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# EFFECT OF TREATED SEWAGE EFFLUENT IRRIGATION ON P DYNAMICS IN SOIL

**R. P. RAJIMOL., M. HEBBARA AND M.V. MANJUNATHA.**
Department of Soil Science and Agricultural Chemistry
University of Agricultural Sciences, Dharwad-580 005, Karnataka, INDIA.
e-mail:rajikovilakam@gmail.com

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***Corresponding author**

## ABSTRACT

A study emphasizing the effect of constructed wetland treatment of domestic sewage effluent on its quality and subsequent effect of irrigation on soil phosphorus dynamics both spatially and temporally with tomato as a test crop was carried out at the Main Agricultural Research Station, Dharwad, Karnataka during January to May, 2014. The effluent after passing through the constructed wetland improved its quality which was reflected by the reduction in pH, EC, BOD, COD, TSS, TN, ON and TP compared to the untreated sewage effluent (USE). The mean reduction in TSS, BOD and COD in the treated effluent over USE was 42, 54 and 39 per cent, respectively. Among the various soil P fractions analyzed, Ca-P was the most dominant active inorganic P fraction whereas the least dominant was saloid P at 0-20 and 20-40 cm depth throughout the experimental course. Similar to other fractions sewage irrigated plots recorded highest organic P. The relative trend of abundance of P fractions was in the order of organic -P> Ca-P> Al-P> Fe-P> occluded -P> reductant soluble P> saloid-P.

## INTRODUCTION

Spectacular increase in global population has created a wide gap in between the supply and demand of water and is reaching such alarming levels that in some parts of the world it is posing a threat to human existence. It is the apt time to think new ways of conserving water. We can refocus on one of the ways to recycle water through the reuse of wastewater. The disposal of wastewater is a major problem faced by our policy makers and administrators. On the other hand, wastewater is also a resource that can be applied for productive uses since wastewater contains nutrients that have the potential for use in agriculture. Thus, wastewater can be considered as both a resource and a problem. It is estimated that more than 15000 million liters of sewage water is produced every day in India, which approximately contributes 3.2 mt of N, 1.4 mt of P and 1.9 mt of K per annum, with an economic value of about Rs. 2600 million in India (Paul *et al.*, 2010). Sewage irrigation is an age old agriculture practice and is being practiced over a long period in different parts of the world. (Pound and Crites, 1973 and Page *et al.*, 1983). Utilization of any kind of wastewater has twin advantages as it reduces the demand for fresh water and reduces the risk of environmental pollution. However, improper discharge of wastewater may provide excess nutrients than the crop requirement and result in bioaccumulation of nutrients at toxic levels owing to reduced crop yield and quality (Schalscha *et al.*, 1999). Wastewater also contains broad spectrum of contaminants *viz*, biodegradable organic compounds, toxic metals, suspended solids, micro pathogens and parasites (Pedrero and Alarcon, 2009) which restrict its direct application to field.

If wastewater is devoid of toxic compounds, heavy metals and other microbial contaminants by proper treatment then the problem can be solved. In this study, an artificially constructed wetland system has been used for the treatment of wastewater which is an eco friendly method of treating wastewater (Vymazal, 2011). Constructed wetland is a wastewater treatment system composed of one or more treatment cells in a built and partially controlled environment, designed and constructed to provide wastewater treatment. Constructed wetland has been used to treat many types of wastewater at various levels of treatment. Natural characteristics are applied to constructed wetlands with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems (Rajimol *et al.*, 2016). The major nutrient removal mechanisms taking place in these treatment systems are biodegradation, precipitation and filtration.

Blanket fertilizer application without understanding the nutrient influx and efflux and crop need creates nutrient imbalances particularly in sewage effluent irrigated soils. Hence, the present study was formulated to evaluate the movement and transformations of phosphorus, a key eutrophication nutrient as influenced by various sources of wastewater together with fertilizer levels in a tomato field.

## MATERIALS AND METHODS

The experiment was conducted in Rabi season of 2014-15 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad.

### Site description

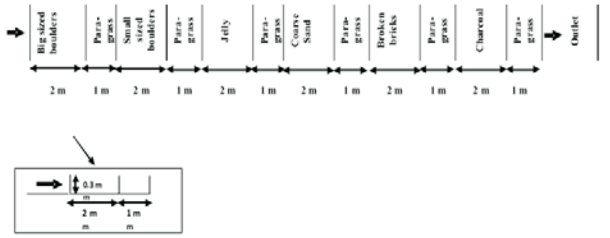
The soil was red sandy loam in the surface and the subsurface soil was sandy clay loam. The soils were slightly alkaline in nature in both surface (pH 7.95 in 0-20 cm) and subsurface depths (pH 8.05 in 20-40 cm). The EC was normal in both the depths. Organic carbon tends to reduce down the depth. Generally, the soils were medium in organic carbon content. Among the exchangeable cations, Ca was the predominant one. Among the inorganic P fractions analysed, Ca -P contributed maximum share; 26.84 and 23.20 mg kg$^{-1}$ at 0-20 and 20-40 cm, respectively. The abundance of inorganic P forms followed the order of Ca –P> Al- P> Fe –P> Red –P> Occl- P> Saloid -P in both the soil depths. The organic P content in the surface depth (147.5 mg kg$^{-1}$) was marginally higher than the subsurface soil (127.1 mg kg$^{-1}$).

### Design of horizontal flow constructed wetland

The sewage effluent, from the university campus was treated by passing through horizontal surface flow wetland system. The dimension of the treatment unit was 29 x 1 x 0.3 m. The filtering materials used were boulders (big and small), jelly, sand, broken bricks and charcoal. The grassed (Brachiaria mutica) channel was sequentially bedded with 2.0 m length strips each of big sized boulders (30-45 cm size), small sized boulders (25-30 cm size), jelly (~ 2.0 cm size), sand (0.025 cm size), broken bricks (5-10 cm size) and lastly charcoal (5-10 cm size). Each such filter strip along the grassy channel was separated by 1.0 m distance. Stumps were placed at the inlet and the discharge rate was measured to be 2 to 5 liters sec$^{-1.}$ The domestic sewage was allowed to flow through treatment plant from inlet and the treated wastewater was collected in outlet and used for irrigation. The layout of the constructed wetland system used is depicted below.

