25**	**12.88**	**16.03**	**14.45**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.197	0.300	0.161	0.520	0.278	0.425	0.736

Gypsum application recorded low ESP at all stages than rest of the amendments.

Among the treatment combinations, gypsum recorded the lowest ESP of 12.47 followed by flyash (13.80). The higher ESP was recorded by NPK treatment (15.49).

4.9.4.1.17. Sodium adsorption ratio (SAR) (Table 4.70)

SAR in soil increased under effluent irrigation than fresh water irrigation at all the stages of crop growth. The SAR increased from 1.28 at vegetative to 1.67 at harvest stage, under effluent irrigation. On the other hand there was no significant change in soil SAR due to siruvani water irrigation.

Among the treatments, gypsum registered the lowest SAR (1.20) which was significantly different from other treatments. The highest SAR was registered in NPK treatment (1.34) which was on par with other amendments.

4.9.5. Soil enzyme activity

4.9.5.1. Amylase (Table 4.71a)

The soil amylase activity ranged between 0.090 and 0.620 mg of glucose g^{-1} of soil. The interaction between flyash amended biosludge and effluent irrigation at vegetative stage registered the least activity. The highest activity was registered at the interaction between poultry manure amended biosludge and siruvani water irrigation at harvesting stage of the crop.

Table 4.70 Effect of effluent, biosludge and amendments on sodium adsorption ratio (SAR) of soil

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	1.17	1.31	**1.24**	1.16	1.52	**1.34**	1.15	1.70	**1.43**	1.16	1.51	**1.34**
T_2 (FYM)	1.15	1.30	**1.22**	1.15	1.53	**1.34**	1.15	1.71	**1.43**	1.15	1.51	**1.33**
T_3 (S_{50})	1.15	1.30	**1.23**	1.14	1.52	**1.33**	1.14	1.70	**1.42**	1.14	1.51	**1.32**
T_4 (S_{50}+Gyp)	1.04	1.17	**1.11**	1.03	1.38	**1.20**	1.02	1.53	**1.28**	1.03	1.36	**1.20**
T_5 (S_{50}+Pr.M)	1.14	1.30	**1.22**	1.14	1.52	**1.33**	1.14	1.69	**1.42**	1.14	1.50	**1.32**
T_6 (S_{50}+Pl.M)	1.15	1.31	**1.23**	1.15	1.53	**1.34**	1.14	1.70	**1.42**	1.15	1.51	**1.33**
T_7 (S_{50}+FA)	1.12	1.27	**1.19**	1.12	1.48	**1.30**	1.10	1.64	**1.37**	1.11	1.46	**1.29**
Mean	**1.13**	**1.28**	**1.20**	**1.13**	**1.49**	**1.31**	**1.12**	**1.67**	**1.39**	**1.13**	**1.48**	**1.30**

CD (p=0.05)

I_1 - Fresh water I_2 - Effluent (100%)

S	T	I	S X T	S X I	T X I	S X T X I
0.017	0.026	0.014	0.045	0.24	0.037	0.064

Table 4.71a **Effect on effluent, biosludge and amendments on amylase (mg of glucose g^{-1} of soil)**

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.130	0.110	**0.120**	0.220	0.200	**0.210**	0.190	0.160	**0.175**	0.180	0.157	**0.168**
T_2 (FYM)	0.310	0.200	**0.255**	0.530	0.370	**0.450**	0.470	0.310	**0.390**	0.437	0.293	**0.365**
T_3 (S_{50})	0.160	0.140	**0.150**	0.290	0.210	**0.250**	0.260	0.170	**0.215**	0.237	0.173	**0.205**
T_4 (S_{50}+Gyp)	0.163	0.130	**0.147**	0.360	0.240	**0.300**	0.340	0.200	**0.270**	0.288	0.190	**0.239**
T_5 (S_{50}+Pr.M)	0.320	0.230	**0.275**	0.610	0.430	**0.520**	0.570	0.380	**0.475**	0.500	0.347	**0.423**
T_6 (S_{50}+Pl.M)	0.360	0.250	**0.305**	0.650	0.490	**0.570**	0.620	0.410	**0515**	0.543	0.383	**0.463**
T_7 (S_{50}+FA)	0.170	0.090	**0.130**	0.300	0.130	**0.215**	0.250	0.100	**0.175**	0.240	0.107	**0.173**
Mean	**0.230**	**0.164**	**0.197**	**0.423**	**0.296**	**0.359**	**0.386**	**0.247**	**0.316**	**0.346**	**0.236**	**0.291**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.006	0.009	0.005	0.016	0.008	0.013	0.022

The mean amylase activity was the highest (0.359 mg of glucose g^{-1} of soil) at flowering stage of the crop. In general, siruvani water irrigation had increased the amylase activity over effluent irrigation at all stages of crop growth (0.230, 0.423 and 0.386 mg of glucose g^{-1} of soil respectively).

Overall mean amylase activity was the highest in poultry manure amended biosludge (0.463 mg of glucose g^{-1} of soil). The least activity of amylase (0.168 mg of glucose g^{-1} of soil) was noticed in NPK application.

4.9.5.2. Invertase (Table 4.71b)

The invertase activity ranged between 13.21 and 44.18 mg of glucose g^{-1} of soil, the least being registered at the interaction between NPK and effluent irrigation during vegetative stage of the crop. The highest was between poultry manure amended biosludge and siruvani water during harvesting stage of the crop. The mean activity of soil invertase showed an increasing trend during the cropping period from 17.89 to 26.53 mg of glucose g^{-1} of soil. In general, siruvani water irrigation had increased the soil invertase activity.

At different stages of crop growth, the poultry manure amended biosludge had shown higher invertase activity than the rest (33.30 mg of glucose g^{-1} of soil). The least was registered under NPK (16.24 mg of glucose g^{-1} of soil).

4.9.5.3. Catalase (Table 4.71c)

The least catalase activity of 3.72 μ mol H_2O_2 g^{-1} of soil was registered at the interaction between biosludge and effluent irrigation at vegetative stage. Interaction between poultry manure amended biosludge and siruvani water irrigation registered the highest catalase activity at the harvesting

Table 4.71b Effect of effluent, biosludge and amendments on invertase (mg of glucose g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	15.43	13.21	**14.32**	17.59	14.33	**15.96**	20.14	16.72	**18.43**	17.72	14.75	**16.24**
T_2 (FYM)	20.17	17.63	**18.90**	22.72	21.69	**22.21**	31.84	24.49	**28.17**	24.91	21.27	**23.09**
T_3 (S_{50})	15.68	14.91	**15.29**	18.27	15.38	**16.83**	19.17	16.97	**18.07**	17.71	15.75	**16.73**
T_4 (S_{50}+Gyp)	19.89	18.12	**19.01**	21.52	19.66	**20.59**	27.23	21.59	**24.46**	22.91	19.79	**21.35**
T_5 (S_{50}+Pr.M)	23.14	16.13	**19.64**	32.79	30.16	**31.48**	36.53	32.43	**34.48**	30.82	26.24	**28.53**
T_6 (S_{50}+Pl.M)	25.16	18.79	**21.98**	37.18	35.33	**36.26**	44.18	39.17	**41.68**	35.51	31.10	**33.30**
T_7 (S_{50}+FA)	17.01	15.13	**16.07**	19.74	17.10	**18.42**	22.19	18.64	**20.42**	19.65	16.96	**18.30**
Mean	**19.50**	**16.27**	**17.89**	**24.26**	**21.95**	**23.10**	**28.77**	**24.29**	**26.53**	**24.18**	**20.84**	**22.51**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.311	0.475	0.254	0.823	0.440	0.672	1.163

Table 4.71c Effect of effluent, biosludge and amendments on catalase (μ mol H_2O_2 g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	4.92	3.69	**4.31**	19.31	14.32	**16.82**	21.42	15.01	**18.22**	15.22	11.01	**13.11**
T_2 (FYM)	7.43	6.83	**7.13**	33.34	29.38	**31.36**	35.42	31.82	**33.62**	25.40	22.68	**24.04**
T_3 (S_{50})	4.02	3.72	**3.87**	20.93	16.85	**18.89**	22.84	17.93	**20.38**	15.93	12.83	**14.38**
T_4 (S_{50}+Gyp)	5.49	4.98	**5.24**	22.84	21.05	**21.95**	24.65	23.56	**24.10**	17.66	16.53	**17.10**
T_5 (S_{50}+Pr.M)	9.98	8.96	**9.47**	42.64	40.13	**41.39**	45.46	43.58	**44.52**	32.70	30.89	**31.79**
T_6 (S_{50}+Pl.M)	11.06	10.53	**10.80**	50.73	47.54	**49.14**	56.37	48.98	**52.67**	39.39	35.68	**37.53**
T_7 (S_{50}+FA)	4.63	3.87	**4.25**	18.69	17.49	**18.09**	20.75	18.96	**19.86**	14.69	13.44	**14.07**
Mean	**6.79**	**6.08**	**6.44**	**29.78**	**26.68**	**28.23**	**32.42**	**28.55**	**30.48**	**23.00**	**20.44**	**21.72**

CD (p=0.05)

I_1 - Fresh water **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.445	0.680	0.363	1.177	0.629	0.961	1.665

stage of the crop (56.37 μ mol H_2O_2 g^{-1} of soil). The highest mean catalase activity was noticed in harvesting stage of the crop (30.48 μmol H_2O_2 g^{-1} of soil).

In general, siruvani water irrigation had increased the mean catalase activity. In treatments, poultry manure amended biosludge had registered the highest catalase activity (37.53 μ mol H_2O_2 g^{-1} of soil) than the rest. The least activity was registered in NPK application (13.11 μ mol H_2O_2 g^{-1} of soil).

4.9.5.4. Phosphatase (Table 4.71d)

The least phosphatase activity (11.46 μg PNP g^{-1} of soil) was registered at the interaction between recommended NPK fertilizer application and siruvani water irrigation at vegetative stage of crop. The highest was (65.83 μg PNP g^{-1} of soil) was registered at the interaction between poultry manure amended biosludge and siruvani water irrigation at flowering stage of crop.

The highest mean phosphatase (44.84 μg PNP g^{-1} of soil) was registered at flowering stage. In general, siruvani water irrigation had increased the phosphatase activity. Among the treatments, poultry manure amended biosludge had registered the highest mean phosphatase activity (53.48 μg PNP g^{-1} of soil) than the rest.

4.9.6. Influence of effluent, biosludge and amendments on residual blackgram

4.9.6.1. Growth and yield attributes

4.9.6.1.1. Dry matter production (Table 4.72)

The increased DMP recorded under siruvani water irrigation (7.80 g pot^{-1}) compared to that under effluent irrigation (7.35 g pot^{-1}) which

Table 4.71d Effect of effluent, biosludge and amendments on phosphatase (μg PNP g^{-1} of soil)

Treatments	Vegetative stage (S_1)			Flowering stage (S_2)			Harvesting stage (S_3)			Mean		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	13.12	11.46	**12.29**	24.61	20.62	**22.62**	20.67	16.15	**10.41**	19.47	16.08	**17.77**
T_2 (FYM)	25.79	25.24	**25.51**	54.30	49.43	**51.86**	50.22	46.63	**40.43**	43.43	40.43	**41.93**
T_3 (S_{50})	17.17	15.35	**16.26**	34.04	27.91	**30.97**	26.17	22.55	**24.36**	25.79	21.94	**23.87**
T_4 (S_{50}+Gyp)	26.91	22.19	**24.55**	49.35	45.43	**47.39**	44.63	39.74	**42.19**	40.30	35.79	**38.04**
T_5 (S_{50}+Pr.M)	32.63	29.36	**31.00**	60.39	58.65	**59.52**	56.92	48.78	**52.85**	49.98	45.60	**47.79**
T_6 (S_{50}+Pl.M)	35.01	32.85	**33.93**	65.83	63.79	**64.81**	64.72	58.67	**61.70**	55.19	51.77	**53.48**
T_7 (S_{50}+FA)	21.43	18.39	**19.91**	39.24	34.17	**36.71**	34.41	27.93	**30.67**	31.36	26.83	**29.10**
Mean	**24.58**	**22.12**	**23.35**	**46.82**	**42.86**	**44.84**	**42.39**	**37.21**	**39.80**	**37.93**	**34.06**	**36.00**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

S	T	I	S X T	S X I	T X I	S X T X I
0.810	1.237	0.661	2.143	1.145	1.750	3.030

was in contrast to the results of maize crop wherein higher DMP was recorded in effluent irrigation.

Among the amendments, poultry manure application recorded the maximum DMP of 8.04 g pot^{-1} followed by pressmud (7.91 g pot^{-1}) and other amendments. The DMP was minimum in biosludge applied soil (6.99 g pot^{-1}) which was on par with FYM (7.02 g pot^{-1}).

4.9.6.1.2. Grain yield (Table 4.72)

Fresh water irrigation recorded higher grain yield (6.01g pot^{-1}) than effluent irrigation (5.65 g pot^{-1}).

Among the amendments, poultry manure recorded the highest grain yield (6.07 g pot^{-1}) followed by pressmud (6.02 g pot^{-1}) which was on par with each other. The lowest yield of 5.46 g pot^{-1} was recorded in biosludge which was on par with FYM (5.50 g pot^{-1}).

4.9.6.2. Soil characteristics

4.9.6.2.1. Available N, P and water extractable K (Table 4.73)

The available NPK of the residual soils decreased gradually from the post harvest soils of maize crop due to continuous effluent as well as freshwater irrigation.

Among the amendments, the availability of N and P was maximum in poultry manure amended soils with the values of 93.30 and 7.70 m Eq/100g of soil respectively. The least availability of N and P was in FYM (90.10 m Eq/100 g of soil) and biosludge (7.25 m Eq/100 g of soil) respectively. In the

Table 4.72 **Effect of effluent, bio-sludge and amendments on dry matter production (g pot^{-1}) and yield (g pot^{-1}) of residual crop**

Treatments	DMP			YIELD		
	I_1	I_2	Mean	I_1	I_2	Mean
T_1	8.02	7.59	**7.81**	6.11	5.75	**5.93**
T_2	7.27	6.76	**7.02**	5.68	5.32	**5.50**
T_3	7.28	6.69	**6.99**	5.69	5.23	**5.46**
T_4	7.90	7.46	**7.68**	6.08	5.74	**5.91**
T_5	8.06	7.76	**7.91**	6.15	5.88	**6.02**
T_6	8.22	7.86	**8.04**	6.23	5.91	**6.07**
T_7	7.87	7.35	**7.61**	6.10	5.70	**5.90**
Mean	**7.80**	**7.35**	**7.58**	**6.01**	**5.65**	**5.83**

CD (p=0.05) I_1 - Fresh water I_2 - Effluent (100%)

	I	T	I X T	I	T	I X T
	0.144	0.270	0.382	0.110	0.206	0.291

Table 4.73 Effect of effluent, bio-sludge and amendments on available nitrogen and phosphorus and water extractable potassium (m Eq 100 g^{-1}) content of post harvest soil (residual crop)

Treatments	Nitrogen			Phosphorus			Potassium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1	90.50	90.10	**90.30**	7.39	7.50	**7.45**	0.078	0.077	**0.078**
T_2	90.00	90.20	**90.10**	7.20	7.39	**7.30**	0.076	0.076	**0.076**
T_3	91.50	91.70	**91.60**	7.20	7.30	**7.25**	0.074	0.070	**0.072**
T_4	91.70	91.87	**91.78**	7.30	7.60	**7.45**	0.075	0.069	**0.072**
T_5	91.87	92.00	**91.93**	7.50	7.50	**7.50**	0.084	0.085	**0.085**
T_6	93.50	93.10	**93.30**	7.60	7.80	**7.70**	0.080	0.083	**0.082**
T_7	91.80	91.50	**91.65**	7.30	7.50	**7.40**	0.078	0.076	**0.077**
Mean	**91.55**	**91.50**	91.53	7.36	7.52	7.44	**0.078**	**0.077**	0.077

I_1 - Fresh water I_2 - Effluent (100%)

CD (p=0.05)	I	T	I X T	I	T	I X T	I	T	I X T
	1.707	3.193	4.515	0.141	0.263	0.372	0.001	0.003	0.004

case of available K, the maximum was registered in pressmud (0.085 m Eq/100 g of soil) followed by poultry manure (0.082 m Eq/100 g of soil). The least availability was registered in both biosludge and gypsum with the same value of 0.072 m Eq/100 g of soil.

4.9.6.2.2. Water extractable cations (Table 4.74)

The water extractable Ca and Na of the soil increased gradually due to continuous effluent irrigation, but water extractable Mg decreased gradually. On the other hand, no significant increase or decrease was found in the case of siruvani water irrigation.

Among the amendments, the mean water extractable Ca, Mg and Na showed different trends. In the case of Ca, the maximum content was recorded in gypsum (1.213 m Eq/100g of soil) followed by flyash (0.999 m.Eq/100 g of soil) where as the water extractable Mg (0.480 m Eq/100g of soil) and Na (0.934 m Eq/100g of soil)) were maximum in flyash amended soil. The least content of Ca (0.905 m Eq/100g of soil) Mg (0.353 m Eq/100g of soil) and Na (0.884 m Eq/100g of soil) were registered in NPK treatment.

4.9.6.2.3. Water extractable anions (Table 4.75)

The water extractable chloride, sulphate and bicarbonate increased gradually because of continuous effluent irrigation. Regarding the other source of irrigation (siruvani water) there was no significant change in the content of these anions in the soil except chloride which showed an increasing trend.

Table 4.74 Effect of effluent, biosludge and amendments on water extractable cations content (m Eq 100 g^{-1}) of post harvest soil (residual crop)

Treatments	Calcium			Magnesium			Sodium		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.845	0.965	**0.905**	0.348	0.358	**0.353**	0.315	1.453	**0.884**
T_2 (FYM)	0.858	0.973	**0.916**	0.359	0.375	**0.367**	0.321	1.449	**0.885**
T_3 (S_{50})	0.890	0.987	**0.939**	0.420	0.455	**0.438**	0.349	1.475	**0.912**
T_4 (S_{50}+Gyp)	1.372	1.053	**1.213**	0.418	0.449	**0.434**	0.349	1.475	**0.912**
T_5 (S_{50}+Pr.M)	0.941	1.039	**0.990**	0.431	0.450	**0.441**	0.355	1.481	**0.918**
T_6 (S_{50}+Pl.M)	0.938	1.010	**0.974**	0.429	0.448	**0.439**	0.359	1.477	**0.918**
T_7 (S_{50}+FA)	0.960	1.038	**0.999**	0.470	0.489	**0.480**	0.386	1.483	**0.934**
Mean	**0.972**	**1.009**	**0.991**	**0.411**	**0.432**	**0.421**	**0.348**	**1.471**	**0.909**

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

	Calcium			Magnesium			Sodium		
	I	T	I X T	I	T	I X T	I	T	I X T
CD (p=0.05)	0.193	0.036	0.051	0.008	0.015	0.021	0.020	0.038	0.054

Table 4.75 Effect of effluent, biosludge and amendments on water extractable anions content (m Eq 100 g^{-1}) of post harvest soil(residual crop)

Treatments	Chloride			Sulphate			Bicarbonate		
	I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	0.509	0.63	**0.571**	0.068	0.238	**0.153**	1.12	1.58	**1.35**
T_2 (FYM)	0.513	0.635	**0.574**	0.090	0.242	**0.166**	1.14	1.65	**1.39**
T_3 (S_{50})	0.529	0.668	**0.598**	0.111	0.257	**0.184**	1.21	1.69	**1.45**
T_4 (S_{50}+Gyp)	0.528	0.643	**0.586**	0.228	0.388	**0.308**	1.21	1.69	**1.45**
T_5 (S_{50}+Pr.M)	0.539	0.672	**0.606**	0.128	0.272	**0.200**	1.25	1.73	**1.49**
T_6 (S_{50}+Pl.M)	0.532	0.667	**0.600**	0.125	0.244	**0.184**	1.22	1.73	**1.47**
T_7 (S_{50}+FA)	0.547	0.658	**0.603**	0.227	0.370	**0.299**	1.20	1.69	**1.44**
Mean	**0.528**	**0.654**	**0.591**	**0.140**	**0.287**	**0.213**	**1.19**	**1.68**	**1.44**

CD (p=0.05)	I	T	I X T	I	T	I X T	I	T	I X T
	0.012	**0.022**	**0.032**	**0.007**	**0.013**	**0.018**	**0.027**	**0.051**	**0.073**

I_1 - Fresh water I_2 - Effluent (100%)

Regarding the amendments, the maximum mean availability of chloride (0.606 m Eq/100g of soil), sulphate (0.308 m Eq/100g of soil) and bicarbonate (1.49 m Eq/100g of soil) were recorded in pressmud, gypsum and pressmud respectively. The least availability of the respective cations were recorded in NPK treatment (0.571, 0.153, 1.35 m Eq/100g of soil respectively).

4.9.6.2.4. Exchangeable cations (Table 4.76)

In the residual blackgram soils, the exchangeable cations *viz.,* Na, Ca and Mg increased while the exchangeable K decreased gradually due to continuous effluent irrigation. The exchangeable cations were higher in effluent irrigation than in fresh water irrigation.

Among the amendments, the exchangeable cations *viz.,* Na and Mg were maximum (5.68 and 8.21 C mol (P^+) kg ha^{-1}) in flyash, whereas exchangeable Ca was maximum (26.80 C mol (P^+) kg ha^{-1}) in gypsum and the exchangeable K was maximum (0.352 C mol (P^+) kg ha^{-1}) in the NPK treatment.

4.9.6.2.5. Exchangeable sodium per cent (ESP) (Table 4.77)

ESP was high under effluent irrigation than that of fresh water irrigation in the residual soils of blackgram.

ESP increased to 18.57 in the residual soils from 17.64 in post harvest soils of maize under effluent irrigation. On the other hand ESP gradually decreased to 12.82 from 12.87 of the post harvest soils of maize under fresh water irrigation.

Table 4.76 Effect of effluent, biosludge and amendments on exchangeable cations content (cmol(p^+)kg^{-1}) of post harvest soil (residual crop)

Treatments	calcium			Magnesium			Sodium			Potassium		
				I_1	I_2	Mean	I_1	I_2	Mean	I_1	I_2	Mean
T_1 (Control)	17.60	19.50	**18.56**	6.98	7.43	**7.21**	4.04	6.66	**5.35**	0.349	0.355	**0.352**
T_2 (FYM)	18.30	20.00	**19.15**	7.00	7.27	**7.14**	4.06	6.78	**5.42**	0.330	0.336	**0.333**
T_3 (S_{50})	19.50	21.30	**20.40**	7.45	7.70	**7.58**	4.18	6.91	**5.55**	0.309	0.313	**0.311**
T_4 (S_{50}+Gyp)	26.30	27.30	**26.80**	7.44	7.71	**7.58**	4.17	6.89	**5.53**	0.322	0.328	**0.325**
T_5 (S_{50}+Pr.M)	20.50	22.10	**21.30**	7.51	7.78	**7.64**	4.25	7.01	**5.63**	0.358	0.365	**0.362**
T_6 (S_{50}+Pl.M)	20.03	22.20	**21.12**	7.48	7.76	**7.62**	4.24	7.02	**5.63**	0.338	0.346	**0.342**
T_7 (S_{50}+FA)	24.03	24.30	**23.30**	8.08	8.35	**8.21**	4.30	7.05	**5.68**	0.330	0.337	**0.334**
Mean	**20.65**	**22.39**	**21.52**	**7.42**	**7.71**	**7.57**	**4.18**	**6.90**	**5.54**	**0.334**	**0.340**	**0.337**

CD (p=0.05)

I_1 - Fresh water I_2 - Effluent (100%)

	I	T	I X T	I	T	I X T	I	T	I X T	I	T	I X T
	0.402	**0.753**	**1.065**	**0.158**	**0.296**	**0.419**	**0.109**	**0.203**	**0.288**	**0.006**	**0.012**	**0.017**

Table 4.77 **Effect of effluent, bio-sludge and amendment on exchangeable sodium per cent (ESP) and sodium adsorption ratio (SAR) of post harvest soil (residual crop)**

Treatments	ESP			SAR		
	I_1	I_2	Mean	I_1	I_2	Mean
T_1	13.95	19.62	**16.79**	1.37	1.82	**1.60**
T_2	13.67	19.72	**16.70**	1.14	1.84	**1.49**
T_3	13.30	19.08	**16.19**	1.14	1.81	**1.48**
T_4	10.91	16.32	**13.62**	1.02	1.65	**1.34**
T_5	13.03	18.82	**15.93**	1.14	1.81	**1.48**
T_6	13.21	18.81	**16.01**	1.14	1.81	**1.48**
T_7	11.70	17.61	**14.66**	1.07	1.75	**1.41**
Mean	**12.82**	**18.57**	15.70	**1.15**	**1.78**	1.47

CD (p=0.05) **I_1 - Fresh water** **I_2 - Effluent (100%)**

	I	T	I X T	I	T	I X T
CD (p=0.05)	0.303	0.567	0.812	0.075	0.139	0.197

Among the treatments, gypsum recorded the lowest ESP of 13.62 which was significantly different from the rest of the amendments. The highest was registered in control (16.79).

4.9.6.2.6. Sodium adsorption ratio (SAR) (Table 4.77)

SAR in soil increased in residual soils under effluent irrigation than fresh water irrigation.

SAR in residual soils of blackgram increased to 1.75 from 1.67 in post harvest soils of maize crop under effluent irrigation and there was no significant change in soil SAR due to siruvani water irrigation.

Among the treatment combinations, gypsum registered the lowest SAR of 1.34 and the highest SAR was in NPK treatment (1.60).

4.10. Evaluating the potential use of some biosorbents for sodium removal through batch and column experiments

4.10.1. Batch experiment

The adsorption of Na on different adsorbent materials at varying initial equilibrium concentration is given in Table 4.78. The adsorption was found low ranging from 0.9 to 35.2 mg kg^{-1}.

The regression constant, and the values of Freundlich constants, 'k' and 1/n are shown in Table 4.79. The regression analysis resulted in low to high correlation coefficient (r) values which ranged between 0.163 and 0.795.

Table 4.78. Adsorption of sodium on different adsorbent materials at different initial equilibrium concentration (mg kg^{-1})

Adsorbents	0 (ppm)	20 (ppm)	40 (ppm)	80 (ppm)	100 (ppm)
1. ICI soil	bdl	1.7	5.0	2.5	8.3
2. Red soil	bdl	6.1	10.0	13.0	14.0
3. Black soil	bdl	7.2	8.7	9.9	11.9
4. Mixed red & black	bdl	6.9	8.1	3.4	14.4
5. Vermiculite	bdl	3.2	6.1	0.9	10.9
6. Saw dust	bdl	4.3	3.5	2.3	17.3
7. Rice husk	bdl	7.2	8.3	8.9	28.9
8. Spent carbon	bdl	7.0	9.3	18.3	35.2

Table 4.79. Freundlich adsorption constants of different materials

Adsorbents	r	k (mg kg^{-1})	1/n	Equation*
1. ICI soil	0.795	0.178	0.771	0.178 $Ce^{0.771}$
2. Red soil	0.683	0.241	0.935	0.683 $Ce^{0.935}$
3. Black soil	0.481	0.675	0.610	0.675 $Ce^{0.610}$
4. Mixed red & black soil	0.344	1.048	0.431	1.048 $Ce^{0.431}$
5. Vermiculite	0.277	0.732	0.379	0.732 $Ce^{0.379}$
6. Saw dust	0.449	0.343	0.641	0.343 $Ce^{0.641}$
7. Rice husk	0.392	0.618	0.669	0.618 $Ce^{0.669}$
8. Spent carbon	0.163	2.555	0.327	2.555 $Ce^{0.327}$

* y = k $Ce^{1/n}$

where k = adsorption capacity (mg kg^{-1})

Ce = equilibrium concentration (mg l^{-1})

1/n = adsorption intensity

The soils examined showed relatively higher 'r' values suggesting a positive relationship.

The constant 'k', a measure of adsorption energy (adsorption capacity) varied from 0.178 to 2.55 mg kg^{-1}. The spent carbon recorded a higher value of 'k' (2.555 mg kg^{-1}), followed by mixed red and black soil (1.05 mg kg^{-1}) showing their effectiveness in removing Na from solution.

4.10.2. Column experiment I. (Adsorption experiment) (Table 4.80)

Among the biosorbents selected from the batch experiment, the adsorption with relevance to time, was observed effectively upto 72 hrs, (132.6 ppm) by the spent carbon whereas for rice husk and saw dust the maximum adsorption was at 24 hrs. (235.1 and 260.6 ppm respectively).

Table 4.80. Removal of Na in the effluent by adsorbents (ppm)

Materials	5 hrs.		10 hrs		24 hrs		48 hrs		72 hrs	
	Distilled water	Effluent	Distilled water	Effluent	Distilled water	Effluent	Distilled water	Effluent	Distilled water	Effluent
Spent carbon	712.5	1462.5	450.4	987.1	381.3	887.6	220.2	150.3	112.8	132.6
Rice husk	50.1	247.4	49.7	240.7	54	235.1	56.8	313.9	55.3	385.3
Saw dust	250.9	309.2	222.5	25.8	112.5	260.6	150.5	300.4	156.7	362.5

DISCUSSION

Chapter - V
DISCUSSION

The discussion on the characteristics of the pharmaceutical industrial wastes, the toxicological investigation, the column studies, the adsorption research and the various pot culture experiments are presented in this chapter.

5.1. Characteristics of pharmaceutical effluent

The effluent released from the pharmaceutical industry of the Imperial Chemical Industries (ICI), Chennai after treatment for disposal was colourless and odourless in nature. This could be ascribed to the absence of coloured materials in the effluent.

The treated effluent contained 1100 mg l^{-1} of total dissolved solids but very negligible amount of total suspended solids (13-38 mg l^{-1}). The present study is in line with the findings of Ng *et al.* (1989). This is an important parameter in evaluating the suitability of the effluent for irrigation since these solids may clog the soil pores and components of water distribution system (Feigin *et al.*, 1991).

The pH of the effluent was 7.4 and EC ranged between 1.7 and 2.8 dSm^{-1}. This moderate EC might be due to the use of different organic chemicals in the manufacturing of drugs in the pharmaceutical industry.

The organic carbon content of the treated effluent was 0.48 per cent. This could be due to presence of varying quantities of dissolved organics in the effluent.

The dissolved oxygen content was 4.8 mg l^{-1} and this low level of dissolved oxygen might be attributed to the microbial utilization of dissolved oxygen towards the breakdown of organic compounds present in the effluent. Similar view points have also been expressed by Wilber and Thomas (1969), Verma *et al.* (1974) and Someshekar *et al.* (1984).

The BOD of the effluent ranged between 15 and 50 mg l^{-1} and this might be due to effective treatment processes used in the industry. Reduction in BOD level could be due to the removal of dissolved organic compounds to some extent during the treatment process. Manivasakam (1987) reported the BOD of general pharmaceutical antibiotic waste to be between 1500 and 1900 mg l^{-1}.

The level of COD (130 - 280 mg l^{-1}) present in the effluent could be attributed to the presence of large quantities of chemical substances used in the manufacturing processes. In contrast, Manivasakam (1987) reported that the pharmaceutical industry effluent possessed very high COD. These differences might be due to the presence of varied chemical substance used by the industry in the manufacturing processes and also due to the different treatment processes adopted in the industry.

The effluent contained low concentration of plant nutrients which might be due to use of raw materials containing negligible quantities of N, P and K in the manufacturing processes. Ng *et al.* (1989) have reported the dosing of N and P in the pharmaceutical effluent to improve the nutrient content to speed up the microbial degradation.

The effluent contained appreciable amount of cations *viz.*, sodium, calcium and magnesium and anions *viz.*, chlorides, sulphates and bicarbonates.

The treated effluent of the pharmaceutical industry contained very low population level of bacteria and actinomycetes and fungal population was completely absent. The natural absence of microbial load might be associated with the raw materials used and low concentration of nutrients in the effluent for the microbial proliferation.

5.2. Characteristics of solid wastes (Plate 5.1)

The biosludge of the pharmaceutical industry was neutral in reaction and its EC was 1.85 dSm^{-1}. The organic carbon content was fairly high (11.8%) indicating that it could be biodegraded. The nitrogen content of the biosludge was 1.24 per cent and its C/N ratio was very narrow. Hence, it could be readily used as an organic manure. It has appreciable quantities of Ca and Mg, hence has ameliorative property too.

Application of solid wastes on land provides an effective and environmentally acceptable option of waste disposal which helps to recycle valuable nutrients into the soil plant system. Effective utilization of indigenous solid wastes tends to increase the soil physical conditions and helps to recycle nutrients in the soil plant ecosystem.

Among the different amendments employed in the present study FYM, pressmud,poultry manure and biosludge showed neutral pH. The highest EC was

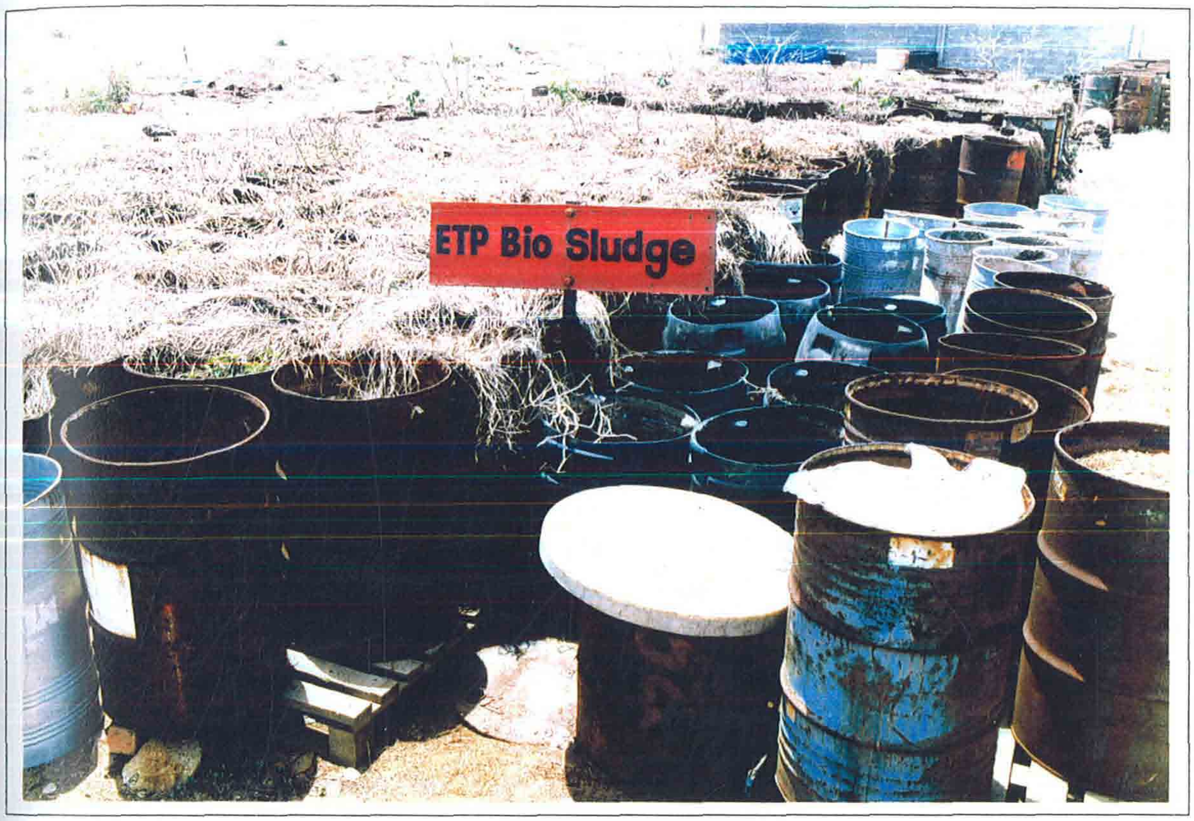


Plate 5.1. Biosludge stored drums at the pharmaceutical industrial site

recorded in poultry manure while flyash recorded the lowest EC of 1.10 dSm^{-1}. The results obtained fall in line with the findings of Kannapiran (1995), Dhevagi (1996), Kiruba (1996) and Baskar (1999).

The organic carbon content was more or less same in all the amendments. Similar trend of organic carbon content of different solid wastes were reported by Mary Celin Sandana (1995).

The essential nutrients were comparatively higher in FYM, pressmud and poultry manure than flyash, biosludge and gypsum. Ponniah (1997) reported similar trend with respect to the nutrient status of solid wastes.

The Ca, Mg and Na content were comparatively higher than FYM in all the solid wastes used as amendments. The present study fall in line with the findings of Kiruba (1996) and Ponniah (1997).

5.3. Evaluation of the biodegradability of biosludge through soil microbial activity

The increased CO_2 evolution in the biosludge (4.31 g/m^2) than control might be due to presence of biodegradable organic matter in biosludge. The increase in organic matter content of the soil due to biosludge application accelerated the microbial activity and inturn accelerated the substrate decomposition with the release of higher volume of carbondioxide. The magnitude of CO_2 formation is often taken as an index of organic matter decomposition (Subba Rao, 1988). It was clearly evident from the experiment that the biosludge emanating from the pharmaceutical industry is undoubtfully biodegradable.

5.4. Evaluation of biodegradability of spent carbon and organic waste through soil microbial activity

The decreased and poor CO_2 evolution in the spent carbon and organic waste than the control might be due to negligible amount of biodegradable organic matter and absence of microbial population in these wastes. The lower level of CO_2 evolution in spent carbon and organic waste might be contributed by the soil organic matter decomposition. So it was evident that these wastes are recalcitrant in nature which is not amenable for rapid biodegradation as that of biosludge which is highly biodegradable.

5.5. Influence of pharmaceutical industry effluent on seed germination to test the toxicity of effluent on plants

Effluent (undiluted) from pharmaceutical industry had slightly an inhibitory effect on the germination of radish seeds but had a positive effect on cucumber seeds. However, the rate of inhibition varied between the treatments. In the present study, better germination of radish seeds was observed at lower effluent concentration, on the other hand better germination was observed even at higher effluent concentration in the case of cucumber. Although salinity affects plant growth, the sensitivity varies from crop to crop. Some are tolerant during germination, become very sensitive during early seedling growth and then become increasingly more tolerant upon acclimatization (Mass and Hoffman, 1977). Dolar *et al.* (1972) reported that the reduction in germination per cent in the plant system was due to toxic effects of salts. However, the increase in germination per cent might be due to the reduction in the level of toxic metabolites by dilution and due to growth promoting substances. Inhibition of germination and growth at higher effluent concentration might be due to ex-osmosis resulting from higher concentration of salts. Germination percentage of cucumber was higher in 100 per cent effluent concentration which could be due to the salt tolerance of the seeds too. Somashekar *et al.* (1984) recorded a favourable effect of undiluted effluent on germination and seedling growth of paddy.

Interestingly the highest shoot length was recorded in the 100 per cent effluent in both radish and cucumber. On the other hand maximum reduction of root length was observed in the same treatment in both test crops. The reduction in root length could be attributed to the inhibitory effect due to the presence of dissolved salts and decomposition products as well as change in soil porosity and aeration (Somashekar *et al.*, 1984).

Though there was a wide variation between these two crops regarding the germination percentage, the most interesting observation was the dry matter production and vigour index which were highest only at lower (50%) effluent concentration for both crops and these parameters decreased as the effluent concentration increased. A similar observation has been made by Israelsen and Hansen (1962) and Mary Celin Sandana (1995).

5.6. Bioassay of pharmaceutical effluent on aquatic fauna

5.6.1. Mosquito larva and fingerlings (Plate 5.2a & 5.2b)

There was no mortality of mosquito larva and fingerlings under any of the effluent concentrations. Hence, it could be inferred that the treated effluent was not toxic to these aquatic fauna.

5.7. Bioassay of pharmaceutical effluent on microorganisms (Fig.5.1; Plate 5.3)

Toxicity of the effluent has been assessed by observing the relative growth of introduced microbes and microbial consortia.

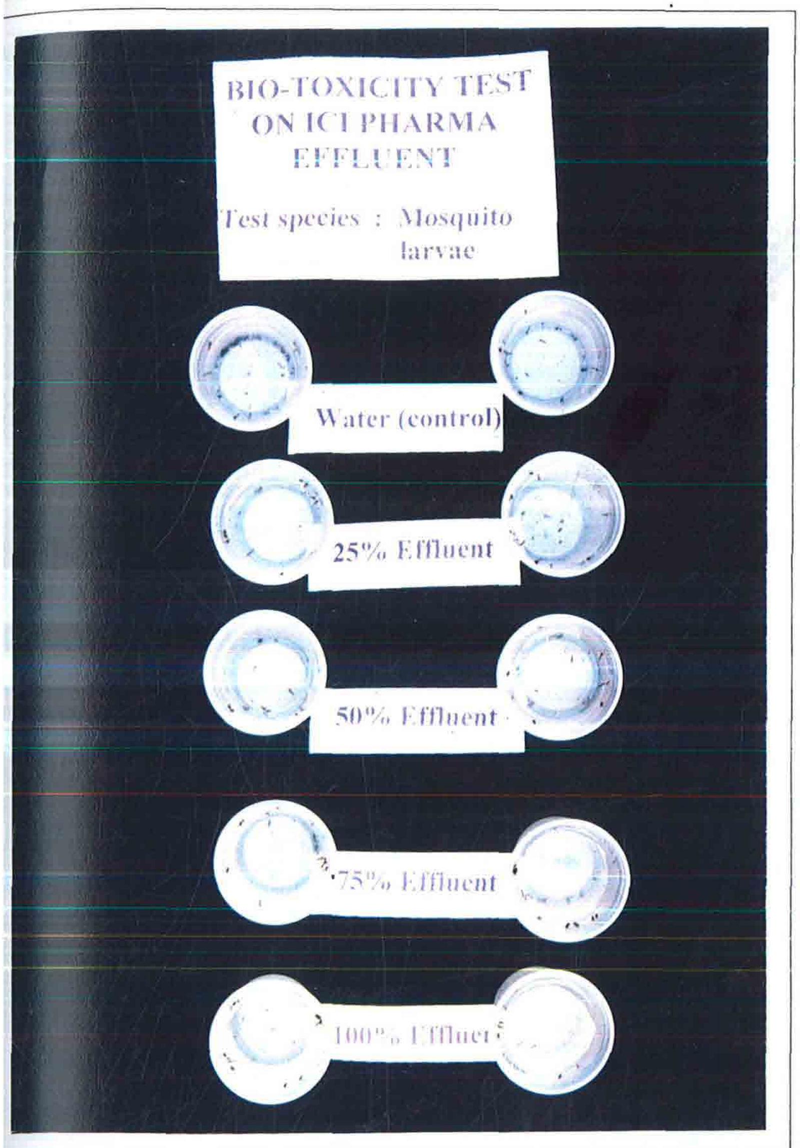


Plate 5.2a.