Layout of the constructed wetland system

### Experimental details



The experiment was laid out in a split plot design with four irrigation sources *viz*. groundwater (GW), treated sewage effluent (TSE), untreated sewage effluent (USE) and untreated sewage effluent alternately irrigated with groundwater (USE-GW) as main plots and four fertilizer levels *viz*., 50 per cent recommended doses of N, $P_2O_5$ and $K_2O$ + biofertilizers (F1), 75 per cent recommended doses of N, $P_2O_5$ and $K_2O$ + biofertilizers ($F_2$), RDF alone; no biofertilizers ($F_3$) and no fertilizers ($F_4$) as sub plots. The water samples were collected periodically at 7 days interval whereas the soil samples were collected at 30 and 60 days after transplanting and at time of harvest of tomato crop from a depth of 0-20 cm.

### Laboratory analysis

Both untreated sewage effluent (USE) and treated sewage effluent (TSE) were analyzed for irrigation water quality parameters *viz*., pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS). These were also analyzed for forms of N *viz*., ammoniacal nitrogen ($NH4^+$ -N), nitrate nitrogen ($NO_3$-N), organic nitrogen (ON), total nitrogen (TN) and total phosphorus (TP) by following the procedures as described by APHA (1998) and was compared with that of groundwater (GW).

Phosphorus fractions were determined by modified method of Chang and Jackson (1957) as outlined by Peterson and Corey (1966).

## RESULTS AND DISCUSSION

### Characterization of sewage effluent

The pH of the untreated (raw) sewage effluent was slightly alkaline in nature (Table 1) which might be due to contribution from soaps and detergents present in domestic sewage effluent added through washing, bathing etc (Rajimol *et al*., 2016). The pH reduction in treated sewage effluent can be attributed to $CO_2$ production from decomposing plant litter and other sewage effluent components trapped in the root mat and nitrification of ammonia (Li *et al*., 2008; and Fan *et al*., 2013). The mean pH of treated sewage effluent was found to be 6.88 which remained on par with the pH of groundwater (6.91).

In general, the electrical conductivity of the raw sewage effluent was higher throughout the experimental period compared to the treated sewage effluent which was collected from the outlet of the constructed wetland treatment system. The decrease in conductivity may be because of the uptake of micro and macro

**Table 1: Physicochemical parameters and nutrient composition of untreated, treated sewage effluent and ground water**

| Parameters | Jan. 2014 | | Feb. 2014 | | Mar. 2014 | | Apr. 2014 | | May, 2014 | | Overall mean | | GW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | USE | TSE | USE | TSE | USE | TSE | USE | TSE | USE | TSE | USE | TSE | |
| 1. pH | 7.62 | 7.24 | 6.71 | 6.63 | 7.86 | 7.43 | 7.22 | 6.41 | 7.26 | 6.68 | 7.33 | 6.88 | 6.91 |
| 2. EC (dS m$^{-1}$) | 0.76 | 0.75 | 0.88 | 0.76 | 0.87 | 0.85 | 0.77 | 0.74 | 0.88 | 0.69 | 0.83 | 0.76 | 0.72 |
| 3. Total suspended solids (mg L$^{-1}$) | 420 | 290 | 480 | 230 | 390 | 250 | 480 | 270 | 630 | 350 | 480 | 278 | 8 |
| 4. BOD (mg L$^{-1}$) | 252 | 113 | 259 | 121 | 268 | 119 | 252 | 116 | 249 | 123 | 256 | 118 | 9 |
| 5. COD (mg L$^{-1}$) | 416 | 241 | 412 | 256 | 402 | 236 | 441 | 253 | 410 | 268 | 410 | 251 | 14 |
| 6. $NH_4$- N (mg L$^{-1}$) | 13.4 | 17.4 | 15.5 | 16.4 | 13.9 | 14.6 | 13.4 | 17.2 | 16.4 | 17.6 | 14.5 | 16.6 | 0.46 |
| 7. $NO_3$- N (mg L$^{-1}$) | 1.40 | 3.82 | 1.23 | 1.33 | 2.28 | 3.34 | 1.48 | 3.23 | 2.06 | 3.23 | 1.69 | 2.99 | 0.75 |
| 8. Organic nitrogen (mg L$^{-1}$) | 8.26 | 1.35 | 5.10 | 2.81 | 7.72 | 2.59 | 10.84 | 1.85 | 9.49 | 1.77 | 8.28 | 2.07 | 0.003 |
| 9. Total nitrogen (mg L$^{-1}$) | 23.1 | 22.6 | 21.8 | 20.5 | 23.9 | 20.5 | 25.7 | 22.3 | 23.9 | 22.6 | 23.7 | 21.7 | 1.25 |
| 10. Total phosphorous (mg L$^{-1}$) | 9.1 | 5.9 | 11.1 | 9.3 | 7.5 | 4.8 | 5.7 | 4.2 | 6.3 | 5.9 | 7.94 | 6.02 | 0.10 |

USE – Untreated Sewage Effluent, TSE- Treated Sewage Effluent, GW- Ground water

**Table 2a: Effect of sewage irrigation and fertilizer levels on saloid-P (mg kg-1) in soil at 30 DAT**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 1.59 | 2.07 | 2.37 | 2.17 | 2.05 | 1.23 | 1.55 | 1.78 | 1.63 | 1.55 |
| F2 | 1.67 | 2.31 | 2.89 | 2.43 | 2.33 | 1.31 | 1.59 | 1.9 | 1.71 | 1.63 |
| F3 | 1.74 | 2.43 | 3.37 | 2.71 | 2.56 | 1.46 | 1.72 | 2 | 1.83 | 1.75 |
| F4 | 1.43 | 1.59 | 1.97 | 1.71 | 1.68 | 1.2 | 1.37 | 1.61 | 1.53 | 1.43 |
| Mean | 1.61 | 2.1 | 2.65 | 2.26 | 2.15 | 1.3 | 1.55 | 1.83 | 1.67 | 1.59 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.02 | | 0.06 | | | 0.01 | | 0.05 | | |
| F | 0.02 | | 0.05 | | | 0.02 | | 0.06 | | |
| S x F | 0.03 | | 0.09 | | | 0.04 | | 0.11 | | |

**Table 2b: Effect of sewage irrigation and fertilizer levels on saloid-P (mg kg-1) in soil at 60 DAT**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 1.72 | 2.3 | 2.41 | 2.34 | 2.19 | 1.27 | 1.6 | 1.82 | 1.67 | 1.59 |
| F2 | 1.81 | 2.46 | 2.93 | 2.51 | 2.43 | 1.35 | 1.65 | 1.97 | 1.76 | 1.68 |
| F3 | 1.86 | 2.57 | 3.52 | 3.09 | 2.76 | 1.51 | 1.75 | 2.13 | 1.91 | 1.82 |
| F4 | 1.44 | 1.62 | 1.98 | 1.84 | 1.72 | 1.22 | 1.39 | 1.64 | 1.54 | 1.45 |
| Mean | 1.71 | 2.24 | 2.71 | 2.45 | 2.28 | 1.34 | 1.6 | 1.89 | 1.72 | 1.64 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.01 | | 0.02 | | | 0.01 | | 0.03 | | |
| F | 0.01 | | 0.03 | | | 0.01 | | 0.03 | | |
| S x F | 0.02 | | 0.07 | | | 0.02 | | 0.07 | | |

**Table 2c. Effect of sewage irrigation and fertilizer levels on saloid-P (mg kg-1) in soil at harvest**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 1.68 | 2.25 | 2.38 | 2.31 | 2.16 | 1.25 | 1.55 | 1.77 | 1.59 | 1.54 |
| F2 | 1.74 | 2.44 | 2.87 | 2.5 | 2.39 | 1.34 | 1.58 | 1.85 | 1.69 | 1.61 |
| F3 | 1.84 | 2.55 | 3.25 | 2.98 | 2.65 | 1.49 | 1.7 | 2.01 | 1.86 | 1.77 |
| F4 | 1.43 | 1.61 | 1.88 | 1.81 | 1.68 | 1.21 | 1.35 | 1.57 | 1.5 | 1.41 |
| Mean | 1.67 | 2.21 | 2.6 | 2.4 | 2.22 | 1.32 | 1.55 | 1.8 | 1.66 | 1.58 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.01 | | 0.03 | | | 0.02 | | 0.06 | | |
| F | 0.02 | | 0.04 | | | 0.02 | | 0.05 | | |
| S x F | 0.03 | | 0.09 | | | 0.03 | | 0.09 | | |

D1 and D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

**Table 3a : Effect of sewage irrigation and fertilizer levels on aluminium -P (mg kg-1) in soil at 30 DAT**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 21.61 | 22.37 | 26.83 | 24.69 | 23.88 | 17.41 | 19.2 | 21.75 | 20.85 | 19.8 |
| F2 | 22.97 | 24.46 | 32.91 | 26.38 | 26.68 | 18.81 | 21.27 | 23.79 | 22.06 | 21.48 |
| F3 | 24.49 | 25.03 | 34.72 | 28.91 | 28.29 | 19.93 | 21.93 | 25.51 | 24.43 | 22.95 |
| F4 | 19.57 | 21.2 | 21.79 | 21.61 | 21.04 | 16.16 | 16.74 | 17.05 | 16.83 | 16.69 |
| Mean | 22.16 | 23.27 | 29.06 | 25.4 | 24.97 | 18.08 | 19.78 | 22.02 | 21.04 | 20.23 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.11 | | 0.38 | | | 0.17 | | 0.6 | | |
| F | 0.23 | | 0.67 | | | 0.15 | | 0.44 | | |
| S x F | 0.46 | | 1.35 | | | 0.3 | | 0.87 | | |

elements and ions by plants and bacteria and their removal through adsorption to plant roots, litter and settleable suspended particles (Vera *et al*., 2011 and Arivoli and Mohanraj, 2013). The EC of groundwater was relatively low (0.72 dS $m^{-1)}$ compared to that of USE and TSE.

A reduction in TSS was observed from 480 to 278 mg $L^{-1}$ after constructed wetland treatment. Efficiency of constructed wetland in the removal of turbidity is reported to depend largely on the size sand/ bedding particles and the depth of the bed (Jing *et al*., 2001). The constructed wetland system acted as a mechanical and biological filter and removed suspended particles from the water (Zurita *et al*., 2009 and Vera *et al*., 2011).

After treatment the mean BOD was reduced from of 256 mg $L^1$

**Table 3b: Effect of sewage irrigation and fertilizer levels on aluminium -P (mg $kg^{-1}$) in soil at 60 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 22.89 | 23.35 | 26.73 | 24.22 | 24.3 | 17.43 | 19.59 | 21.99 | 21.12 | 20.03 |
| F2 | 23.27 | 24.74 | 31.91 | 26 | 26.48 | 18.85 | 21.88 | 24.42 | 22.53 | 21.92 |
| F3 | 24.52 | 25.78 | 34.52 | 28.22 | 28.26 | 19.99 | 22.29 | 25.83 | 24.7 | 23.2 |
| F4 | 19.58 | 20.8 | 21.43 | 21.33 | 20.79 | 16.17 | 16.76 | 17.08 | 16.89 | 16.72 |
| Mean | 22.56 | 23.67 | 28.65 | 24.94 | 24.96 | 18.11 | 20.13 | 22.33 | 21.31 | 20.47 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.14 | | 0.48 | | | 0.16 | | 0.54 | | |
| F | 0.24 | | 0.71 | | | 0.1 | | 0.28 | | |
| S x F | 0.49 | | 1.42 | | | 0.19 | | 0.56 | | |