Biotoxicity of pharma effluent on aquatic fauna - Mosquito larva

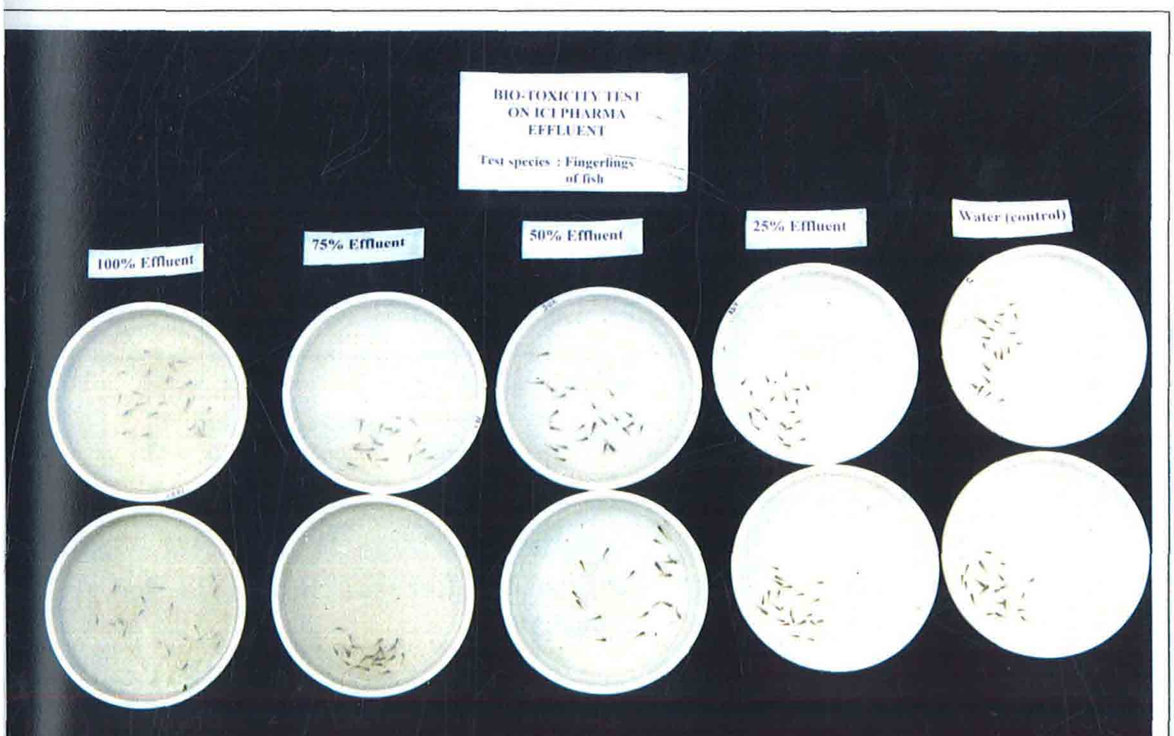
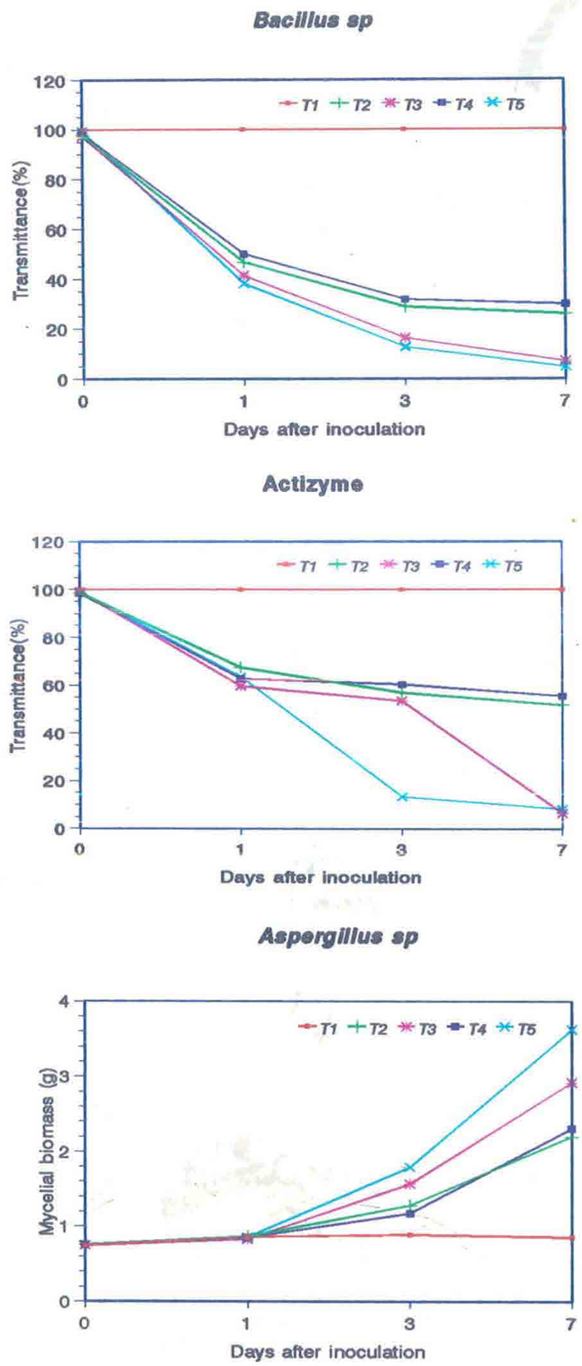
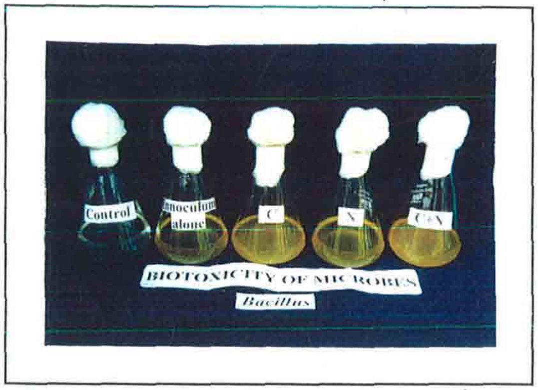


Plate 5.2b. Biotoxicity of pharma effluet on aquatic fauna - Fingerlings

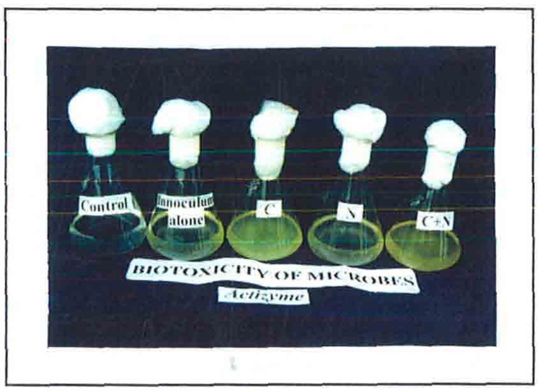


T1=Control T2=Control+Innoculant
T3=Control+Cabon+Inoculant T4=Control+Nitrogen+Inoculant
T5= Conrol+Carbon+Nitrogen +Innoculant

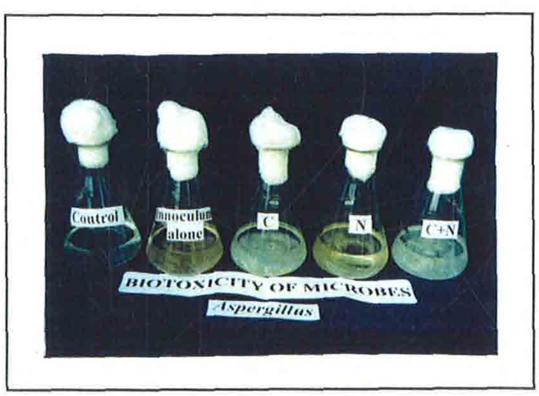
Fig.5.1 Microbial assessment of toxicity of the pharmaceutical effluent



Bacillus sp.



Actizyme



Aspergillus sp.

Plate 5.3. Biotoxicity - Microbial assessment of the pharma effluent

When the effluent was amended with carbon plus nitrogen source and inoculated with these microbes *viz., Bacillus* sp., *Aspergillus* sp. and bacterial consortia (Actizyme) had registered maximum growth of microorganisms reflecting the least toxicity of the effluent. Effluent amended with carbon source also stimulated profuse microbial biomass. It is of interest to know that the effluent amended with nitrogen source did not reduce the toxicity much. Interestingly the growth was observed even in the effluent inoculated with microorganisms alone without any nutrient sources showing clearly that the effluent was not toxic to the microorganisms tried in this study.

5.8. Pot culture experiment - Influence of graded levels of biosludge under effluent irrigation on crop growth and soil characteristics

5.8.1. Growth characteristics (Plate 5.4a, 5.4b & 5.4c)

The experimental results from the study on the influence of irrigation with treated effluent and graded levels of biosludge application on growth and yield of maize are discussed here under.

5.8.1.1. Plant height and dry matter production (DMP) (Fig.5.2)

Irrigating maize with undiluted treated effluent reduced the plant height by 5.68 per cent than 50 per cent dilution and the reduction in dry matter production was meagre (3.47 per cent). This indicated that the undiluted treated effluent could support good crop growth.

The taller plants and increased DMP recorded in 50 per cent effluent irrigation compared to 100 per cent effluent irrigation might be due to reduction in the level of dissolved salt and toxic metabolites as a consequence

Plate 5.4a. Pot culture experiment - Graded levels of biosludge and effluent irrigation on maize

Plate 5.4b. Pot culture experiment - Graded levels of biosludge under 100% effluent irrigation on maize

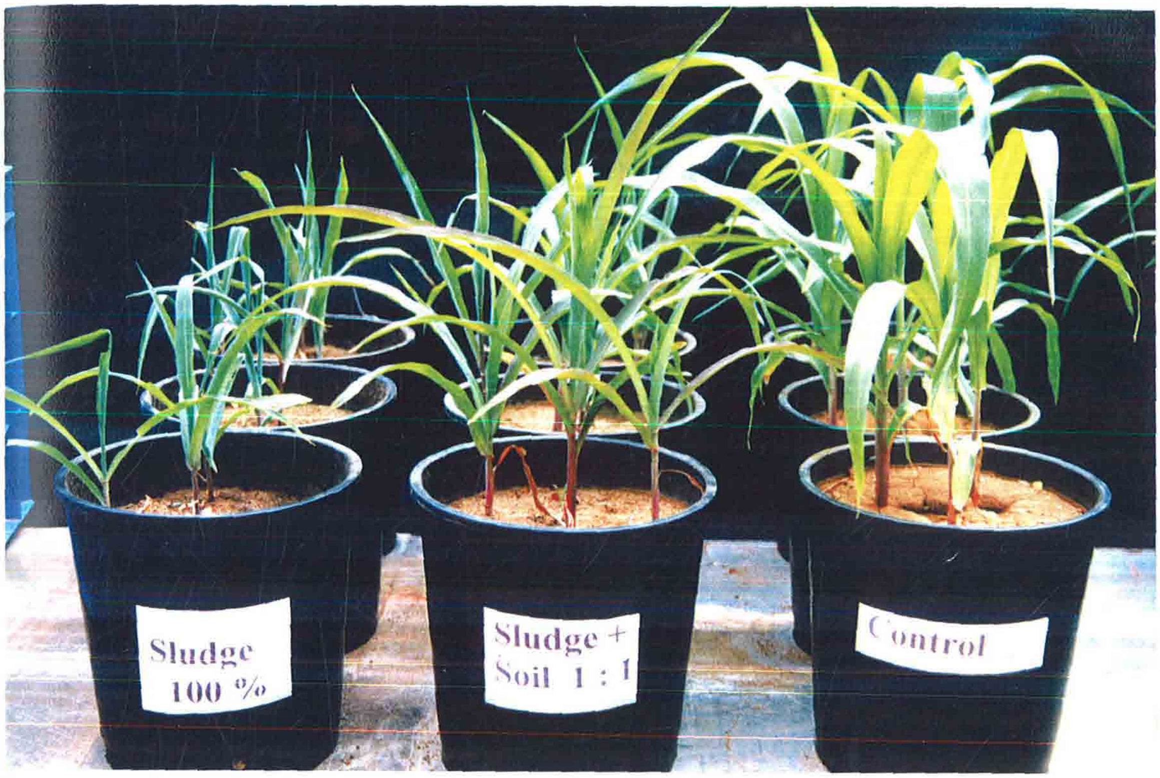
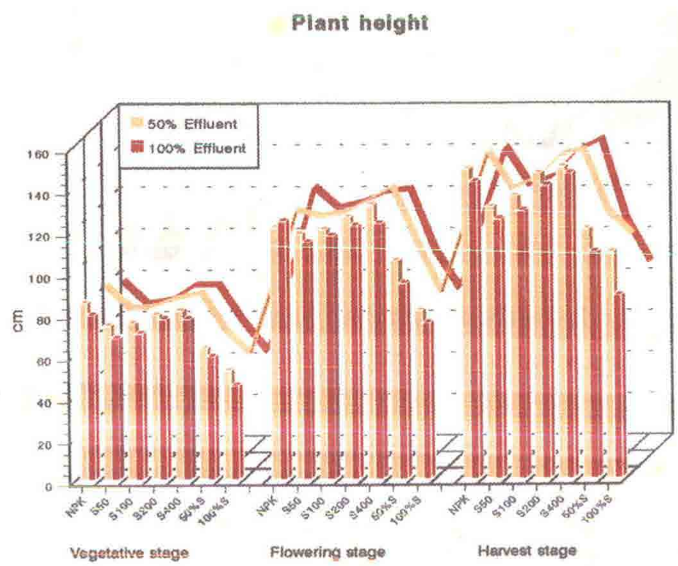


Plate 5.4c. Differences in plant height as influenced by levels of biosludge on maize

Plate 5.5. Pot culture experiment - Biosludge with amendments under effluent irrigation on maize



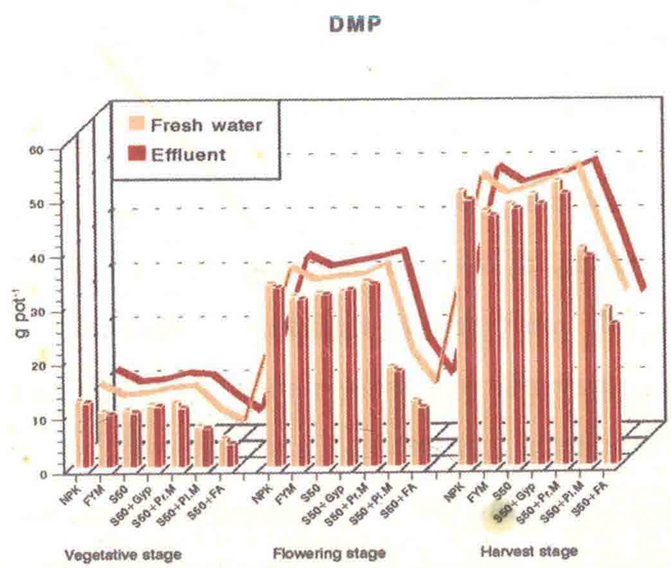


Fig.5.2 Influence of effluent and biosludge on plant height and DMP of maize

of dilution resulting in enhanced growth parameters. Sandana (1995) also observed better grain yield in maize under 50 per cent concentration of paper mill effluent than the raw effluent.

Among the graded levels of biosludge application, irrespective of sources of irrigation, dosage at 400 t ha^{-1} recorded significantly taller plants and maximum DMP which was comparable with that of standard NPK treatment. On the other hand, as the dosage of biosludge increased beyond 400 t ha^{-1}, the growth of plant decreased. This was evident from this experiment wherein the shorter plants and the lowest DMP were recorded in the 100 per cent biosludge application without soil media, followed by 50 per cent biosludge application. This growth reduction in plant system might be due to the toxic effects of excessive salts on soil permeability and nutrient availability.

5.8.2. Grain yield (Fig.5.3)

Fifty per cent effluent irrigation recorded increasing grain yield compared to that of 100 per cent effluent irrigation which might be due to availability of enhanced nutrient status from the soil resulting from the dilution. Similar results were reported by Dhevagi (1996) with diluted paper mill effluent for the crops *viz.*, groundnut, sunflower and maize. The grain yield increase under 50 per cent dilution was only 4.5 per cent and hence even undiluted effluent has been established to support good crop growth and productivity.

Among the graded levels of biosludge, the maximum yield was noticed under NPK fertilizer application followed by biosludge @ 200 t ha^{-1} which

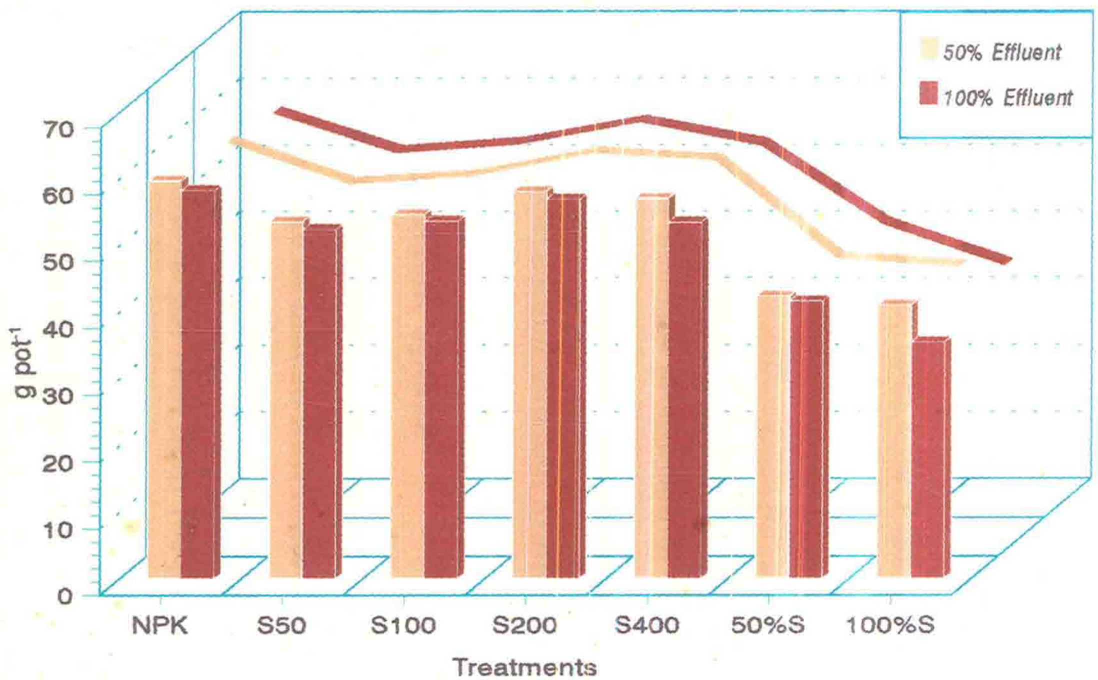


Fig.5.3 Influence of effluent and biosludge on grain yield of maize

ranked first among the different graded levels and was comparable in effect with that of NPK application. It could be inferred that incorporation of the biosludge alone at the dose of 200 t ha^{-1} was equal in its manurial value with that of NPK fertilization and hence substitute the costly inorganic fertilizer and significantly reduce the cost of cultivation too. This might be due to correct blend of soil and biosludge with the effluent irrigation which made the microflora of the soil to produce more enzymes at this level of treatments. Interestingly, the grain yield went down as the dosage of biosludge increased. So at a point of dosage, (200 t ha^{-1}) the maximum yield was obtained which clearly showed that biosludge at 200 t ha^{-1} will be the optimum dosage for application in the soil. The lowest grain yield was registered in the 100 per cent biosludge application followed by 50 per cent biosludge which might be due to the lower biomass production in these treatments and also due to the shocking load of the biosludge which contained excessive salts which impaired the biological activity and nutrient availability.

5.8.3. Plant nutrient uptake

5.8.3.1. Stalk uptake

5.8.3.1.1. Uptake of macro nutrients (Fig.5.4)

The nutrient uptake in maize stalk increased in treatments receiving effluent diluted to 50 per cent than 100 per cent treated effluent.

In general, the nutrients (N and P) uptake showed an increasing trend till flowering stage, later declined as the crop approached the harvesting stage. On the other hand, K showed increasing trend till the harvesting stage.

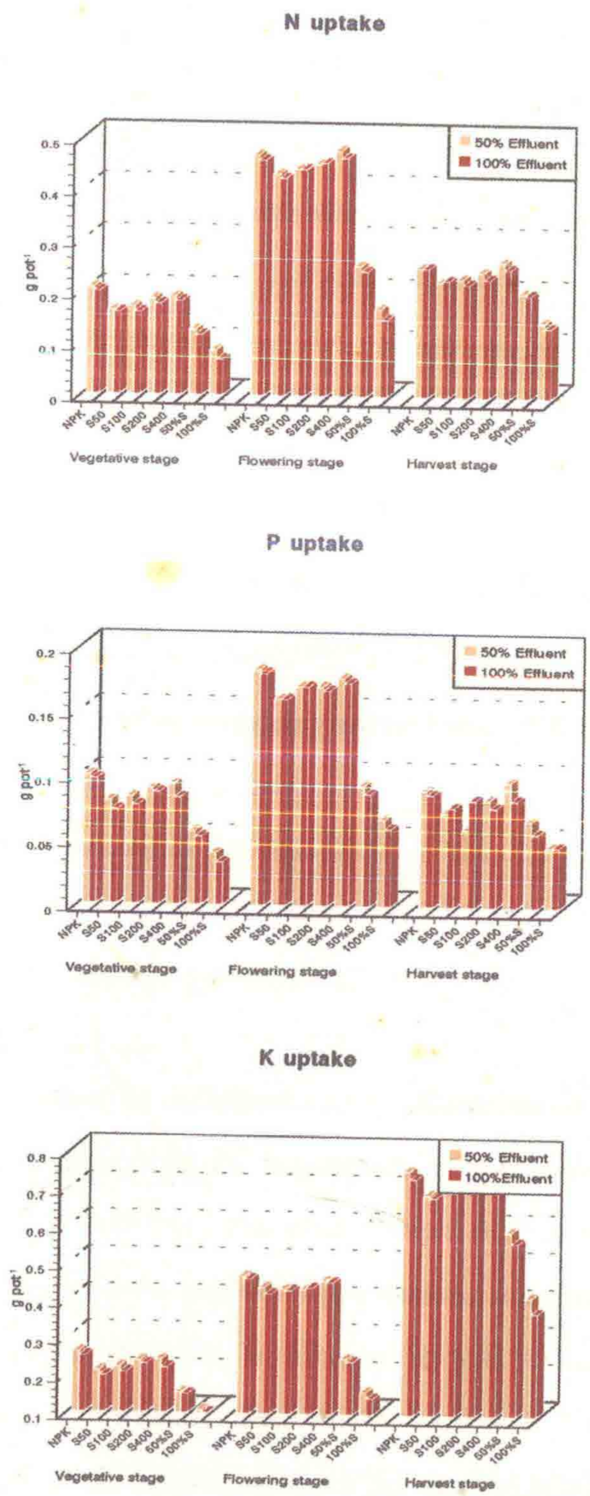


Fig.5.4 Influence of effluent and biosludge on NPK uptake of maize stalk

The nutrient uptake was maximum in NPK application which was followed by application of biosludge at 200 t ha^{-1} and 400 t ha^{-1}. The least uptake was in treatment having 100 per cent biosludge which might be due to high shocking load of biosludge which inhibited the availability of nutrients to the plant and subsequently lowered biomass production in the 100 per cent biosludge applied treatment. The results of present study in these aspects contradicted the findings of Alfred (1998) who reported that the application of effluent treatment plant (ETP) sludge emanating from paper mill industry had higher uptake of plant nutrients when applied as such in the soil. This may be due to higher percentage of N, P and K in the ETP- sludge.

5.8.3.1.2. Uptake of secondary nutrients (Fig.5.5)

The secondary nutrients *viz.*, Ca, Mg and Na uptake in maize stalk increased in treatments irrespective of the 50 per cent and 100 per cent effluent irrigation along with the graded levels of biosludge. This might be due to presence of these constituents in the effluent as well as the biosludge.

With respect to different levels of biosludge application, the uptake of Ca and Mg was higher in treatment with biosludge @ 100 t ha^{-1} which significantly differed from the other levels of biosludge application and least uptake was noticed in control application, whereas the uptake of Na was higher in treatment with biosludge @ 400 t ha^{-1} in which the biomass production was maximum. This might be due to the presence of appreciable level of these secondary nutrients in the biosludge which contributed to higher uptake of Ca, Mg and Na in the maize stalk.

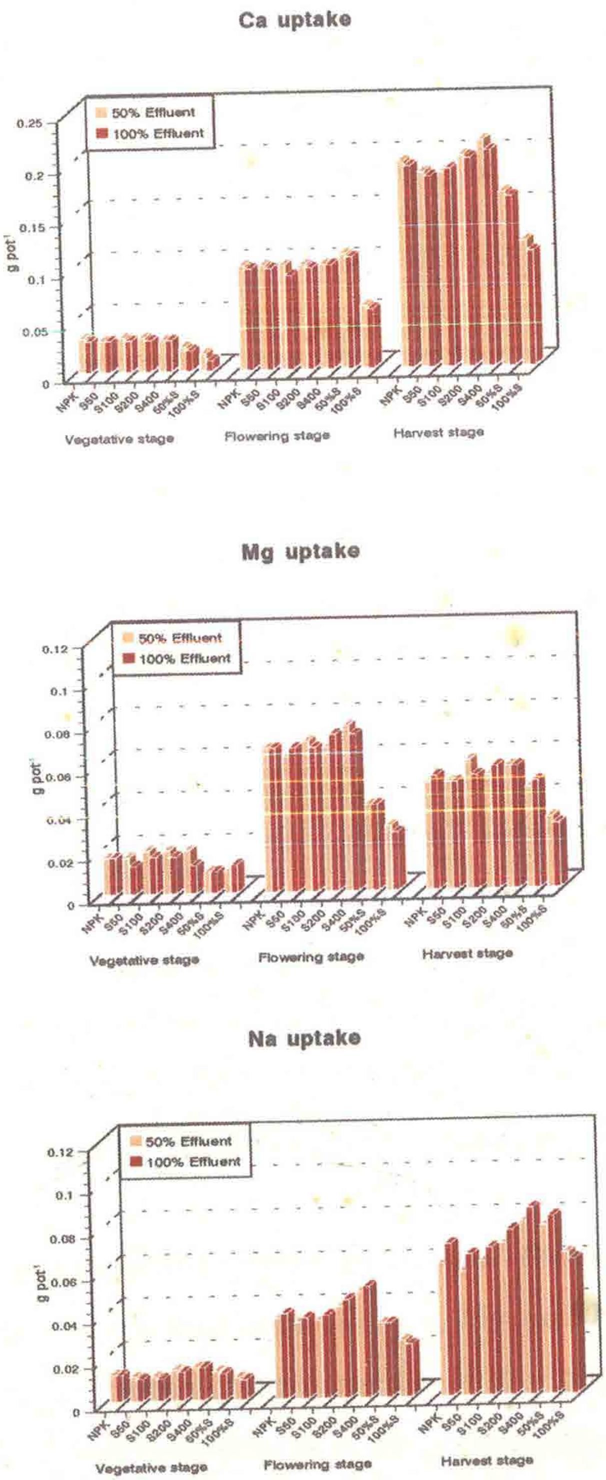


Fig.5.5 Influence of effluent and biosludge on Ca,Mg and Na uptake of maize stalk

5.8.3.2. Grain uptake

5.8.3.2.1. Uptake of macro nutrients (Fig.5.6)

The nutrient uptake by maize grain had increased in treatment receiving 50 per cent effluent irrigation than the 100 per cent effluent irrigation.

Regarding the different levels of biosludge application, the maximum uptake was found in NPK application which was on par with biosludge @ 200 t ha^{-1} followed by other graded levels of biosludge application. It could be inferred that the quality of grain too was not affected by exclusively applying the biosludge alone @ 200 t ha^{-1} as against the 100 per cent NPK application. The uptake was least in the treatment containing 100 per cent biosludge application which was on par with 50 per cent biosludge application. This might be due to heavy load of these biosludge which might have altered the physical and biological environment of the soil thereby blocking the availability of the nutrients from soil to plant system and also due to very low drymatter production in these treatments which again contributed to low supply of these nutrients to the grains. The present study was in line with the findings of Sankar *et al.* (1995) who reported a decrease in nutrient uptake by groundnut due to sludge application.

5.8.3.2.2. Uptake of secondary nutrients (Fig.5.7)

The secondary nutrients *viz.*, Ca, Mg and Na uptake in maize grain increased under treatments irrespective of the irrigation sources. In general, the treatment receiving effluent of 50 per cent dilution increased the uptake than the 100 per cent effluent irrigation. On the other hand, there was no significant difference in sodium uptake between the effluent concentrations.

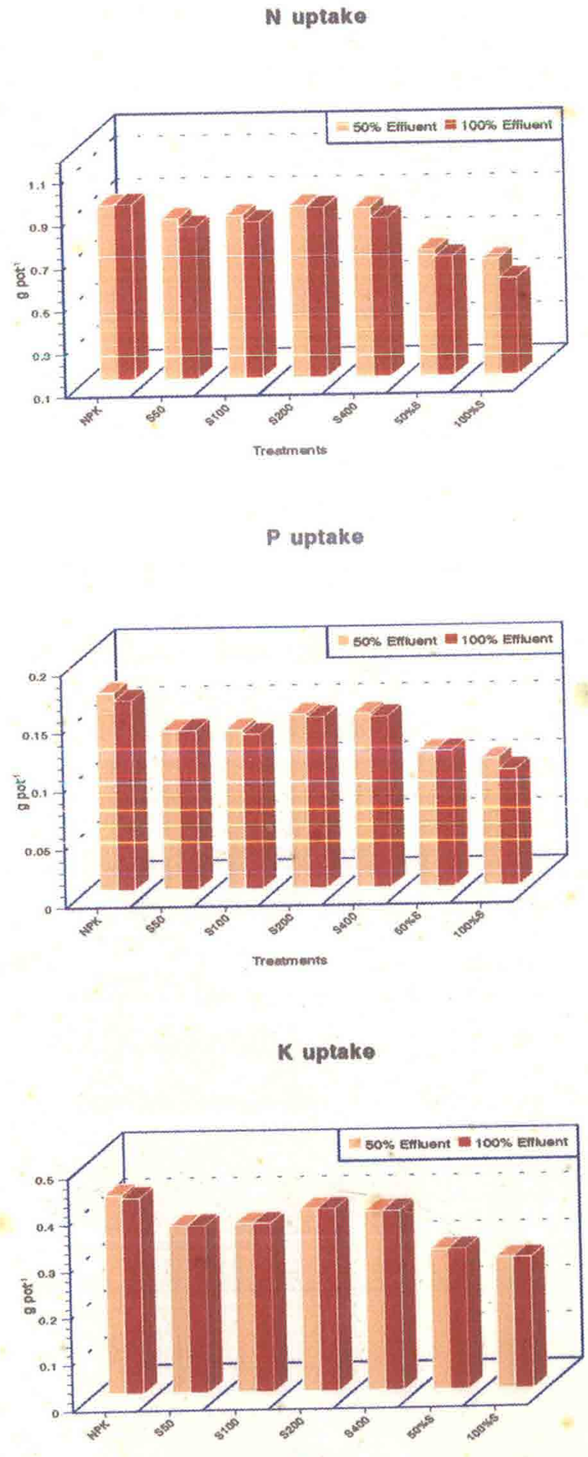
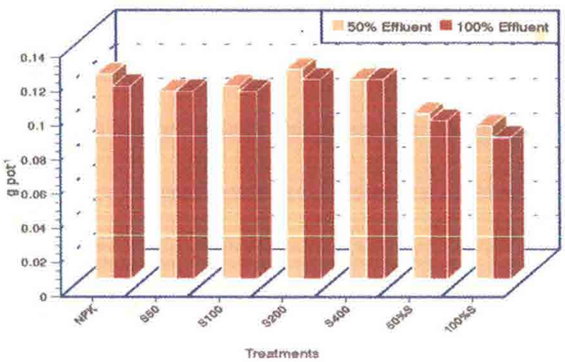
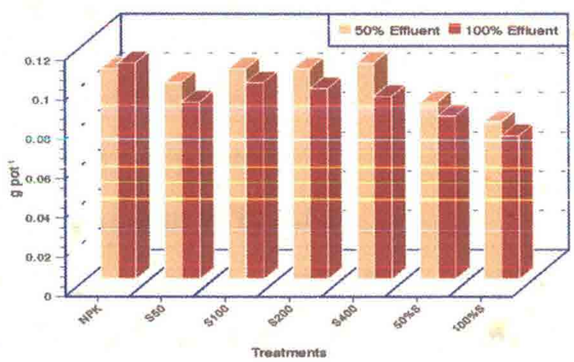


Fig.5.6 Influence of effluent and biosludge on NPK uptake of maize grain

Ca uptake



Mg uptake



Na uptake

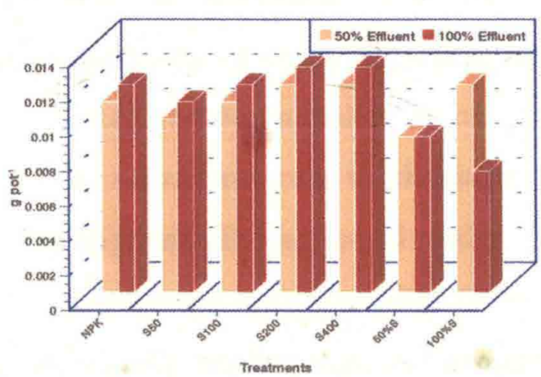


Fig.5.7 Influence of effluent and biosludge on Ca,Mg and Na uptake of maize grain

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With respect to different levels of biosludge application, the uptake of Ca by the maize grain was higher at 200 t ha^{-1} of biosludge application whereas the maximum of Mg by the grain was in the NPK fertilizer application. The least uptake of the secondary nutrients by the grain was registered in 100 per cent biosludge application. Martens *et al.* (1970) reported that there were possibilities of obtaining inconsistent trend in the uptake of Ca and Mg and they attributed to the interactions of those elements in the root-soil-solution interface or within the plant system. Regarding the sodium uptake by grains, the higher uptake was registered in 200 and 400 t ha^{-1} of biosludge application and there was no significant difference between the other treatments.

5.8.4. Soil characteristics

5.8.4.1. Chemical properties

5.8.4.1.1. Soil reaction (Fig.5.8)

Continuous effluent irrigation irrespective of the concentration increased slightly the soil pH gradually from vegetative to harvesting stage. The soil reaction was higher by 0.02 units only in 100 per cent effluent irrigation than under 50 per cent effluent irrigation both being on par. This might be due to reduction of salts and other metabolites because of dilution which was supported by Somashekar *et al.* (1984) who also reported that dilution played an important role in checking the soil reaction towards the extreme pH. The highest pH was found under NPK treatment and the lowest was recorded in the 50 per cent biosludge followed by 100 per cent biosludge treatment. The organic acids released through microbial decomposition of biosludge could be the reason for the observed reduction in pH (Olaniya *et al.*, 1991).

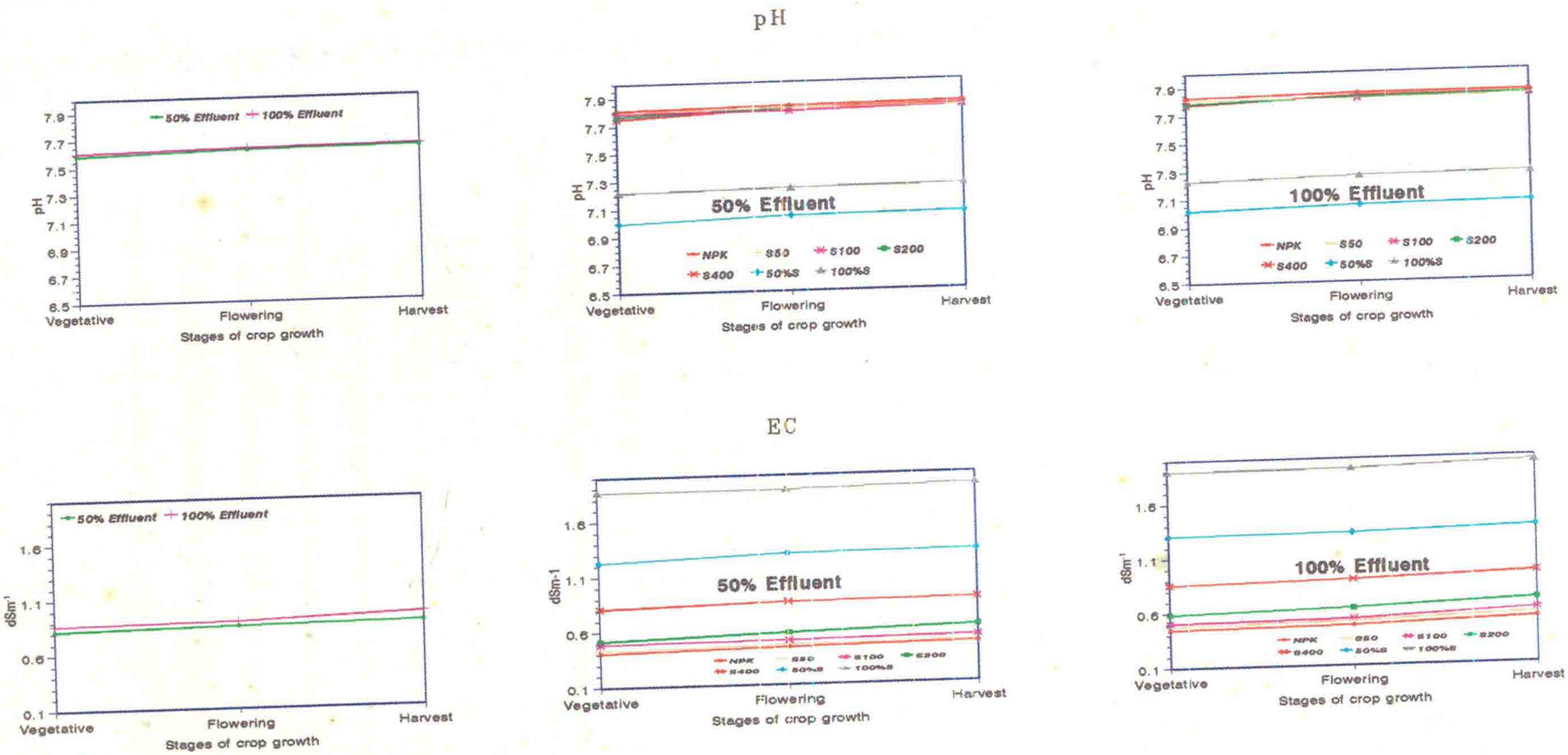


Fig.5.8 Influence of effluent and biosludge on pH and EC of soil

5.8.4.1.2. EC (Fig.5.8)

The EC of the soil increased at all critical stages of crop growth due to continuous effluent irrigation irrespective of graded levels of biosludge application and dilution. But a higher EC value (an increase of meagre 0.05 unit) was recorded in the 100 per cent effluent irrigation because of the presence of high soluble salts in it when compared to the diluted one (50% effluent). Among the dosage of biosludge applied, 100 per cent biosludge applied treatment recorded the highest EC value followed by 50 per cent biosludge application. This might be due to the contribution of salts both from the biosludge as well as the irrigation source. The standard NPK treatment recorded the lowest EC which was in line with the findings of Shivakant and Rajkumar (1992).

5.8.4.1.3. Available NP & Water extractable K (Fig.5.9)

The availability of the essential nutrients in soil showed decreasing trend as the crop growth advanced, irrespective of irrigation source. This might be due to the utilization of part of these nutrients for plant growth. This is in line with the findings of Mary Celin Sandana (1995) in case of paper mill effluent.

Among the graded levels of biosludge application, the overall availability of N and P was maximum in 100 per cent biosludge and the availability decreased as the dose of biosludge decreased. On the other hand the availability of K was very low in 100 per cent biosludge and it increased as the dose of biosludge decreased to that of the soil mixture. This might be due to presence of N and P in higher amount in contrast to that of K in the

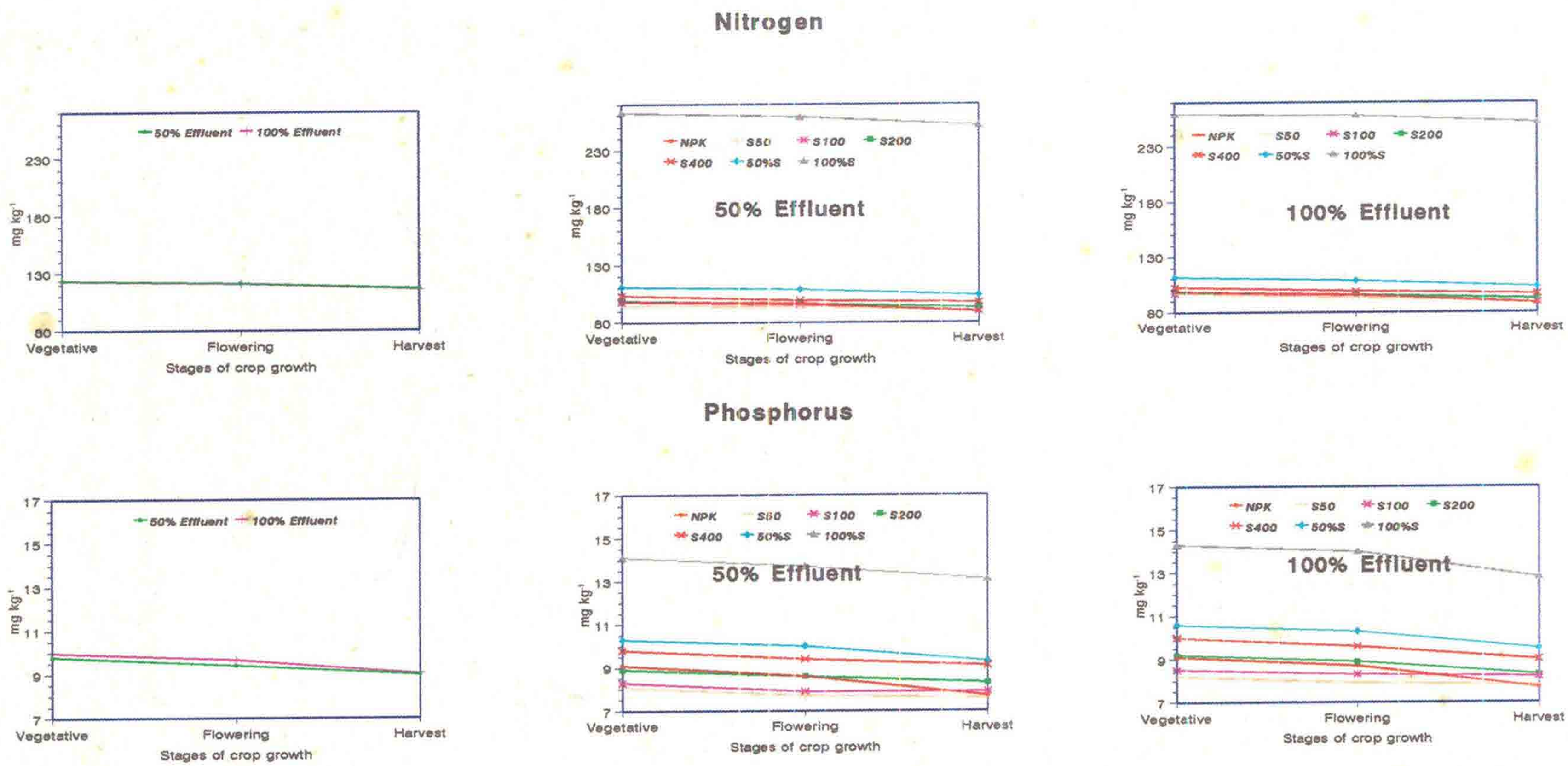


Fig.5.9 Influence of effluent and biosludge on available N and P contents of soil

biosludge. So it could be inferred that biosludge should be supplemented with potash to improve the balanced nutrient status of the biosludge.

5.8.4.1.4. Water extractable cations

The water extractable cations Ca, Mg and Na increased in the soil both under 50 and 100 per cent effluent irrigation and under different graded levels of biosludge application. The 100 per cent effluent irrigation recorded higher water extractable cations compared to 50 per cent effluent irrigation.

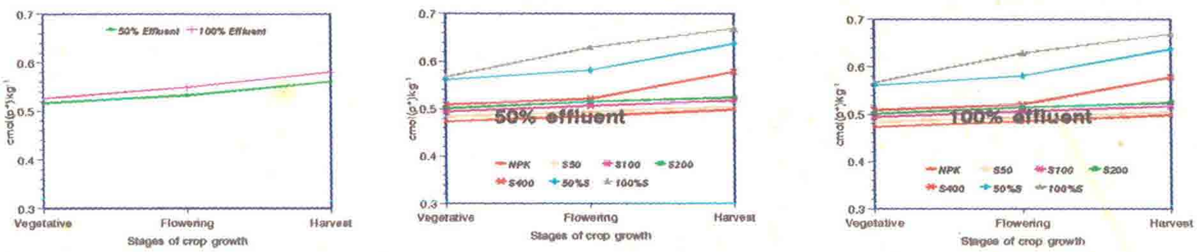
The water extractable Ca and Na increased from vegetative to harvest stage of crop growth but soil water extractable Mg decreased as the crop growth advanced towards the harvest stage which might be due to continuous uptake of Mg till the harvest stage of crop growth.