**Table 3c: Effect of sewage irrigation and fertilizer levels on aluminium-P (mg $kg^{-1}$) in soil at harvest**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 22.41 | 23.03 | 25.62 | 23.6 | 23.66 | 17.41 | 19.63 | 21.36 | 20.78 | 19.79 |
| F2 | 23.05 | 24.32 | 27.55 | 25.47 | 25.1 | 18.79 | 21.76 | 23.3 | 22.16 | 21.5 |
| F3 | 24.25 | 25.09 | 31.35 | 27.19 | 26.97 | 19.55 | 22.2 | 25.66 | 23.08 | 22.62 |
| F4 | 19.57 | 20.83 | 21.8 | 21.47 | 20.92 | 16.16 | 16.78 | 17.15 | 16.91 | 16.75 |
| Mean | 22.32 | 23.32 | 26.58 | 24.43 | 24.16 | 17.98 | 20.09 | 21.87 | 20.73 | 20.17 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.21 | | 0.71 | | | 0.1 | | 0.34 | | |
| F | 0.19 | | 0.55 | | | 0.18 | | 0.52 | | |
| S x F | 0.38 | | 1.1 | | | 0.36 | | 1.04 | | |

D1 and D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater;TSE, treated sewage effluent; USE, untreated sewage effluent.

**Table 4a. Effect of sewage irrigation and fertilizer levels on iron-P (mg $kg^{-1}$) in soil at 30 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 16.81 | 21.44 | 23.41 | 21.96 | 20.91 | 13.41 | 16.66 | 19.68 | 18.22 | 16.99 |
| F2 | 18.69 | 23.65 | 28.54 | 26.15 | 24.26 | 15.2 | 17.81 | 22.94 | 20.81 | 19.19 |
| F3 | 19.62 | 25.74 | 30.4 | 27.82 | 25.9 | 16.12 | 19.24 | 26.53 | 23.6 | 21.37 |
| F4 | 14.35 | 14.82 | 14.96 | 14.93 | 14.76 | 12.8 | 13.02 | 13.23 | 13.12 | 13.04 |
| Mean | 17.37 | 21.41 | 24.33 | 22.72 | 21.46 | 14.38 | 16.68 | 20.6 | 18.94 | 17.65 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.2 | | 0.69 | | | 0.23 | | 0.79 | | |
| F | 0.15 | | 0.43 | | | 0.2 | | 0.59 | | |
| S x F | 0.29 | | 0.85 | | | 0.41 | | 1.19 | | |

**Table 4b: Effect of sewage irrigation and fertilizer levels on iron-P (mg $kg^{-1}$) in soil at 60 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 16.89 | 22.11 | 25.72 | 23.85 | 22.14 | 13.44 | 17.08 | 20.66 | 19.71 | 17.72 |
| F2 | 19.6 | 24.74 | 29.75 | 27.1 | 25.3 | 15.87 | 17.95 | 23.66 | 21.23 | 19.68 |
| F3 | 20.64 | 26.03 | 31.18 | 29.43 | 26.82 | 16.27 | 20.06 | 27.02 | 24.7 | 22.02 |
| F4 | 14.41 | 14.9 | 15.08 | 15.04 | 14.86 | 12.78 | 13.14 | 13.71 | 13.39 | 13.26 |
| Mean | 17.88 | 21.94 | 25.43 | 23.85 | 22.28 | 14.59 | 17.06 | 21.26 | 19.76 | 18.17 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.25 | | 0.85 | | | 0.15 | | 0.51 | | |
| F | 0.22 | | 0.64 | | | 0.22 | | 0.63 | | |
| S x F | 0.44 | | 1.27 | | | 0.43 | | 1.26 | | |

in USE to 118 mg $L^{-1}$. The groundwater recorded the lowest BOD of 9 mg $L^{-1}$. The COD of TSE varied from 236 to 268 mg $L^{-1}$ with the mean value of 251mg $L^{-1}$. The GW registered the lowest COD of 14 mg $L^{-1}$ among different sources of irrigation water used in the present study. The presence of macrophytes as a bio-filter is reported to provide a more effective distribution of the roots and a more propitious habitat encouraging the development of a great diversity of microbial communities. Higher BOD and COD removal efficiencies were reported due to increased retention time and higher rhizhosphere oxidation caused by diversity of roots (Zurita *et al*,.2009)

In contrast to other parameters, $NH4^+$-N concentration in the

**Table 4c : Effect of sewage irrigation and fertilizer levels on iron-P (mg kg$^{-1)}$ in soil at harvest**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 16.01 | 21.65 | 24.73 | 22.56 | 21.24 | 13.37 | 17.01 | 19.88 | 18.37 | 17.16 |
| F2 | 17.87 | 23.63 | 27.55 | 25.42 | 23.62 | 15.54 | 17.79 | 22.48 | 20.55 | 19.09 |
| F3 | 18.96 | 25.2 | 29.35 | 27.02 | 25.13 | 16.19 | 19.78 | 26.01 | 23.79 | 21.44 |
| F4 | 14.34 | 14.97 | 15.11 | 15.09 | 14.88 | 12.69 | 13.16 | 13.75 | 13.59 | 13.3 |
| Mean | 16.8 | 21.36 | 24.19 | 22.52 | 21.22 | 14.45 | 16.93 | 20.53 | 19.07 | 17.75 |
| | SEm. ± | | CD (P=0.05) | | | SEm. ± | | CD (P=0.05) | | |
| S | 0.18 | | 0.62 | | | 0.21 | | 0.74 | | |
| F | 0.12 | | 0.36 | | | 0.23 | | 0.67 | | |
| S x F | 0.24 | | 0.71 | | | 0.46 | | 1.35 | | |

D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

**Table 5a: Effect of sewage irrigation and fertilizer levels on reductant soluble-P (mg kg$^{1)}$ in soil at 30 DAT**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 11.87 | 13.41 | 14.82 | 14.02 | 13.53 | 9.18 | 9.92 | 11.67 | 10.87 | 10.41 |
| F2 | 12.34 | 14.37 | 15.62 | 15.5 | 14.46 | 9.8 | 10.91 | 12.65 | 11.7 | 11.26 |
| F3 | 14.51 | 15.57 | 17.01 | 16.7 | 15.95 | 10.18 | 11.88 | 15.84 | 13.01 | 12.73 |
| F4 | 10.31 | 10.54 | 10.86 | 10.73 | 10.61 | 8.25 | 8.32 | 8.57 | 8.46 | 8.4 |
| Mean | 12.26 | 13.48 | 14.58 | 14.24 | 13.64 | 9.35 | 10.26 | 12.18 | 11.01 | 10.7 |
| | SEm. ± | | CD (P=0.05) | | | SEm. ± | | CD (P=0.05) | | |
| S | 0.23 | | 0.79 | | | 0.04 | | 0.14 | | |
| F | 0.18 | | 0.51 | | | 0.11 | | 0.32 | | |
| S x F | 0.35 | | 1.03 | | | 0.22 | | 0.64 | | |

**Table 5b: Effect of sewage irrigation and fertilizer levels on reductant soluble-P (mg kg$^{1}$) in soil at 60 DAT**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 12.16 | 14.57 | 15.24 | 14.82 | 14.2 | 9.23 | 10.14 | 12.09 | 11.7 | 10.79 |
| F2 | 13.04 | 16.01 | 17.02 | 16.86 | 15.73 | 10.13 | 11.08 | 13.05 | 12.12 | 11.6 |
| F3 | 14.91 | 17.21 | 18.67 | 18.07 | 17.22 | 10.22 | 12.01 | 16.03 | 14.34 | 13.15 |
| F4 | 10.33 | 10.59 | 10.92 | 10.81 | 10.66 | 8.25 | 8.37 | 8.61 | 8.54 | 8.45 |
| Mean | 12.61 | 14.59 | 15.46 | 15.14 | 14.55 | 9.46 | 10.4 | 12.45 | 11.68 | 10.99 |
| | SEm. ± | | CD (P=0.05) | | | SEm. ± | | CD (P=0.05) | | |
| S | 0.13 | | 0.45 | | | 0.1 | | 0.36 | | |
| F | 0.14 | | 0.39 | | | 0.11 | | 0.32 | | |
| S x F | 0.27 | | 0.79 | | | 0.22 | | 0.64 | | |

**Table 5c: Effect of sewage irrigation and fertilizer levels on reductant soluble-P (mg kg$^{1}$) in soil at harvest**

| Fertilizer levels | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (F) | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 12.05 | 14.35 | 15.16 | 14.64 | 14.05 | 9.22 | 9.96 | 11.84 | 11.21 | 10.56 |
| F2 | 12.8 | 15.72 | 16.62 | 16.76 | 15.48 | 9.84 | 10.37 | 12.09 | 11.56 | 10.97 |
| F3 | 14.71 | 16.59 | 18.22 | 17.98 | 16.88 | 10.22 | 11.92 | 15.91 | 12.68 | 12.68 |
| F4 | 10.31 | 10.62 | 10.96 | 10.84 | 10.68 | 8.24 | 8.39 | 8.66 | 8.54 | 8.46 |
| Mean | 12.47 | 14.32 | 15.24 | 15.06 | 14.27 | 9.38 | 10.16 | 12.12 | 11 | 10.67 |
| | SEm. ± | | CD (P=0.05) | | | SEm. ± | | CD (P=0.05) | | |
| S | 0.06 | | 0.21 | | | 0.07 | | 0.26 | | |
| F | 0.11 | | 0.32 | | | 0.12 | | 0.34 | | |
| S x F | 0.22 | | 0.64 | | | 0.23 | | 0.67 | | |

D1 and D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater;TSE, treated sewage effluent; USE, untreated sewage effluent.

USE was less (14.5 mg L$^{-1}$) than that in the TSE (16.6 mg L$^{-1}$) throughout the experimental period. The $NH4^{+}$ -N concentrations in the USE ranged from 13.4 to 16.4 mg L$^{-1}$ while that in TSE varied between 14.6 and 17.6 mg L$^{-1}$. The results obtained were contrasting to the findings of Arivoli and Mohanraj (2013) and Vera *et al.* (2011). Removal of ammonia-N is limited by lack of dissolved oxygen in filtration beds caused by permanent saturation. Moreover, in domestic sewage effluent, organic nitrogenous fractions will be more. Because of the enhanced bacterial action taking place in a constructed wetland, the organic nitrogen might be converted into ammoniacal nitrogen, which further because of the phenomenon of matrix adsorption might be coming back to the treated water. Ammoniacal-N is known to get adsorbed

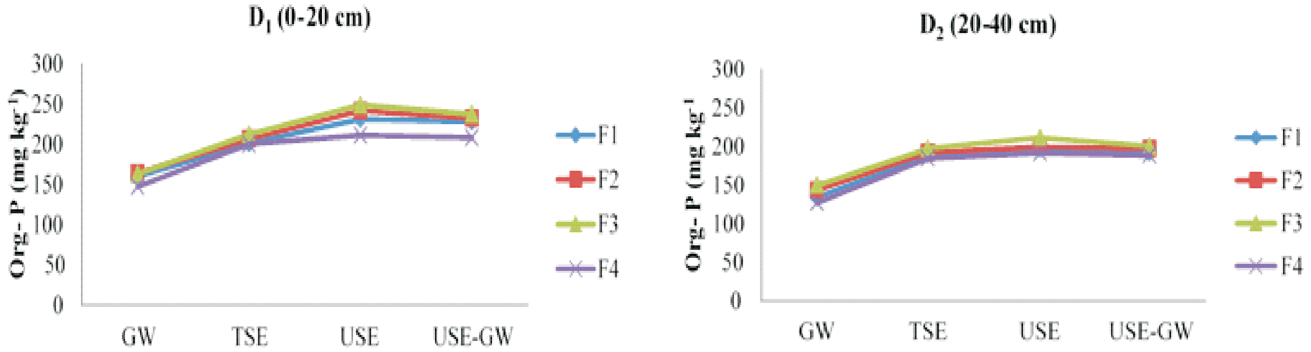


Fig 1a.Effect of sewage irrigation and fertilizer levels on organic-P in soil at 30 DAT