Among the graded levels of biosludge application, the maximum water extractable cations was recorded in 100 per cent biosludge with 100 per cent effluent irrigation followed by 50 per cent biosludge application and the least cation content was recorded in control which was comparable with that of application of biosludge at 50 t ha^{-1}. The presence of high content of these cations in soils might be due to the presence of these salts in the two component systems of effluent as well as the biosludge. This was in agreement with the findings of Sastry *et al.* (1974) and Oblisami and Palanisami (1991) who recorded higher concentration of water extractable cations under effluent irrigation along with sludge application.

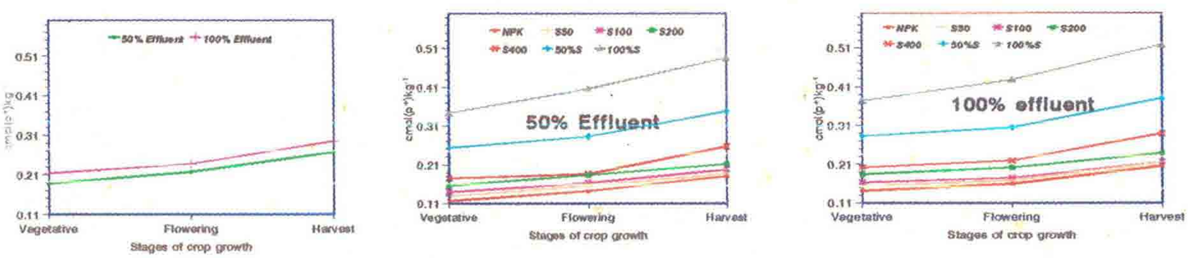
5.8.4.1.5. Water extractable anions (Fig.5.10)

The water extractable anions *viz.*, chlorides, bicarbonates and sulphates in the soil increased under all the levels of biosludge application

Chloride



Sulphate



Bicarbonate

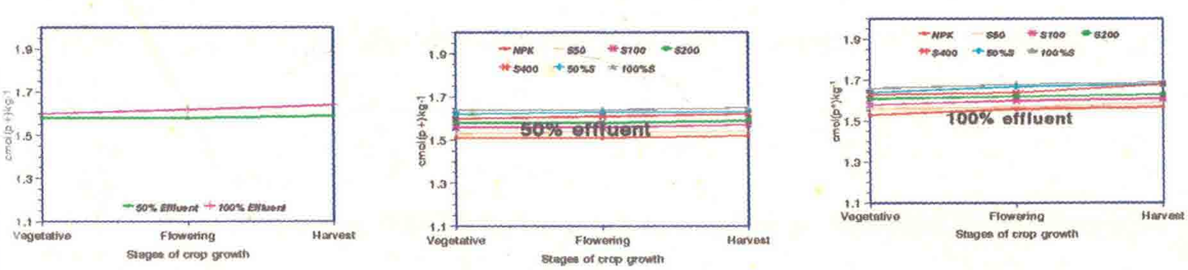


Fig.5.10 Influence of effluent and biosludge on water extractable anions of soil

irrespective of the irrigation sources. But the availability of these anions was higher in soils irrigated with 100 per cent effluent irrigation than the 50 per cent effluent irrigation. This could be due to the presence of these anions in the effluent. The availability of these anions registered an increasing trend from the vegetative to harvest stage which could be due to the continuous irrigation of the effluent in the soil. Somashekar *et al.* (1984) reported similar results in soils irrigated continuously with the paper mill effluent.

Among the different levels of biosludge application, the water extractable anions were higher in the treatments containing 100 per cent biosludge followed by 50 per cent, 400 t ha^{-1} and 200 t ha^{-1} and thereon. The least availability was registered in NPK treatment without any biosludge application. These could be due to presence of these anions both in the effluent as well as the biosludge.

5.8.4.1.6. Exchangeable cations (Fig.5.11)

In general, the exchangeable cations were higher under 100 per cent effluent than its diluted form (50% form). This was due to the reduction in the level of metabolites and salts as a consequence of dilution. The exchangeable cations *viz.* Na, Ca and Mg increased in soil irrespective of the dilution as the stages of crop growth advanced.

The exchangeable K decreased towards the harvest stage irrespective of dilution. The reason for the former might be due to presence of these cations in considerable amount in the pharmaceutical effluent and the latter might be due to higher uptake of K by plant system.

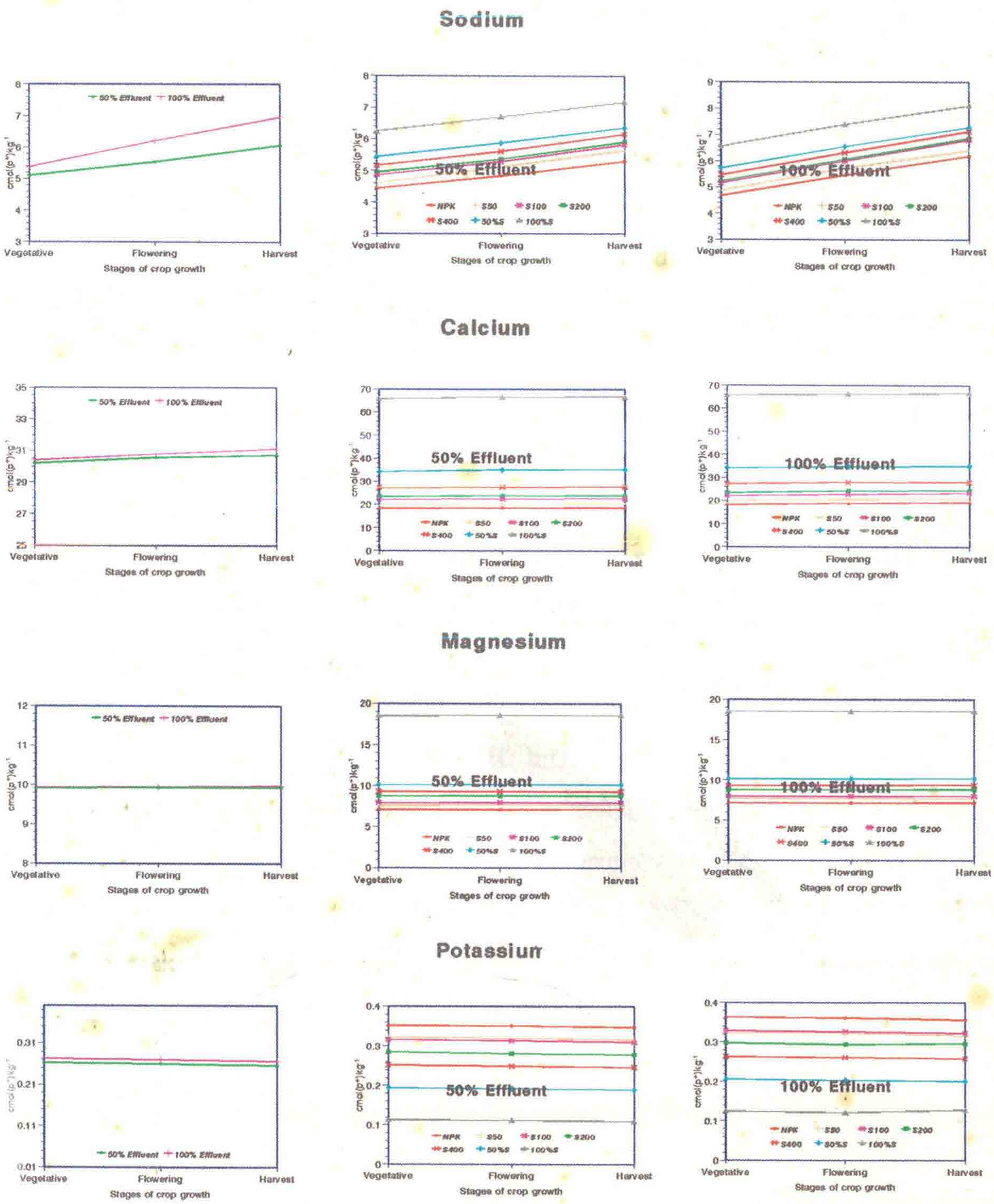


Fig.5.11 Influence of effluent and biosludge on exchangeable cations of soil

Among the graded levels of biosludge application, the maximum content of exchangeable cations *viz.*, Na, Ca and Mg were recorded under 100 per cent biosludge application and least exchangeable values were in control. The reverse trend was true in the case of exchangeable K wherein the maximum exchangeable K was in control and the least was in 100 per cent biosludge application. Alfred (1998) reported that papermill sludge application increased the concentration of exchangeable Na, Ca and Mg in soil.

5.8.4.1.7. ESP and SAR (Fig.5.12)

ESP and SAR of the soil increased under cent per cent effluent irrigation than that of its diluted form of 50 per cent concentration at all stages of crop growth. This might be due to reduction of these exchangeable cations in the effluent of 50 per cent dilution.

Among the graded levels of biosludge application, 100 per cent biosludge recorded lower ESP (7.63%) and SAR (1.08) at all critical stages of crop growth which might be due to higher proportion of exchangeable Ca and Mg ratio to that of exchangeable Na in the biosludge. Hence it could be inferred that the soil salinity or sodicity was not in anyway enhanced by the biosludge application even at its highest dosage of application.

5.8.5. Effect of effluent and graded levels of biosludge on soil enzyme activity

5.8.5.1. Amylase (Fig.5.13)

Generally, 50 per cent effluent irrigation recorded higher amylase activity over 100 per cent effluent irrigation at all stages of crop growth.

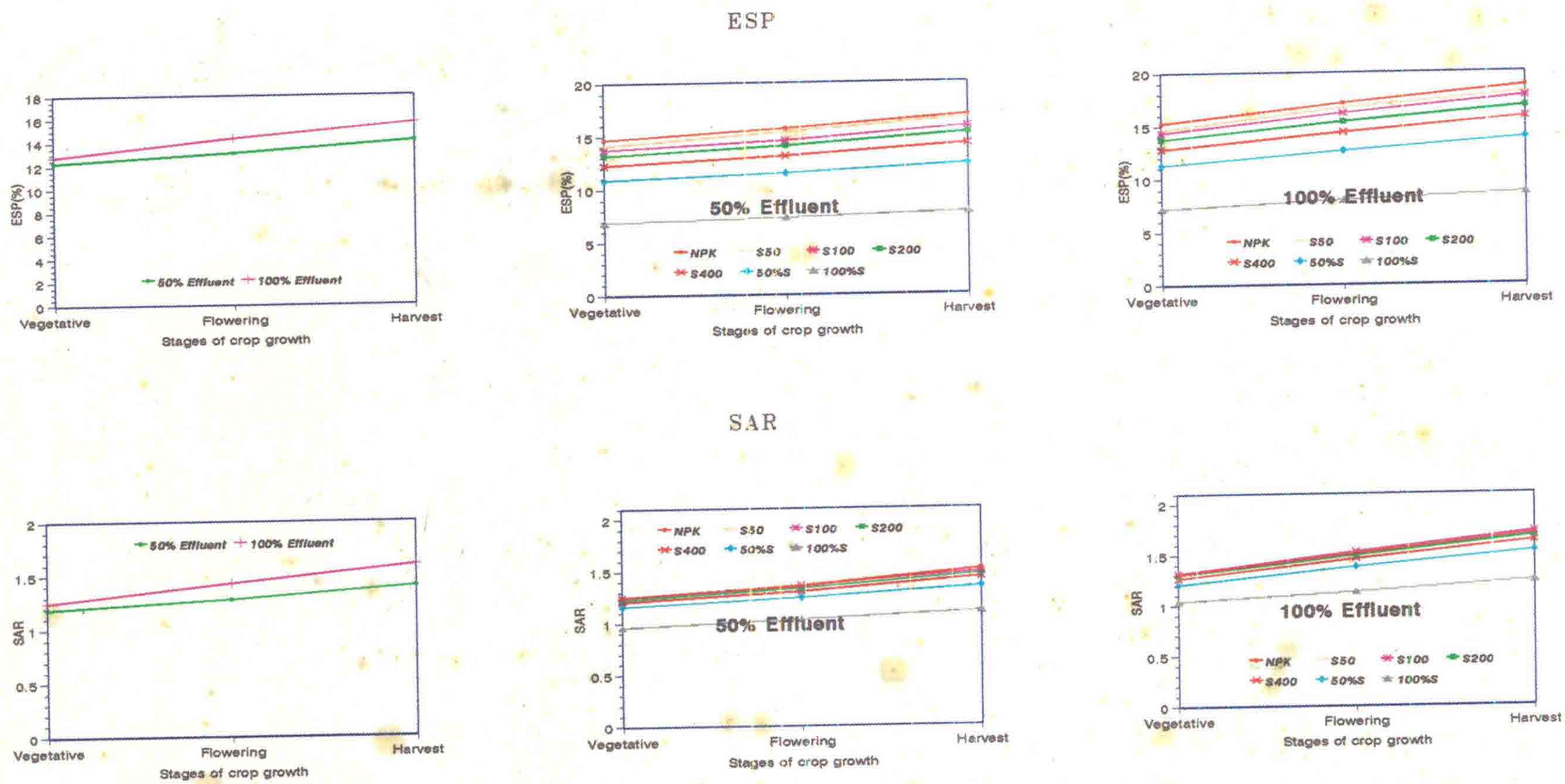


Fig.5.12 Influence of effluent and biosludge on ESP and SAR of soil

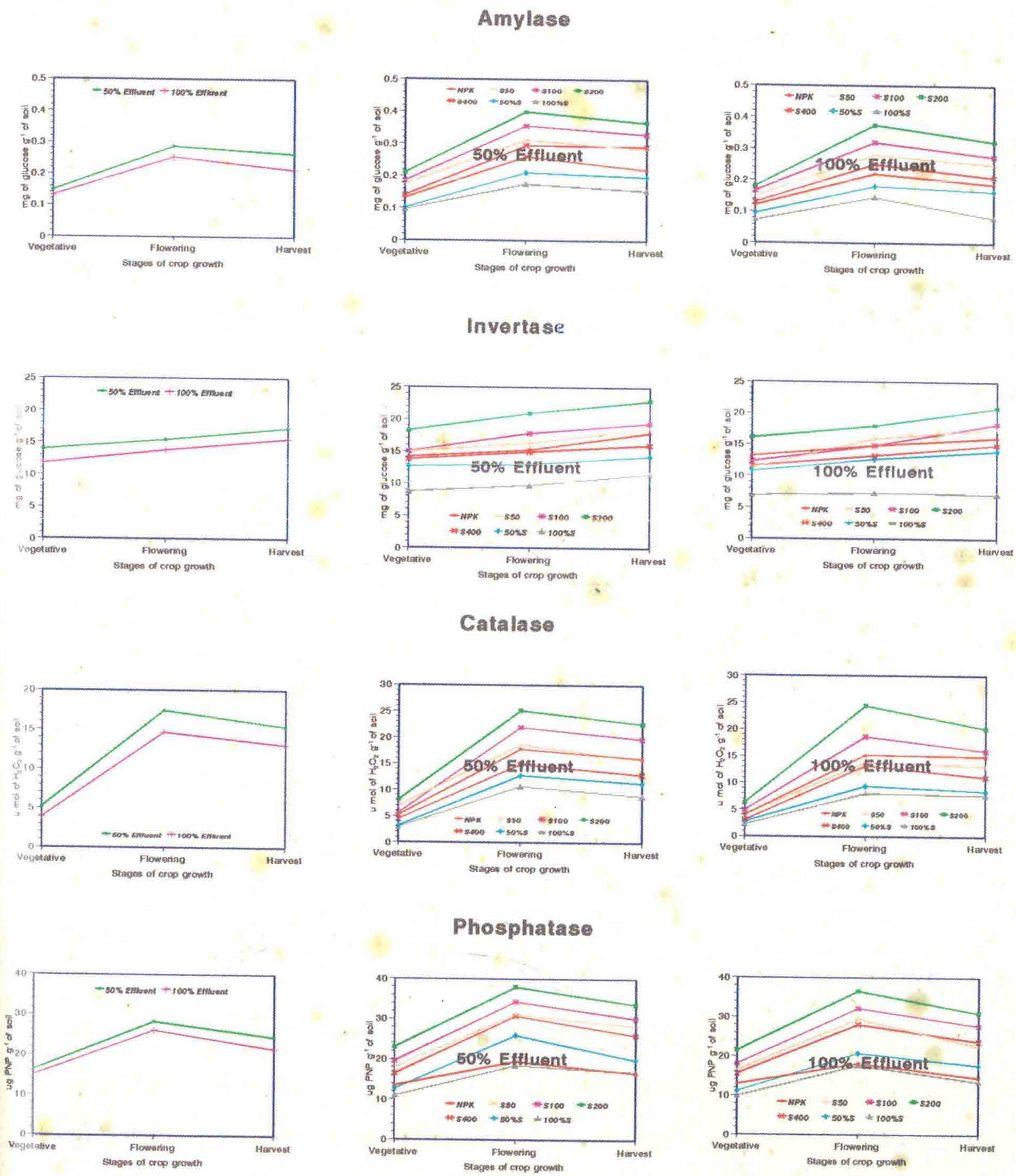


Fig.5.13 Influence of effluent and biosludge on enzyme activities of soil

Behra (1986) reported that it was due to the accumulation of dissolved and suspended solids leading in blockage of porespaces and perhaps arrest of microbial activity in the soil. The soil amylase activity was highest at the flowering stage and decreased at the harvesting stage of crop growth.

Among the treatments, soil treated with 200 t ha^{-1} of biosludge recorded the highest amylase activity and a declining trend was observed as the dose of biosludge increased and the activity was minimum at 100 per cent biosludge treatment. This could be due to high concentration of salts and low availability of nutrients in the biosludge which might impart deleterious effect on the soil microflora. The findings of the present study was in line with the finding of Behra (1986). He also reported an increase in the activity in situations where there was a chance of adaptation of microorganism to the polluted environment.

5.8.5.2. Invertase (Fig.5.13)

In general, 50 per cent effluent irrigation had increased the invertase activity over 100 per cent effluent irrigation. There was increasing trend in the activity of soil invertase from vegetative to harvest stage.

Regarding the treatments, the invertase activity increased and reached the maximum at 200 t ha^{-1} biosludge amended soil and thereafter it registered an inverse relation as the dose of biosludge increased and the least activity was observed in 100 per cent biosludge without soil. This might be due to deleterious effect of biosludge alone and suppression of the soil microflora.

5.8.5.3. Catalase (Fig.5.13)

The catalase activity in general, increased in the 50 per cent effluent irrigated treatment than the 100 per cent effluent irrigated treatments at all the critical stages of crop growth. The activity was maximum at the flowering stage and it declined to certain extent at harvest.

Regarding the graded levels of biosludge application, the maximum catalase activity was registered at 200 t ha^{-1} applied soil and activity touched the lowest in the 100 per cent biosludge treatment without any soil medium, indicating that the catalytic activity mediated by this enzyme was enhanced by the application of 200 t ha^{-1} of the biosludge due to favourable microbial-soil-biosludge interaction.

5.8.5.4. Phosphatase (Fig.5.13)

In the present investigation, 50 per cent effluent irrigation had increased the phosphatase activity over 100 per cent effluent irrigation at all the critical stages of plant growth. The activity was highest at the flowering stage and declined slightly at the harvesting stage of crop growth. The decreased activity during reproductive stage might be due to utilization of a part of nutrient for grain production.

The overall activity of the phosphatase was maximum at 200 t ha^{-1} of biosludge applied soils and the least activity was observed in the 100 per cent biosludge without soil medium. This proved favourable microbial activity due to biosludge incorporation.

5.8.6. Influence of effluent and graded levels of biosludge on residual crop blackgram (Plate 5.6)

5.8.6.1. Dry matter production and grain yield

Increased DMP and grain yield was recorded in 50 per cent effluent compared to 100 per cent effluent irrigation. This might be due to reduction in the level of metabolites and salt as a consequence of dilution resulting in enhanced nutrient status of soil.

Among the graded levels of biosludge application, dosage at 200 t ha^{-1} recorded the maximum DMP and grain yield. The increase in the yield and productivity of the residual crop in the biosludge incorporated pots during the first season indicated that the biosludge continued to release the nutrients in a phased manner and supported the productivity of the crop. This was in contrast to the earlier findings with maize wherein the maximum DMP was registered in biosludge @ 400 t ha^{-1}. On the other hand, as the dosage of biosludge increased, the DMP and grain yield decreased. Findings of Alfred (1998) was contradictory to the present findings. He reported that paper mill sludge applied as such increased the growth and yield of blackgram. It was evident from the present experiment that lower DMP and grain yield was obtained in 100 per cent biosludge application. This could be due to fall in enzyme production in higher dose of biosludge starting from 400 t ha^{-1} to 100 per cent biosludge. This growth reduction and lower grain yield might also be due to the toxic effects of excessive salts on permeability, microbial activity and nutrient availability.

5.8.6.2. Soil characteristics

5.8.6.2.1. Available N, P and Water extractable K

The availability of the essential nutrients N, P and K followed the same decreasing trend in the residual blackgram soils as that of the post harvest soil of maize irrespective of the irrigation sources. This might be due to the uptake of these essential nutrients by plant for its growth and reproduction. The findings of the present study was in consonance with that of Mary celin sandana (1995) who has worked with paper mill effluent.

Among the graded levels of biosludge application, the results were similar to the post harvest soils of maize crop wherein the residual availability of N and P was maximum in 100 per cent biosludge and availability decreased as the dosage of biosludge decreased. The enhanced availability of N and P in the residual soil situation in treatment which received cent per cent biosludge confirmed steady biodegradation and release of these nutrients. On the other hand the availability of K was very low in 100 per cent biosludge and K availability was inversely proportional to dose of biosludge. This might be due to the presence of N and P in higher amount in contrast to K in the biosludge. To improve the nutrient status of biosludge, potash should be added to enrich the biosludge for crop production.

5.8.6.2.2. Water extractable cations

Due to continuous effluent irrigation the water extractable Ca and Na increased gradually except the Mg, irrespective of the levels of biosludge application. The availability of these cations were higher in 100 per cent effluent than 50 per cent effluent irrigation as a consequence of dilution.

Among the graded levels of biosludge application, the water extractable cations were higher in 100 per cent biosludge with 100 per cent effluent irrigation followed by 50 per cent biosludge application and least availability was in NPK treatment. The increased residual content of these cations under higher doses of biosludge incorporation might be due to presence of these nutrients in the biosludge which gets slowly biodegraded and released and also due to the contribution from the continuous effluent irrigation. Sastry *et al.* (1974) also confirmed the same under continuous irrigation with paper mill effluent.

5.8.6.2.3. Water extractable anions

Similar to that of cations, the water extractable anions also increased in soil irrespective of the dilution and graded levels of biosludge. The content was higher in 100 per cent effluent than 50 per cent effluent irrigation, which showed the presence of these anions in the effluent to a considerable quantity.

Among the graded levels of biosludge application, the lowest was recorded in 50 t ha^{-1} biosludge and content increased as the percentage of biosludge increased to that of the soil and reached the maximum in 100 per cent biosludge treatment without any soil medium. The least content was in the NPK treatment.

This direct relationship of biosludge with the water extractable anions might be attributed to the presence of these salts in effluent as well as the biosludge. Alfred (1999) reported a similar increase of anions due to the application of paper mill sludge on agricultural fields.

5.8.6.2.4. Exchangeable cations

In residual blackgram soil the exchangeable cations *viz.,* Na, Ca, Mg and K were higher under 100 per cent effluent than the 50 per cent irrigation which might be due to reduction in the dissolved salts because of dilution.

In the residual blackgram soil the exchangeable cations increased due to continuous effluent irrigation irrespective of dilution. This might be due to the presence of higher amount of these cations in the pharmaceutical effluent.

Among the graded levels of biosludge application, the maximum exchangeable cations *viz.*, Na, Ca, Mg were under 100 per cent biosludge and these exchangeable cations were directly proportional to the dose of biosludge. It could be inferred that even after 6 months of cropping, the release of exchangeable cations and anions under the graded levels of biosludge application indicated the favourable residual effect which supported the soil fertility. On the other hand, the exchangeable K was low in 100 per cent biosludge and the maximum exchangeable K was in NPK treatment. This might be due to presence of higher amount of Na, Ca and Mg in the biosludge and also from the continuous effluent irrigation. Alfred (1998) reported higher concentration of Na, Ca, Mg in soil applied with paper mill sludge.

5.8.6.2.5. ESP and SAR

The continuous increase in the SAR and ESP from the post harvest soils of maize to residual blackgram was observed. ESP and SAR of the soil increased under 100 per cent effluent irrigation than that of the 50 per cent effluent irrigation which might be due to reduction in the exchangeable cation as a consequence of dilution.

Among the graded levels of biosludge application, similar results were obtained in the residual soil of blackgram as that of the post harvest soils of main crop which showed that 100 per cent biosludge application registered lower ESP which might be due to presence of higher exchangeable Ca and Mg in biosludge compared to the exchangeable Na.

5.9. Influence of biosludge with amendments under effluent irrigation on productivity of maize and soil characteristics

5.9.1. Growth characters (Plate 5.5)

The experimental results from the study on the influence of irrigation and amendments on growth and yield of maize are discussed hereunder.

5.9.1.1. Plant height and dry matter production (DMP) (Fig.5.14)

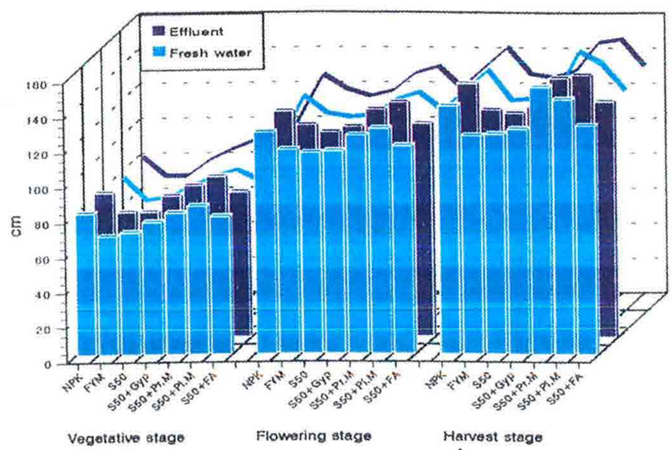
The taller plants and increased DMP was registered under effluent irrigation compared to siruvani water irrigation. Maize has been noted to be more tolerant to salinity and alkalinity than other crops (Anon, 1959). The irrigation of maize with 100 per cent effluent resulted in the significant influence on the growth or plant characteristics, which could be due to the favourable influence of the effluent and the ameliorating effect of the organic wastes on the effluent irrigation.

Among the amendments, poultry manure and pressmud recorded taller plants and maximum DMP irrespective of irrigation. Poultry manure and pressmud application along with 50 t ha^{-1} of biosludge enhanced the DMP by 5.9 and 3.8 percentage respectively at vegetative stage and 4.3 and 2.4 at flowering stage and 7.3 and 5.7 percentage at harvest. It could be inferred that the biosludge when amended with poultry manure or pressmud resulted

Plate 5.6. Pot culture experiment - Graded levels of biosludge and effluent irrigation on residual crop of blackgram

Plate 5.7. Pot culture experiment - Biosludge with amendments under effluent irrigation on residual crop of blackgram

Plant height



DMP

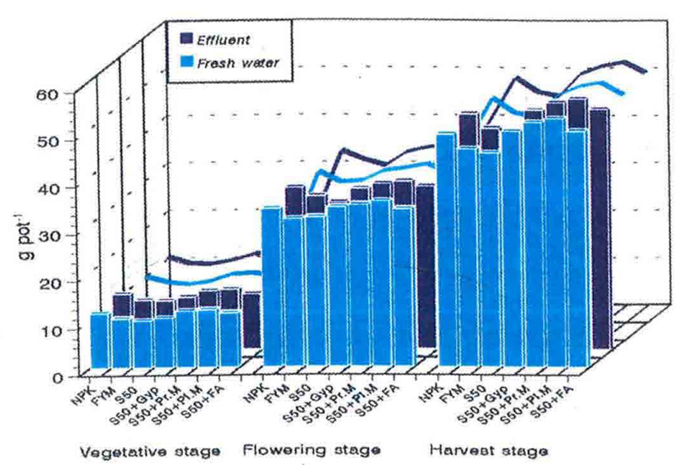


Fig.5.14 Influence of effluent, biosludge and amendments on plant height and DMP of maize

in maximum biomass production. Their synergistic role has to be further investigated. This might be due to the presence of essential nutrients in considerable amount in these organic wastes compared to others. Alfred (1998) was also of the same opinion that the application of organic waste as amendments established an increasing crop growth in case of rice. The shorter plants and lowest DMP was recorded in biosludge which was comparable with FYM application which clearly shows that biosludge @ 50 t ha^{-1} could be a better substitute for the farmyard manure which would also ensure good crop productivity.

5.9.2. Grain yield (Fig.5.15)

The irrigation of maize with effluent resulted in increased grain yield without any adverse effect on the growth of the plant. Effluent irrigation recorded higher grain yield (3.7 %) compared to siruvani water. This might be due to the nutrient supply from effluent and the alleviating effect of the organic amendments on the effluent irrigation.

Among the amendments, the average yield obtained from poultry manure was the highest irrespective of the irrigation source, followed by pressmud and NPK application. This positive effect of amendments on yield of grain could be attributed to the presence of essential nutrients in the amendments and that of the ameliorative effect of Ca. The present finding is in confirmation with the findings of Shiv Kant and Rajkumar (1992) and Alfred (1998). The lowest grain yield among the organic wastes was registered in FYM which was comparable with biosludge at 50 t ha^{-1} which showed that biosludge @ 50 t ha^{-1} could be applied for crop production in the place of farmyard manure for obtaining comparable yield.

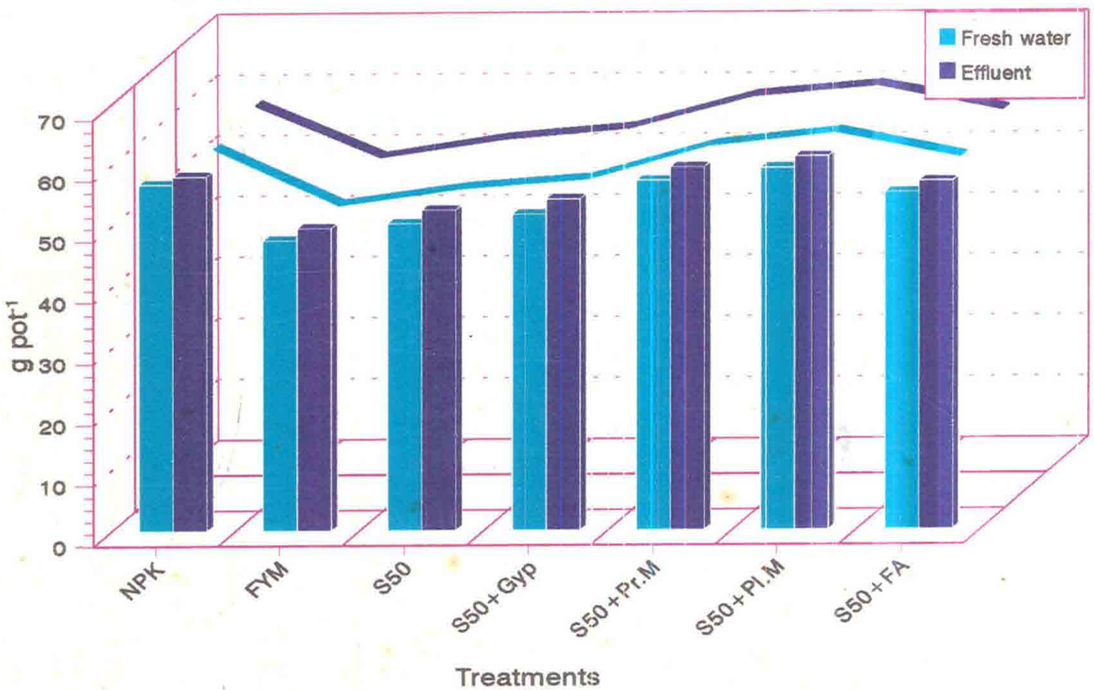


Fig.5.15 Influence of effluent, biosludge and amendments on grain yield of maize

5.9.3. Plant nutrient uptake

5.9.3.1. Stalk uptake

5.9.3.1.1. Uptake of macro nutrients (Fig.5.16)

The macro nutrient (NPK) uptake in maize stalk increased in treatments which received effluent irrigation along with the amendments. This might be due to the increased combination of nutrient to the soil by the addition of organic amendments with effluent irrigation.

In general, the nutrient uptake registered an increasing trend from vegetative to flowering stage and decreased at the post harvest stage. But in the case of potassium, an increasing trend of uptake was noticed at the post harvest stage also.

The quantum of nutrient uptake which is a quality parameter was much higher in treatments amended with poultry manure followed by pressmud with combined application of biosludge. Another interesting observation was the uptake of nutrients in biosludge alone applied treatment which was comparable with FYM amended treatment. The N, P and K present in these organic wastes might have been solubilised and enriched the available pool in the soil thereby facilitating their absorption in higher quantities. Similar results of N, P and K uptake were reported by Selvakumari *et al.* (1998) in groundnut and sunflower grown under flyash and other organic waste application.

Integration of biosludge with organic amendments along with effluent irrigation was found to record uptake of macro nutrients in amounts higher than any other treatments. Such excellent performance of these components

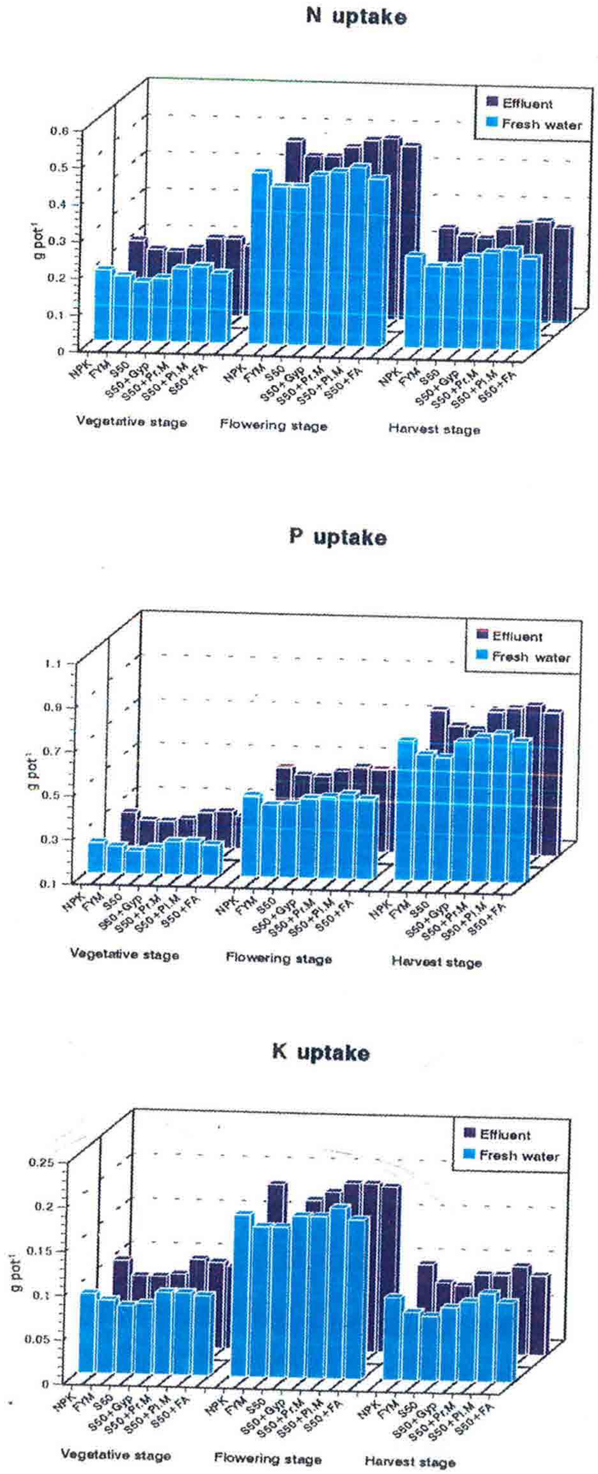


Fig.5.16 Influence of effluent, biosludge and amendments on NPK uptake of maize stalk

might be due to the synergistic effect of organic amendments and biosludge with effluent irrigation as evidenced by the higher nutrient uptake in maize stalk. The least contribution of plant nutrients supplied by the effluent might have been compensated by the complementary effect of the organic amendments and biosludge which helped in releasing these nutrients to the available pool.

5.9.3.1.2. Uptake of secondary nutrients (Fig.5.17)

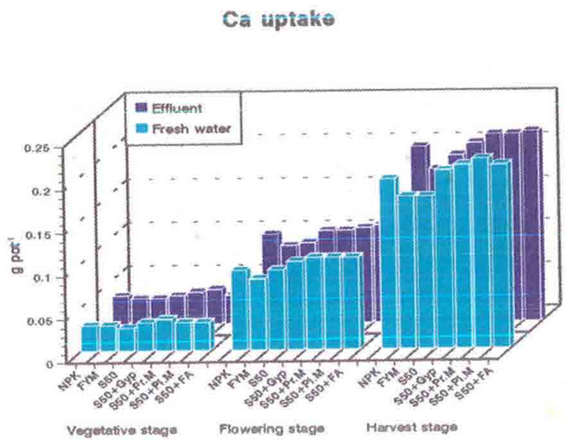
The secondary nutrients (Ca, Mg and Na) uptake in maize stalk increased in treatments receiving effluent irrigation along with the amendments. This might be due to the presence of these nutrients in the effluent as well as in the organic amendments.

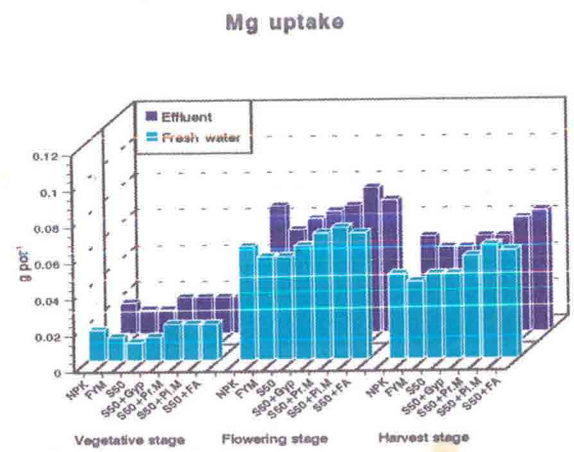
With respect to various amendments, the uptake was higher in poultry manure treatment and others were on par with it and least uptake was in FYM. This, might be due to high amount of Ca, Mg and Na in these organic wastes, Raghupathy (1988) reported increased uptake of Ca and Mg by rice, maize and sugarcane grown under organic wastes.

5.9.3.2. Grain uptake

5.9.3.2.1. Uptake of macro nutrients (Fig.5.18)

In general, uptake of N, P and K by the maize grain was found to increase in treatments receiving effluent irrigation along with the organic wastes incorporated as amendments which might be due to increased availability of nutrients to the soil-plant ecosystem by the addition of organic amendments to biosludge and subsequent effluent irrigation.





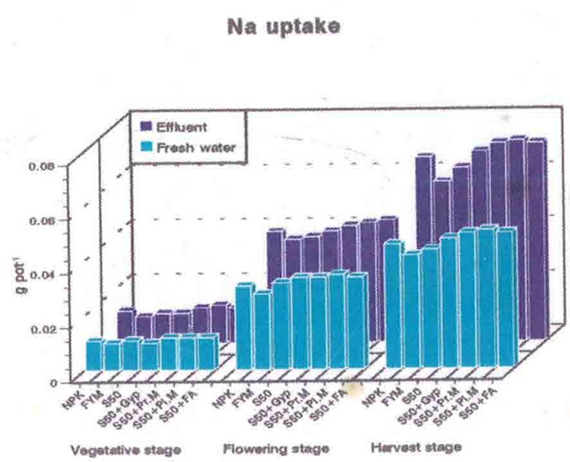
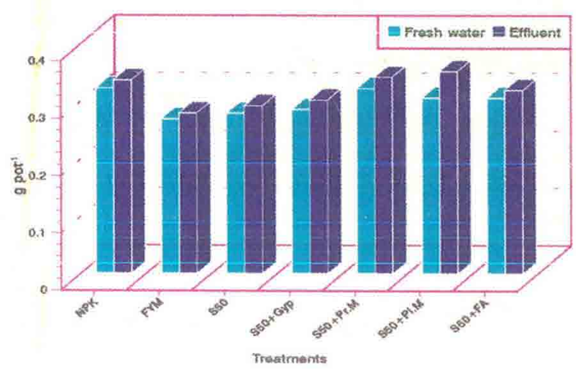
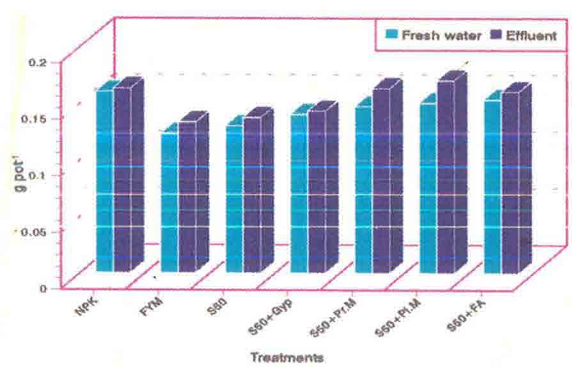


Fig.5.17 Influence of effluent, biosludge and amendments on Ca,Mg and Na uptake of maize stalk

N uptake



P uptake



K uptake

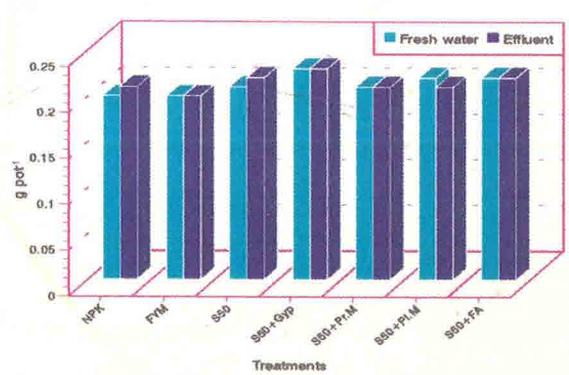


Fig.5.18 Influence of effluent, biosludge and amendments on NPK uptake of maize grain

The nutrients N and P uptake by maize grain was higher in treatments amended with poultry manure followed by pressmud and other treatments. This could be attributed to higher amount of N and P in these amendments. The grain uptake of K was high in the case of gypsum treatment. The variations in uptake of these nutrients might be due to the presence of more amount of these nutrients in the organic wastes used as amendments along with the biosludge. The least uptake was in the treatments containing FYM which was comparable with the biosludge alone applied treatments. By providing conducive physical environment and essential nutrient elements, these organic wastes would have accelerated the microbial activity in the soil which inturn would have supplied N, P and K to the crop indirectly from the native source. The cojoint addition of these organic wastes and biosludge was more effective than the individual biosludge application.

Integration of these organic amendments with biosludge was found to record grain uptake of macronutrients in amounts higher than control which might be attributed to the higher biomass production in these organic wastes tested in this experiment. Similar increase in the nutrient uptake by soybean was reported by Lal *et al.* (1996).

5.9.3.2.2. Uptake of secondary nutrients (Fig.5.19)

The secondary nutrients (Ca, Mg and Na) uptake by maize grain increased in treatments which received effluent irrigation along with these amendments. This might be due to the supply of these nutrients through continuous irrigation with effluent as well as their availability in the organic wastes.