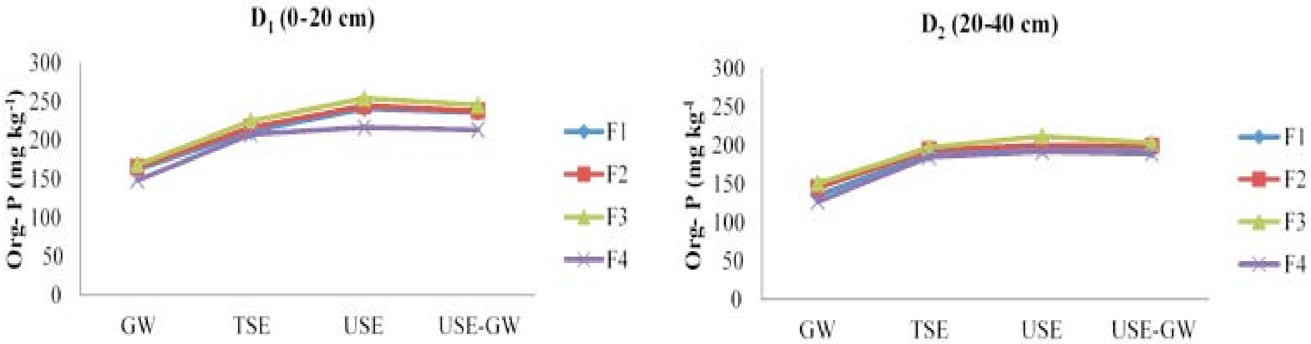


Fig 1b.Effect of sewage irrigation and fertilizer levels on organic-P in soil at 60 DAT

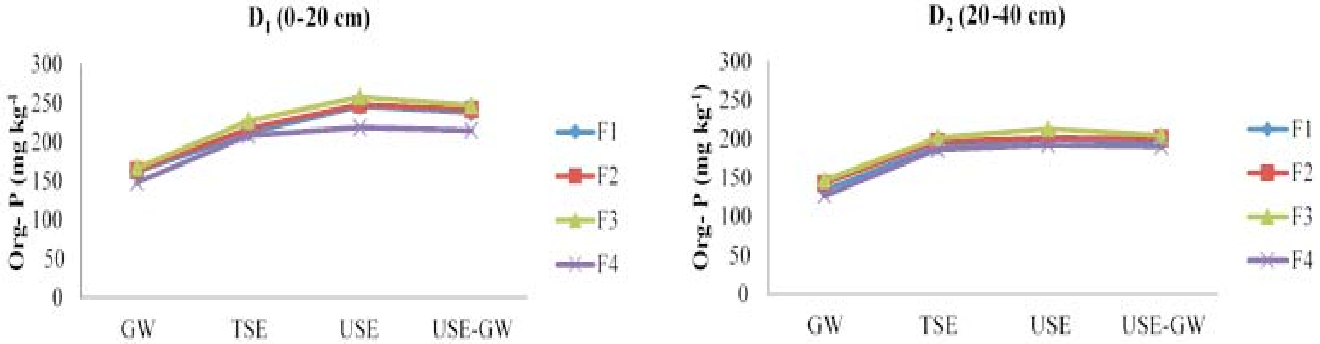


Fig 1c.Effect of sewage irrigation and fertilizer levels on organic-P in soil at Harvest

Table 6a: Effect of sewage irrigation and fertilizer levels on occluded-P (mg kg$^{-1}$) in soil at 30 DAT

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 12.34 | 14.37 | 16.41 | 15.5 | 14.66 | 9.56 | 10.58 | 15.84 | 12.49 | 12.12 |
| F2 | 14.51 | 17.16 | 19.03 | 17.88 | 17.15 | 10.57 | 11.88 | 17.31 | 15.65 | 13.85 |
| F3 | 16.09 | 18.75 | 20.8 | 19.48 | 18.78 | 11.1 | 13.31 | 17.83 | 16.38 | 14.65 |
| F4 | 11.35 | 11.44 | 11.66 | 11.59 | 11.51 | 8.98 | 9.04 | 9.11 | 9.08 | 9.05 |
| Mean | 13.57 | 15.43 | 16.98 | 16.11 | 15.52 | 10.05 | 11.2 | 15.02 | 13.4 | 12.42 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.16 | | 0.57 | | | 0.14 | | 0.49 | | |
| F | 0.31 | | 0.9 | | | 0.12 | | 0.35 | | |
| S x F | 0.61 | | 1.79 | | | 0.24 | | 0.7 | | |

onto active sites of the bed matrix. Since it is a reversible process, as the cation exchange site of matrix is saturated, $NH4^+$ -N will be released back into the water system. The higher $NO3^-$ -N content in the treated water might be because of the enhanced rhizosphere microbial activity under the plant species in the wetland treatment unit.