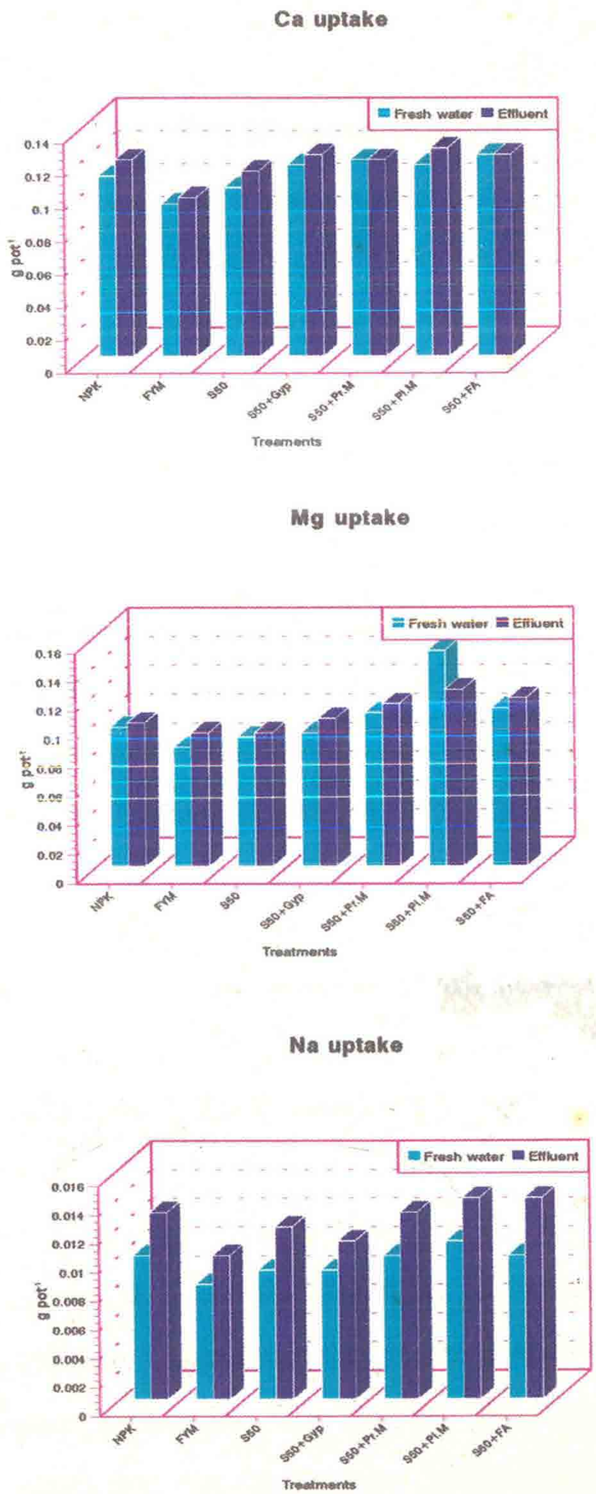


Fig.5.19 Influence of effluent, biosludge and amendments on Ca,Mg and Na uptake of maize grain

Among the different organic wastes used as amendments, the grain uptake of Ca, Mg and Na was found to be higher in poultry manure and others were on par with it and the least uptake was in FYM. This might be due to variations in their availability in the soil on account of their contribution from these organic wastes and effluent irrigation and quantum of biomass production. Not only the supply of these nutrients, but also the physical and biological changes brought about in the soil by the addition of these organic wastes would have favoured the crop to grow well and absorb more of these nutrients.

5.9.4. Soil characteristics

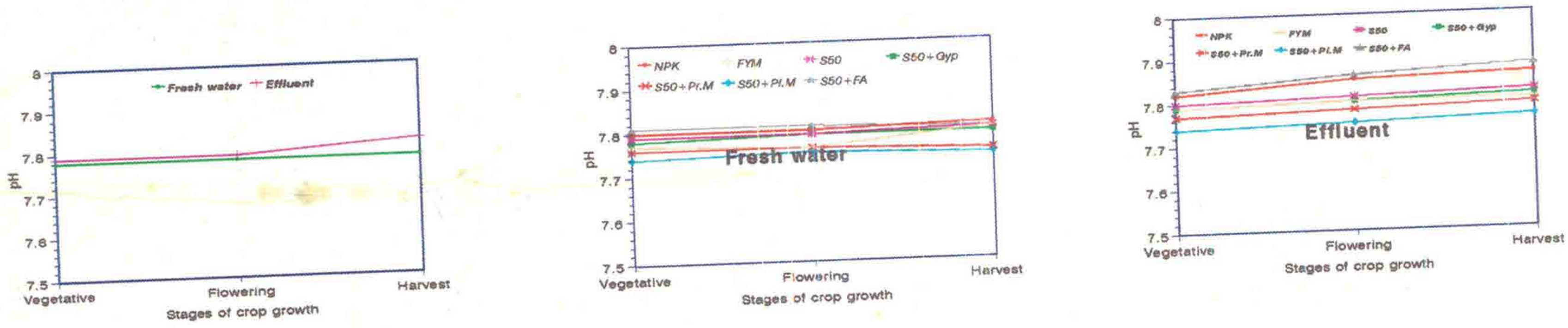
5.9.4.1. Chemical properties

5.9.4.1.1. Soil reaction (Fig.5.20)

Continuous effluent irrigation which was alkaline in nature increased the soil pH gradually from vegetative to harvest stage. The highest pH was recorded in flyash applied treatment which was on par with other organic amendments used. Several workers reported similar view points in their findings (Reddy *et al.*, 1981; Narashimha Rao and Narashimha Rao, 1992; Vasconcelos and Cabrel, 1993) while working with various effluents.

5.9.4.1.2. EC (Fig.5.20)

The EC of the soil increased at all stages of crop growth due to continuous effluent irrigation irrespective of the amendments as compared to siruvani water irrigation. The higher EC values in effluent receiving treatment might be due to organic polyelectrolytes which bind divalent cations, increasing the EC of the water and soil (Metzger *et al.*, 1983). The salt content of effluent increased the soluble salt in soil. Gypsum recorded pH



EC

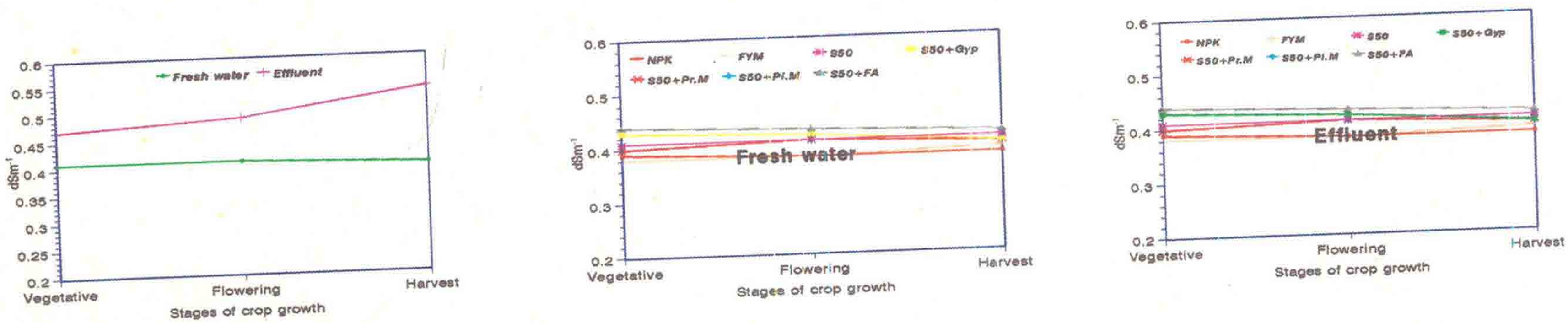


Fig.5.20 Influence of effluent, biosludge and amendments on pH and EC of soil

high EC followed by other organic amendments which might be due to presence of soluble salts in gypsum. These findings were in line with reports of several authors (Mary Celin Sandana, 1995; Ponniah, 1997; Alfred 1998). FYM recorded low EC followed by standard NPK treatment which fell in line with the findings of Shiva Kant and Rajkumar (1992).

5.9.4.1.3. Available N, P and Water extractable K (Fig.5.21)

The availability of N, P and K decreased as stages of plant growth advanced due to effluent irrigation under all the amendments which might be due to uptake of the essential nutrients for the plant growth as the stages advanced. This is in line with the findings of Mary Celin Sandana (1995). The findings of Rajannan and Oblisami (1979) was contradictory to the above, reporting that the paper factory effluent irrigation increased the available nutrient status of red and black soils.

Among the amendments, the overall availability of NPK was maximum in poultry manure followed by other amendments. The highest availability of inorganic nutrients in the presence of organics was clearly observed. This corroborated with the findings of Bache Byron and Heathcote (1969) who reported that application of organic manures increased soil available nitrogen. The availability of the essential nutrients in biosludge was comparable with that of FYM. Similar findings were reported earlier by Paramasivam (1991), Kiruba (1996), Alfred (1998) and Basker (1999).

5.9.4.1.4. Water extractable cations

The water extractable cations like Ca, Mg and Na increased in soil irrespective of the irrigation sources. In general, effluent irrigation recorded

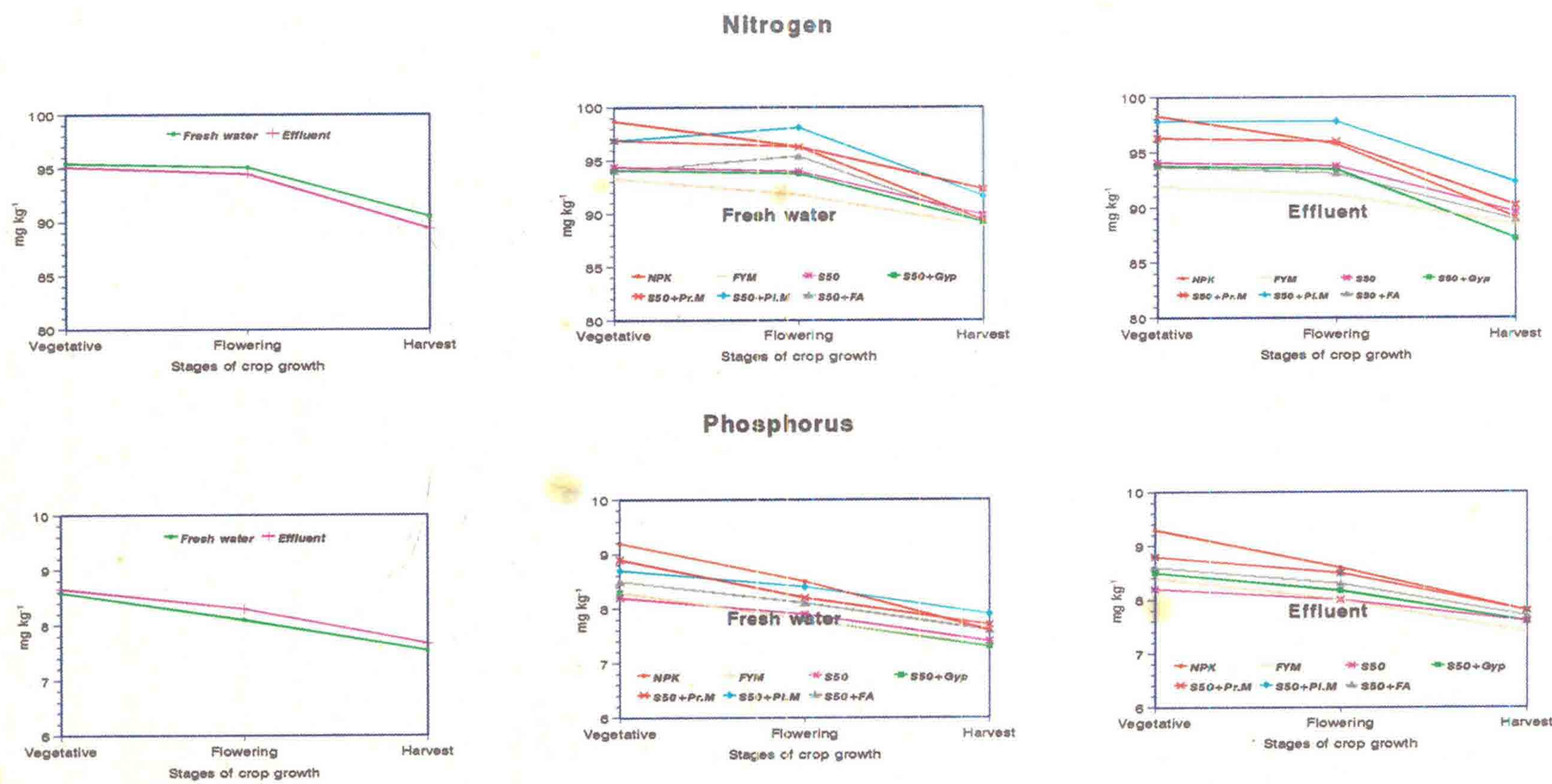


Fig.5.21 Influence oc effluent, biosludge and amendments on available N and P contents of soil

higher sodium contents than the siruvani water irrigation at all the critical stages of crop growth in all the treatments. This might be due to the presence of a high amount of salts especially the cations present in the effluent. Sastry *et al.* (1974) and Oblisami and Palaniswami (1991) recorded higher concentration of exchangeable cation under effluent irrigation.

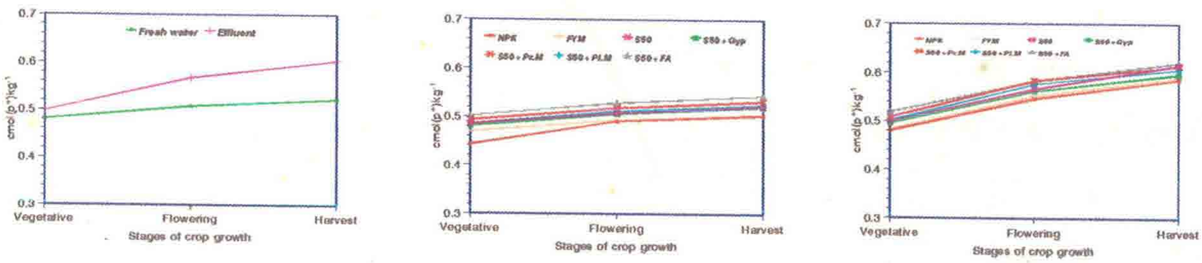
The water extractable Ca and Na increased in the soil from the vegetative to the harvest stage of the crop growth but soil Mg content showed a decreasing trend as crop approached the harvesting stage. This might be due to the high uptake of magnesium in the plant.

Among the treatments, the maximum water extractable Ca was registered in Gypsum amended soil followed by flyash and other treatments and least content was found in control. But in the case of Mg and Na content, the maximum was found in flyash amended soil followed by other treatments and least was registered in the NPK applied soils. Here the highest utilization of inorganic nutrients in the presence of organics was clearly observed. The present findings of this study was in line with the findings of Alfred, (1998). This also corroborated with the findings of Bache Byron and Heathcote (1969) who reported that the application of organic waste increased the water extractable cations in the soil.

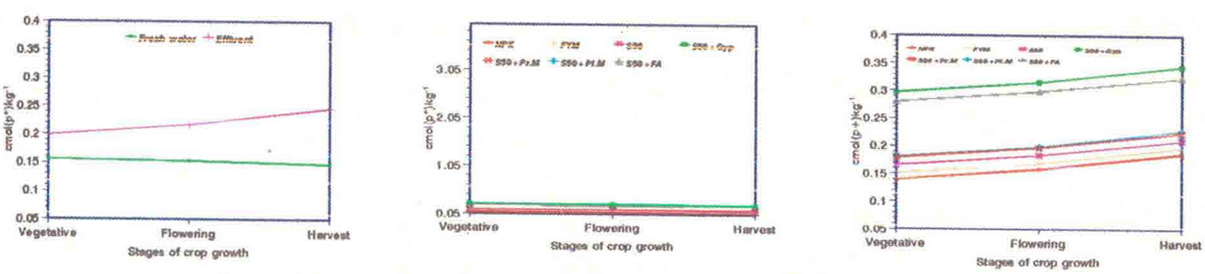
5.9.4.1.5. Water extractable anions (Fig.5.22)

The water extractable chloride in soils increased in all the treatments irrespective of the irrigation sources. The content of chloride was higher in effluent irrigated soils than the siruvani water irrigated soil which might be due to presence of comparatively more of chlorine in the effluent. The content of chloride registered an increasing trend as the crop growth advanced

Chloride



Sulphate



Bicarbonate

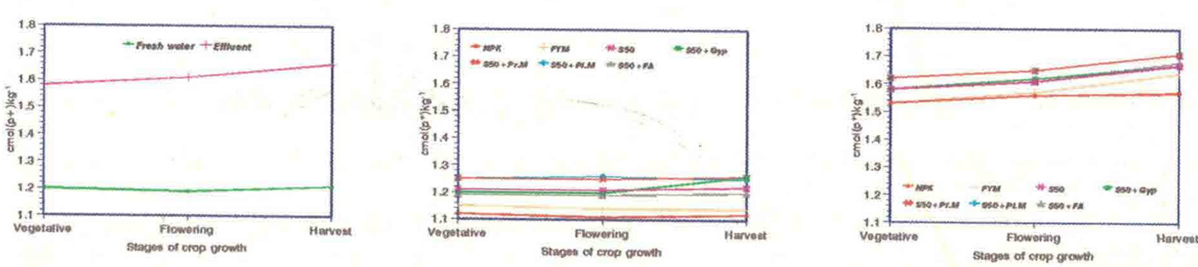


Fig.5.22 Influence of effluent, biosludge and amendments on water extractable anions of soil

towards the harvesting stage. Alfred (1998) was also of the same opinion because of irrigation with paper mill effluent in sugarcane fields.

Among the treatments, the maximum water extractable chloride was registered in soil treated with flyash and it was on par with other organic wastes which might be due to presence of these salts in the organic wastes as well as in the irrigation sources and least content was found in the control (NPK treatment).

The water extractable bicarbonates and sulphates increased in all the treatments irrespective of the irrigation sources. Here the availability of HCO_3 and SO_4 increased in soils irrigated with effluent than the siruvani water irrigation. This was due to presence of these anions in higher proportion in the effluent. As the crop approached the harvesting stage, the availability of these HCO_3 and SO_4 increased in all the treatments.

Among the treatments, the HCO_3 content was highest in poultry manure and pressmud amended soils which was compatible with other organic waste amended soils and least content was registered in the control treatment. But the SO_4 registered maximum content in gypsum amended soil followed by flyash due to the presence of sulphate in both and the least content was in the control treatment. This might be due to the presence of these anions in higher proportions in the two component systems namely the amendments and the effluent. The present findings of the study was in line with the findings of Alfred (1998) who reported more availability of SO_4 in gypsum amended soils irrigated with papermill effluent.

5.9.4.1.6. Exchangeable cations (Fig.5.23)

In general, the exchangeable cations Na, Ca, Mg and K were higher under effluent irrigation than under fresh water irrigation. The exchangeable cations *viz.,* Na, Ca and Mg increased in soil due to effluent irrigation while the trend was reverse due to fresh water irrigation. This might be due to the presence of these specific cations in higher amount in the pharmaceutical effluent. Oblisami and Palanisami (1991) recorded higher concentration of exchangeable cations under effluent irrigation. On the other hand, the exchangeable K showed gradual decrease irrespective of irrigation source which might be attributed to higher uptake of K in the plant system.

Among the amendments, the exchangeable Na and Mg were found to be higher in flyash and the least was in NPK treatment. Regarding the exchangeable Ca, the highest was in gypsum as it was a carrier of Ca and the lowest was in control. But the exchangeable K was maximum in pressmud and the least was in biosludge applied treatment. This variation in the exchangeable complex due to amendments application might be due to presence of these cations in higher proportions in the respective amendments and their available forms in the soil which contributed to the exchangeability in the soil. This corroborated with the findings of Bache Byron and Heathcoto (1969) who reported that application of organic manures increased exchangeable Ca and Mg in soils.

The present findings of this study corroborated with the findings of Alfred (1998) with reference to the organic amendments under paper mill effluent irrigation.

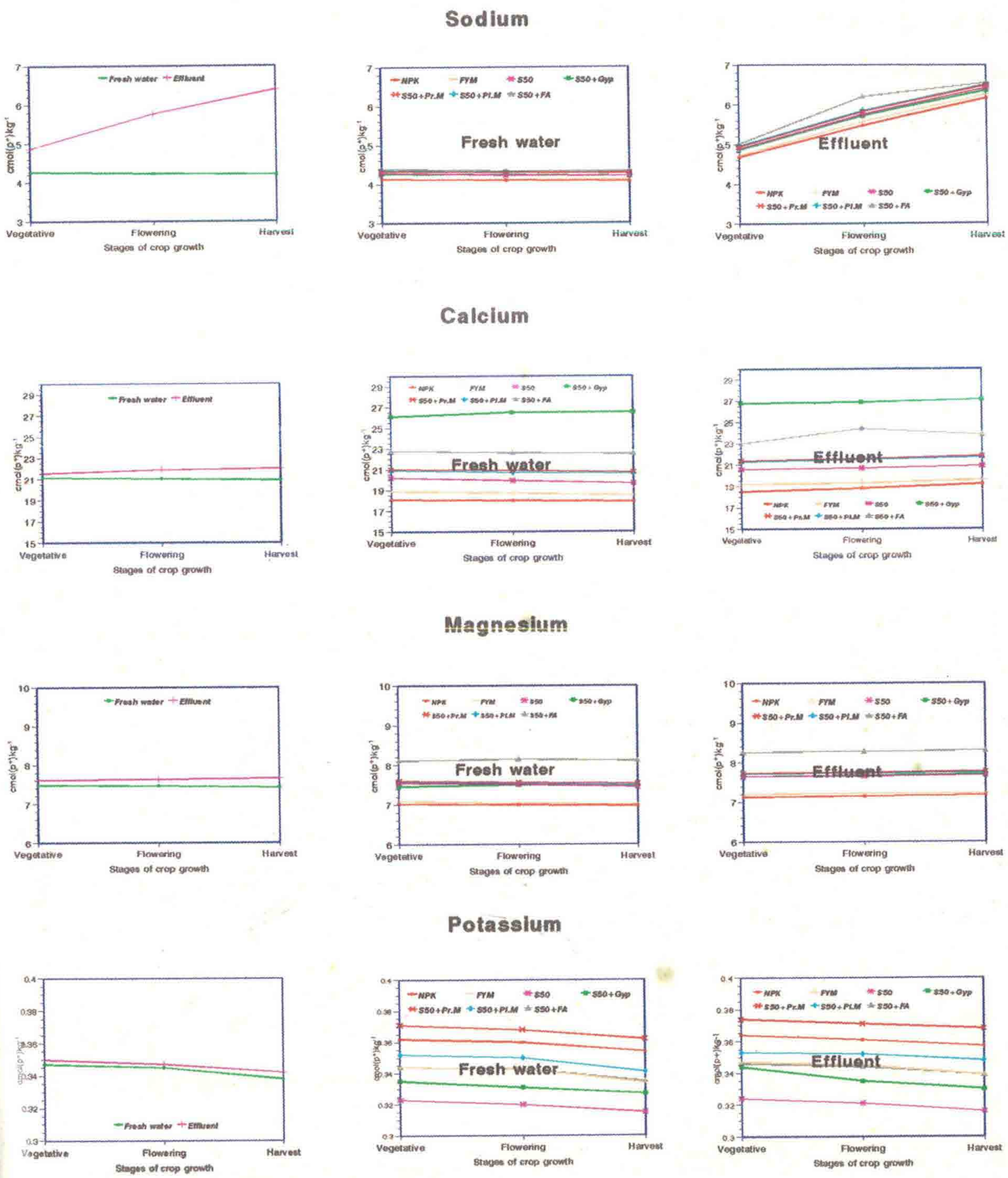


Fig.5.23 Influence of effluent, biosludge and amendments on exchangeabke cations of soil

5.9.4.1.7. ESP and SAR (Fig.5.24)

ESP and SAR of the effluent irrigated soils increased gradually at all critical stages of crop growth due to continuous effluent irrigation with high exchangeable cations. Alfred (1998) opined the same results due to paper mill effluent irrigation.

Among the amendments used, gypsum recorded lower ESP and SAR at all the critical stages of crop growth. Gypsum proved superior in improving the soil properties among the amendments (Shiva Kant and Rajkumar, 1992). Juwarkar *et al.* (1987) reported that high toxicity of sodium can be reduced by decreasing the SAR of waste water which can be augmented by increasing the proportion of Ca and Mg salts.

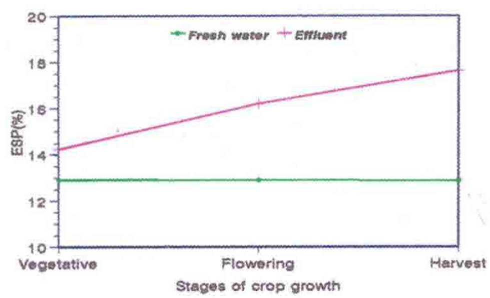
5.9.5. Effect of effluent and amendment on soil enzyme activity

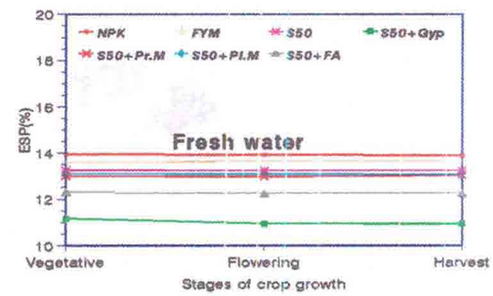
Soil enzymes mostly secreted by microorganisms in the soil are involved in various decomposition and chemical transformation in the soil. The measurement of enzyme activities give an index of the extent of specific biochemical processes in soil and in many situations act as indicators of soil fertility and soil health. Tateno (1988) reported that enzyme activities in natural soil are limited by substrate supply and not by the amount of enzymes. Amylase, cellulase, invertase and catalase are the broad enzymes responsible for the degradation of organic matter of plant and animal origin reaching the soil (Reddy *et al.*, 1981).

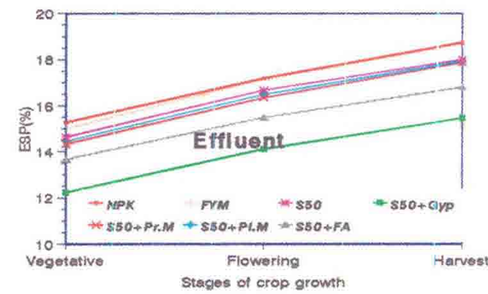
5.9.5.1. Amylase (Fig.5.25)

In general, siruvani water irrigation increased the amylase activity over effluent irrigation at all stage of crop growth. This could be due to the

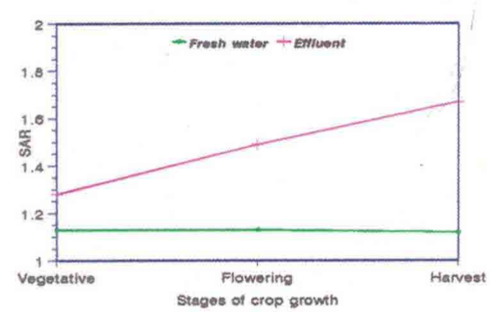
ESP

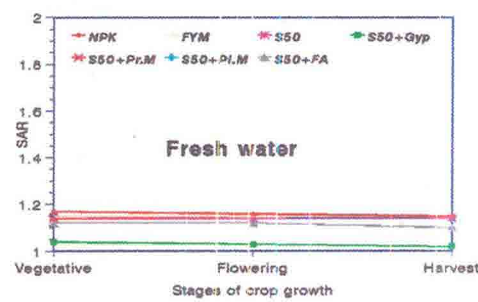






SAR





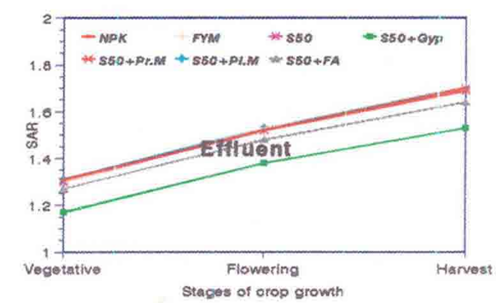


Fig.5.24 Influence effluent, biosludge and amendments on ESP and SAR of soil

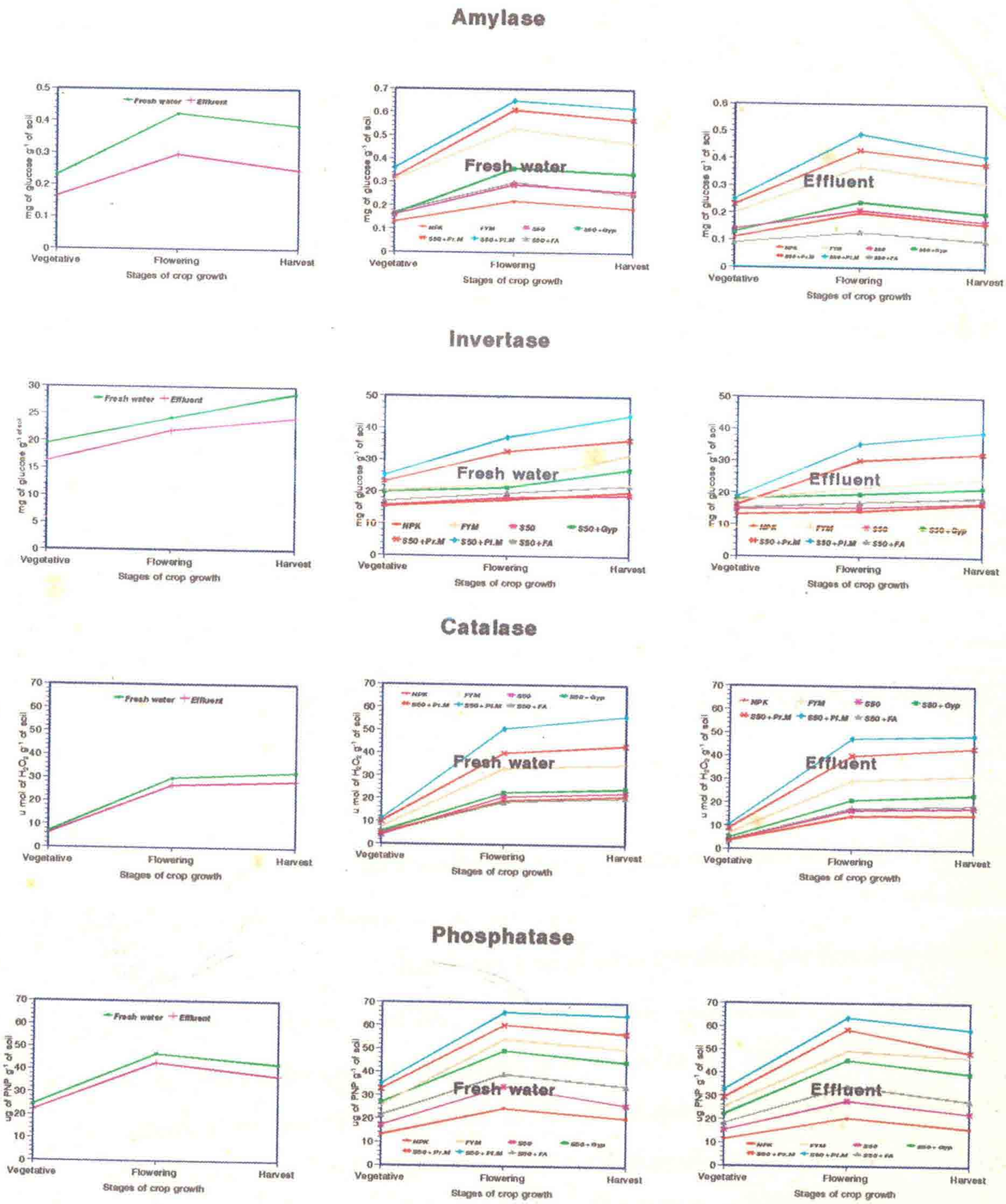


Fig.5.25 Influence of effluent, biosludge and amendments on enzyme activities of soil

accumulation of dissolved and suspended solids leading to blockage of pore spaces, high alkalinity and perhaps arrest of microfloral activity as reported by Behra (1986). The soil amylase activity was the highest at the flowering stage and decreased at the harvesting stage of the crop.

The overall activity of amylase was highest in poultry manure amended soil and least was in control. The highest activity in the amendments might be due to the addition organic matter through organic wastes which contributed enough of substrate for microbial activity. Earlier Kozlov (1965) has reported similar observation.

5.9.5.2. Invertase (Fig.5.25)

In general, siruvani water irrigation had increased the invertase activity over effluent irrigation at all stages of crop growth. The soil invertase activity showed an increasing trend as the crop growth progressed towards the harvest stage.

Regarding the treatments, the poultry manure amended soil registered higher invertase activity than the rest of the treatments. Vaugham and Malcolm (1979) reported that humic acid in organic matter fraction enhanced the protein synthesis which simultaneously increased the soil invertase activity. The increase in soil invertase activity in organic waste amended treatments fell in line with the findings of several workers (Sastry *et al.*, 1974; Kannan and Oblisami, 1989; Anita Kanagaswarna, 1997).

5.9.5.3. Catalase (Fig.5.25)

In general, siruvani water irrigation had increased the catalase activity over effluent irrigation at all stages of crop growth. The soil catalase activity was maximum at harvesting stage which showed an increasing trend from the vegetative stage.

Regarding the treatments, the poultry manure amended soil registered the highest catalase activity than the rest. This is in agreement with the findings of De (1989).

5.9.5.4. Phosphatase (Fig.5.25)

The role of phosphatase is to make the unavailable phosphorus into the available form for the plants. In the present investigation, the siruvani water irrigation had increased the phosphatase activity over effluent irrigation at all stages of crop growth. The soil phosphatase activity was highest at the flowering stage which slightly declined towards the harvesting stage of the crop growth.

The overall activity of the phosphatase was highest in poultry manure amended soil than the others. This increased activity in the soil amended with organic wastes might be due to presence of appreciable amount of phosphorus in these amendments. Herbein and Neal (1990) reported similar findings.

5.9.6. Influence of effluent and amendments on residual crop blackgram

5.9.6.1. Dry matter production and grain yield (Plate 5.7)

The increased DMP and grain yield was recorded in fresh water irrigation than the effluent irrigation which was in contrast to the earlier results in the maize crop wherein the effluent irrigation increased the plant growth characters. But the continuous irrigation of black gram with effluent did not result in any adverse effect on the growth or plant characteristics. Comparatively lower production in residual black gram due to continuous effluent irrigation was due to the constant uptake of nutrients by plants and heavy loss of nitrogen from the soil due to the volatilization because of effluent irrigation which contains higher amount of sodium.

Among the amendments, poultry manure recorded the maximum DMP and grain yield followed by pressmud and other organic amendments. This might be due to presence of considerable amount of nutrients in these organic wastes. Sandana (1995) reported similar findings in organic amendments with effluent irrigation. The lowest DMP and grain yield were recorded in biosludge which was comparable with FYM application and it might be a better substitute for FYM for crop production.

5.9.6.2. Soil characteristics

5.9.6.2.1. Available N, P and Water extractable K

The availability of the N, P and K followed the similar decreasing trend in the residual soils to that of the post harvest soils of maize crops irrespective of the irrigation sources in all the amendments. This might be due to the uptake of plant nutrients for the crop growth and reproduction. The findings of Palanisami and Sree Ramulu (1994) was in contrast to the above, reporting that increasing trend due to combined effluent irrigation over a period of 15 years. Pushpavalli (1990) and Palaniswami (1989) reported similar findings in the case of continuous irrigation with paper mill effluent. But findings of this experiment was supported by Mary Celin Sandana (1995) in the same paper mill effluent irrigation.

Among the amendments, the maximum availability of N and P was in poultry manure and K was in pressmud followed by poultry manure which were comparable with other amendments which shows that the high availability of inorganic nutrients in the presence of organics was clearly observed. This corroborates with the findings of Bache Byron and Heethcote (1969) who reported that application of organic manures increased soil available nitrogen.

5.9.6.2.2. Water extractable cations

The water extractable Ca and Na of the soil increased gradually due to continuous effluent irrigation in residual crop experiment also. On the other hand, the availability of Mg decreased as that of the main crop which might be due to the uptake of Mg by the plant for crop growth.

Among the amendments, the maximum Ca availability was in gypsum amended soil followed by other treatments and the least availability was in NPK treatment. This might be due to higher proportion of Ca in the gypsum. But the Na and Mg availability was maximum in the flyash amended soil followed by other amendments and the least availability was in NPK treatment. Bach Byron and Heathcote (1969) reported that application of organic wastes increased the exchangeable cation in the soil.

5.9.6.2.3. Water extractable anions

Similar to that of cations, the water extractable anions also increased gradually due to continuous effluent irrigation. On the other hand, Siruvani water irrigation had no significant change in the availability of these anions in the soil except chloride that showed an increasing trend due to continuous irrigation. This might be due to the excess amount of residual chlorine in the fresh water (Siruvani water) when compared to other anions.

Among the amendments, the availability of chloride, sulphate and bicarbonate were maximum in pressmud, gypsum and pressmud respectively similar to that of the post harvest soils of the main crop and the least availability of the respective anions were in the NPK treatment. The higher availability of these anions might be due to the presence of these anions in higher proportion in the two component systems namely the organic waste and the effluent.

5.9.6.2.4. Exchangeable cations

In the residual black gram the same trend as that of main crop was observed wherein, the exchangeable cations Na, Ca, Mg and K were higher under effluent irrigation than under fresh water irrigation. This might be due to the presence of these specific cations in higher proportions in the pharmaceutical effluent. Oblisami and Palanisamy (1991) recorded higher concentration of exchangeable cations under effluent irrigation. On the other hand, the exchangeable K content decreased from the post harvest soils of maize crop which might be attributed to higher uptake of K for plant growth.

Among the amendments, the exchangeable Na and Mg was found to be higher in flyash whereas the exchangeable Ca and K was higher in gypsum and NPK treatment respectively. This clearly shows the contribution of amendments which contains higher amount of the respective cations. Alfred (1998) reported higher exchangeable cations in soil amended with gypsum, pressmud, FYM and paper mill sludge.

5.9.6.2.5. ESP and SAR

ESP and SAR of the soils of residual black gram increased due to continuous effluent irrigation from that of the post harvest soils of maize crop with high exchangeable cations. Alfred (1998) reported similar findings in rice fields due to continuous irrigation with paper mill effluent.

Among the amendments, gypsum recorded the lower ESP and SAR and it proved superior in improving the properties of soil. Shiva Kant and Rajkumar, 1992 was also of the same opinion that the gypsum reduces the ESP and SAR by reducing the percentage of toxic sodium in the soil.

5.10. Evaluating the potential use of some biosorbents for sodium removal through batch and column experiments

5.10.1. Batch experiment

In general the adsorption increased with an increase in the initial concentration of Na though there were few exceptions. Irrespective of the materials, the maximum adsorption per unit mass of adsorbent occurred at 100 mg l^{-1}. Amongst the materials used, the spent carbon was found to adsorb higher level of Na, followed by rice husk. High reactive surface area and cation exchange capacity of the materials could be attributed to the higher adsorption. However vermiculite, a high CEC mineral, adsorbed only a small amount of Na, which could be due to high pH of the material.

The regression analysis resulted in low to high correlation coefficient (r) values which ranged between 0.163 and 0.795. The soils examined showed relatively higher 'r' values suggesting a positive relationship.

The constant 'k', a measure of adsorption energy (adsorption capacity) varied from 0.178 to 2.55 mg kg^{-1}. The activated carbon recorded the higher value of 'k' (2.555 mg kg^{-1}), followed by mixed red and black soil (1.05 mg kg^{-1}) showing their effectiveness in removing Na from solution. As has already been mentioned, relatively higher reactive surface area and CEC could be attributed to the higher k values. In general the adsorbent material examined were not very effective in removing the Na from the aqueous solution.

5.10.2. Column experiment I (Adsorption experiment)

Among the selected biosorbents picked up from batch experiment, spent carbon was found to be more effective with relevance to time of adsorption even upto 72 hrs. In the rice husk and saw dust the effective adsorption was only upto 24 hrs. and thereafter the desorption took place.

SUMMARY AND CONCLUSION

Chapter - VI

SUMMARY AND CONCLUSION

The salient findings and conclusion drawn from the present investigation are presented here.

6.1a. The treated effluent released from the Imperial Chemical Industry (ICI) pharmaceutical , Chennai was colourless and odourless in nature with a pH of 7.4 and EC of 1.7 to 2.8 dSm^{-1}. The effluent had moderate quantity of organic carbon with dissolved oxygen level of 4.8 mgl^{-1}. The pollutant load in terms of BOD and COD were well within the permissible safe limits of Tamil Nadu Pollution Control Board. Though the nutrient status of the effluent was not appreciable, it had considerable amount of cations and anions. It harboured very low population of bacteria and actinomycetes and fungal load was completely absent.

6.1b. The biosludge of the pharmaceutical industry was neutral in reaction and its EC was 1.85 dSm^{-1}. The organic carbon content was fairly high (11.8 per cent) indicting that it could be biodegradable. The nitrogen content of the biosludge was 1.24 per cent and its C/N ratio was very narrow. Hence it could be readily used as an organic manure. It has appreciable quantity of Ca and Mg hence has ameliorative property too.

6.2. Biodegradability of solid wastes

Among the solid wastes of pharmaceutical industry, the biosludge was found to be highly biodegradable and the biodegradability could be further accelerated by the addition of any carbon source whereas the spent carbon and organic waste were recalcitrant in nature.

6.3. Ecotoxicology

a) Floral toxicity

The test crops, cucumber and radish registered higher germination percentage, DMP and vigour index under all dilution levels and even under undiluted situation.

b) Faunal toxicity

The effluent of different concentration was found to be non toxic to the aquatic fauna (Mosquito larvae and fingerlings).

c) Microbial toxicity

Bioassay of effluent with *Bacillus* sp, Actizyme and *Aspergillus* sp. showed that the pharmaceutical effluent was not toxic to these microbes.

6.4. Pot culture experiment - Biosludge and effluent on maize

a) The undiluted effluent has been established to support the growth and productivity of maize as compared to 50 per cent dilution which enhanced the productivity by 4.5 per cent only.

b) Incorporation of biosludge at 200 t ha^{-1} was equal in effect with that of 100 per cent NPK fertilization with reference to grain yield and DMP of maize. Biosludge could possibly be a substitute for the inorganic fertilizers and could reduce the cost of cultivation.

c) Biosludge incorporation @ 50 t ha^{-1} was comparable in effect with that of FYM at 12.5 t ha^{-1} hence biosludge could be an organic manure substitute.

d) The uptake of various nutrient elements @ 200 t ha^{-1} level of biosludge application was comparable with that of 100 per cent NPK application confirming that the quality of maize grain was also high under biosludge incorporation.

e) The soil pH under 100 per cent effluent irrigation increased by a meagre of 0.02 units only during the cropping season. The EC too increased by 0.05 units.

f) The available N and P were significantly higher under 100 per cent biosludge treatment whereas K was the least in the above treatment. Hence to have a balanced nutritional value, biosludge has to be enriched with potash.

g) The ESP which is a measure of degree of sodicity decreased steadily as the level of biosludge incorporation increased indicating that it could be used as a bioamendment for sodic soils.

h) With reference to soil enzyme activity, it was found that the enzyme activity was higher under 50 per cent effluent irrigation than under 100 per cent. Among the graded levels of biosludge, biosludge @ 200 t ha^{-1} registered the highest enzyme activity ensuring that 200 t ha^{-1} level was conducive for soil-biosludge-microbial interaction.

6.5. Pot culture experiment - Biosludge, amendments and effluent on maize

a) The undiluted effluent significantly influenced the growth characteristics and yield of maize over fresh water irrigation.

b) Incorporation of poultry manure or pressmud along with biosludge enhanced the dry matter production and grain yield of maize.

c) Biosludge @ 50 t ha^{-1} recorded comparable yield and DMP with FYM application established that biosludge at 50 t ha^{-1} could possibly be an organic manure substitute for FYM.

d) Amending biosludge with poultry manure or pressmud registered significantly higher nutrient uptake by maize.

e) Water extractable cations and anions were significantly higher under effluent irrigation as compared to fresh water irrigation.

f) Application of gypsum with biosludge registered higher exchangeable Ca and Mg and accordingly ESP and SAR was lowered by this amendment.

g) Poultry manure amended soil registered higher enzyme activity with reference to amylase, invertase, catalase and phosphatase because of favourable microbial interactions.

6.6. Biosorbents and sodium adsorption

Batch experiment

The adsorption of Na by biosorbents ranged from 0.9 to 35.2 mg kg^{-1}. Spent carbon of pharmaceutical industry adsorbed the maximum Na from the effluent followed by rice husk and sawdust. Adsorption data confirmed to Freundlich isotherm.

Thus the characterization, toxicological evaluation, pot culture experiments and adsorption studies with the pharmaceutical treated effluent and that of biosludge indicates that there is lot of potential to use the effluent as irrigation water substitute and the biosludge as organic manure and as an ameliorant for sustaining soil health and crop productivity.

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