The USE recorded higher organic and total nitrogen concentration compared to TSE. The mean organic nitrogen content was considerably higher in USE (8.28 mg L$^{-1}$) followed by TSE (2.07 mg L$^{-1}$) and least in the GW (0.003 mg L$^{-1}$). The

**Table 6b: Effect of sewage irrigation and fertilizer levels on occluded-P (mg kg$^{-1}$) in soil at 60 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 12.45 | 15.32 | 17.15 | 15.98 | 15.23 | 9.65 | 11.22 | 16.17 | 13.19 | 12.56 |
| F2 | 14.68 | 18.54 | 19.04 | 18.97 | 17.81 | 10.65 | 12.58 | 18.31 | 16.24 | 14.45 |
| F3 | 16.26 | 19.83 | 21.2 | 20.27 | 19.39 | 11.28 | 15.08 | 20.5 | 17.18 | 16.01 |
| F4 | 11.36 | 11.46 | 11.73 | 11.63 | 11.54 | 8.99 | 9.07 | 9.14 | 9.1 | 9.07 |
| Mean | 13.69 | 16.29 | 17.28 | 16.71 | 15.99 | 10.14 | 11.99 | 16.03 | 13.93 | 13.02 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.25 | | 0.88 | | | 0.12 | | 0.42 | | |
| F | 0.24 | | 0.71 | | | 0.15 | | 0.43 | | |
| S x F | 0.49 | | 1.42 | | | 0.29 | | 0.85 | | |

**Table 6c: Effect of sewage irrigation and fertilizer levels on occluded- P (mg kg$^{-1}$) in soil at harvest**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 12.4 | 15.33 | 17.05 | 15.83 | 15.15 | 9.6 | 11.17 | 15.71 | 12.89 | 12.35 |
| F2 | 14.57 | 17.56 | 18.74 | 18.33 | 17.3 | 10.43 | 12.25 | 17.97 | 15.8 | 14.11 |
| F3 | 16.11 | 19.25 | 20.63 | 20.18 | 19.04 | 11.24 | 14.97 | 19.67 | 16.15 | 15.51 |
| F4 | 11.36 | 11.47 | 11.76 | 11.67 | 11.56 | 8.99 | 9.03 | 9.15 | 9.11 | 9.07 |
| Mean | 13.61 | 15.9 | 17.05 | 16.5 | 15.77 | 10.07 | 11.86 | 15.63 | 13.49 | 12.76 |
| | SEm.± | | CD (P=0.05) | | | | SEm.± | | CD (P=0.05) | |
| S | 0.13 | | 0.44 | | | 0.2 | | 0.7 | | |
| F | 0.21 | | 0.6 | | | 0.18 | | 0.54 | | |
| S x F | 0.41 | | 1.21 | | | 0.37 | | 1.08 | | |

D1 and D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

**Table 7a.:Effect of sewage irrigation and fertilizer levels on calcium-P (mg kg$^{-1}$) in soil at 30 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 29.2 | 31.7 | 33.37 | 32.07 | 31.58 | 24.68 | 30.43 | 32.5 | 31.45 | 29.76 |
| F2 | 30.8 | 33.37 | 36.91 | 34.63 | 33.93 | 25.72 | 32.57 | 35.02 | 32.99 | 31.58 |
| F3 | 32.43 | 36.52 | 42.83 | 40.74 | 38.13 | 28.24 | 33.52 | 38.45 | 37.96 | 34.54 |
| F4 | 26.93 | 27.38 | 27.93 | 27.69 | 27.48 | 23.28 | 23.42 | 23.73 | 23.57 | 23.5 |
| Mean | 29.84 | 32.24 | 35.26 | 33.78 | 32.78 | 25.48 | 29.98 | 32.42 | 31.49 | 29.85 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.18 | | 0.61 | | | 0.19 | | 0.66 | | |
| F | 0.25 | | 0.73 | | | 0.15 | | 0.42 | | |
| S x F | 0.5 | | 1.45 | | | 0.29 | | 0.85 | | |

**Table 7b: Effect of sewage irrigation and fertilizer levels on calcium-P (mg kg$^{-1}$) in soil at 60 DAT**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 29.44 | 32.57 | 34.41 | 32.86 | 32.32 | 24.81 | 30.92 | 32.69 | 31.96 | 30.1 |
| F2 | 30.93 | 34.64 | 38.02 | 36.79 | 35.1 | 25.82 | 31.87 | 36.18 | 33.06 | 31.73 |
| F3 | 32.74 | 36.94 | 43.2 | 41.53 | 38.6 | 28.55 | 34.03 | 41.43 | 38.92 | 35.73 |
| F4 | 26.94 | 27.43 | 28.01 | 27.72 | 27.53 | 23.32 | 23.55 | 23.81 | 23.72 | 23.6 |
| Mean | 30.01 | 32.9 | 35.91 | 34.73 | 33.39 | 25.63 | 30.09 | 33.53 | 31.91 | 30.29 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 0.18 | | 0.61 | | | 0.12 | | 0.4 | | |
| F | 0.16 | | 0.48 | | | 0.1 | | 0.29 | | |
| S x F | 0.33 | | 0.96 | | | 0.2 | | 0.59 | | |

temporal mean value of total nitrogen was relatively higher in USE (23.7 mg L$^{-1}$) compared to TSE (21.7 mg L$^{-1}$) while, groundwater registered the lowest total nitrogen content (1.25 mg L$^{-1}$). Accelerated bacterial action taking place in a constructed wetland may have major responsible role in reduced organic nitrogen levels in the treated sewage effluent.

The total phosphorous concentration in USE varied greatly between 5.70 and 11.1 mg L$^{-1}$ with the mean value of 7.94 mg L$^{-1}$. Similarly, the TP content varied from 4.2 to 9.3 mg L$^{-1}$ with the mean value of 6.40 mg L$^{-1}$ in TSE. The TP concentration in the groundwater was very less (0.10 mg L$^{-1}$). The processes like precipitation, plant uptake and adsorption taking place in

**Table 7c: Effect of sewage irrigation and fertilizer levels on calcium-P (mg kg$^{-1}$) in soil at harvest**

| Fertilizer levels (F) | D1 (0-20 cm) | | | | | D2 (20-40 cm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GW | TSE | USE | USE-GW | Mean | GW | TSE | USE | USE-GW | Mean |
| F1 | 29.3 | 32.35 | 33.97 | 32.5 | 32.03 | 24.77 | 30.04 | 32.1 | 31.21 | 29.53 |
| F2 | 30.67 | 34.05 | 37.5 | 35.37 | 34.4 | 25.47 | 31.11 | 33.39 | 32.96 | 30.73 |
| F3 | 32.53 | 36.53 | 42.7 | 41.18 | 38.24 | 28.3 | 33.95 | 41.11 | 37.95 | 35.33 |
| F4 | 26.94 | 27.46 | 28.09 | 27.85 | 27.59 | 23.28 | 23.61 | 23.9 | 23.79 | 23.64 |
| Mean | 29.86 | 32.6 | 35.56 | 34.23 | 33.06 | 25.45 | 29.68 | 32.63 | 31.48 | 29.81 |
| | SEm.± | | CD (P=0.05) | | | SEm.± | | CD (P=0.05) | | |
| S | 2.21 | | 7.64 | | | 0.08 | | 0.27 | | |
| F | 2.24 | | 6.54 | | | 0.08 | | 0.22 | | |
| S x F | 4.48 | | 13.09 | | | 0.15 | | 0.44 | | |

D1 and D2, soil depths; DAT, days after transplanting; S, sources of irrigation water; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

the constructed wetland treatment system might be responsible for the reduction in TP in the treated sewage effluent (Vera *et al.*, 2011; Arivoli and Mohanraj, 2013).

## Effect of sewage irrigation and fertilizer levels on phosphorus dynamics in soil

### Effect of sewage irrigation and fertilizer levels on saloid- P in soil

The effect of both sources of irrigation water and levels of fertilizer and even their interaction on saloid -P was significant at 30 and 60 DAT and at harvest. (Tables 2a, b and c). The per cent contribution of this form to the total-P was lowest in all the cases. Saloid -P content was significantly higher at 60 DAT of tomato than that at 30 DAT and at harvest. Throughout the experimental period, greater saloid-P concentration was observed at 0-20 cm than at 20-40 cm. Higher saloid -P (2.71 mg kg$^{-1}$) was observed with USE irrigated plots at 60 DAT. Across the fertilizer levels, F3 (RDF alone) accounted for higher saloid- P (2.76 mg kg-1) at 60 DAT. Singh and Sharma (2007) also observed relatively least dominance of saloid- P among different P fractions. This was accounted for the high P-fixation capacity of these soils and also to transformation of soluble forms of P into relatively less soluble forms.

### Effect of sewage irrigation and fertilizer levels on aluminium and iron bound phosphorus (Al-P and Fe-P) in soil

The surface soils regardless of treatments accounted for relatively higher content of both Al and Fe bound P, which may be because of lower pH in the surface soils compared to the deeper soils, irrespective of sources of irrigation water and fertilizer levels (Table 3 and 4 a, b and c). The distribution of aluminium and iron bound phosphorus is reported to be associated with the soil pH (Saha *et al.*, 2013). The elevated contents of Fe –P and Al- P under USE irrigation can be attributed to the presence of more organic carbon, resulting in release of more organic acids leading to solubilization of iron and aluminium and further their precipitation as iron and aluminium phosphates. Along the sources of irrigation water, both iron and aluminium P status followed the order of USE> TSE> USE-TSE> GW regardless of depth of soil and experimental duration. Whereas, across the fertilizer levels, the iron and aluminium P content was in the order of $F_3>F_2>F_1>F_4$.

### Effect of sewage irrigation and fertilizer levels on reductant soluble phosphorus (Red-P) and occluded phosphorus (Occl-P)

Among all phosphorus forms, Red- P and Occl-P were the most dominant inactive forms (Table 5 and 6 a, b and c). The topsoil contained higher Red-P and Occl-P compared to subsurface soil. Both Red-P and Occl-P was slightly increased from 30 to 60 DAT and decreased thereafter irrespective to irrigation water sources and fertilizer levels. With increasing levels of fertilizers both these forms, in general, increased. Untreated sewage effluent irrigated soils registered higher content of both Red-P and Occl-P, which were followed by conjunctively irrigated and treated sewage irrigated soils. Groundwater irrigated plots recorded lowest of these two forms compared to sewage irrigated soils.

### Effect of sewage irrigation and fertilizer levels on calcium bound phosphorus (Ca-P)

The Ca-P was the most dominant inorganic P fraction found in soil which, in general, decreased with the depth (Table 7 a, b and c). The predominance of Ca-P might be due to slightly alkaline nature of the soils and the predominance of Ca among cations in the soil (data not shown). Among the sources of irrigation water, the USE irrigated plots accounted for higher Ca-P content since the alkalinity in these soils were more pronounced compared to the rest of the treatments and was closely followed by TSE irrigated soils. Among the fertilizer levels application of RDF alone (F3) accounted for significantly higher Ca-P throughout the course of experimentation irrespective of soil depth. Badrinath *et al.* (2011) reported the predominance of Ca-P in Vertisols and Inceptisoils of Karnataka. Hong *et al.* (2013) reported the dominance of Ca-P in the sewage effluent irrigated conditions compared to normal watered soils.

### Effect of sewage irrigation and fertilizer levels on organic phosphorus (Org-P)

The data related to Org-P revealed accumulation of organic P in the sewage effluent irrigated soils compared to groundwater irrigated soils (Fig. 1a, b and c). Organic P was the most prominent form of P in the studied soil. Higher organic P was observed in the surface soils which decreased down the depth in all the cases. This data further proved that organic P is associated with organic matter. More organic matter was observed in the surface soil, irrespective of treatments. Untreated sewage effluent irrigated soils accounted for higher organic P content than treated sewage effluent and groundwater irrigated soils obviously because of higher existence of organic carbon in these soils.

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