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Research Article

RECYCLING OF TREATED PAPER BOARD FACTORY EFFLUENT THROUGH DRIP IRRIGATION WITH MINIMAL IMPACT ON GROUNDWATER QUALITY

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Abstract: The investigation on the effect of drip irrigation using treated paperboard factory effluent and on groundwater quality under banana cultivation was carried out at the ITC Ltd, Thekkampatti village, (Mettupalayam taluka) located in Coimbatore district of Tamil Nadu. A Randomized block design was adopted to conduct the experiment with three replications. River water and treated effluent were irrigated through a drip irrigation system and through traditional surface irrigation along with half and three fourth of the recommended dose of NK fertilizers. Drip and surface irrigation treatments were compared with farmer's practice (surface irrigation of river water with 100% recommended NPK, plant–1y-1) (Recommended dose was 110:35:330 g of NPK plant–1 y-1). All treatments uniformly received the recommended dose of P applied as a basal dressing in the pit before planting the suckers. Monitoring wells were installed at the canter of each plot. Water samples collected from the piezometers installed in the plot of respective treatments indicated that the groundwater quality parameters *viz*., BOD, COD, EC, TDS, Na, K, Cl, SO_4, NO_3 contents and SSP values were low in drip irrigation treatments while the above contents were higher due to basin irrigation of treated board factory effluent. Hence it is recommended to adopt drip irrigation for recycling treated paper board factory effluent for the banana to protect the wells from contamination in and around ITC limited paper board factory.

Keywords: *Drip irrigation, Treated paper board factory effluent, Groundwater pollution*

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Introduction

Intensive cultivation of crops with traditional surface application of fertilizers has affected the environment in several ways (including groundwater depletion and pollution with nitrates) and created economic problems in different parts of the world, Similarly, uncontrolled dumping of industrial effluent affected the soil and groundwater health. Treated effluent also has nutrients for crop growth recycling of treated effluent for agriculture protects the natural resources *viz*., water sources from pollution and extraction It also conserves energy in areas where water is available at deeper depths.

Using treated effluent for high water-requiring horticultural crops like bananas through drip irrigation conserves groundwater and minimizes fertilizer input and energy use. Moreover, it provides a convenient means of sewage disposal through land treatment to prevent potential health and environmental hazards caused by the uncontrolled flow of wastewater. Another major benefit of effluent reuse by irrigation is the decrease in wastewater discharges to natural waterways.

FAO has estimated that between 2008 and 2013, the annual increase rate of global fertilizer consumption was 2.2 percent for N, 3.8 percent for P_2O_5, and 5.3 percent for K_2O. The projected worldwide consumption of nutrients in 2013 and 2016 is 184 and 194 million tons, respectively. To address this issue, the most practical solution is to adopt advanced management systems such as drip fertigation, which can help improve fertilizer and water management. The demand for irrigation water has gone up due to increased cultivation. The climatic changes and decline in rainfall further added to the state's water woes in the form of inadequate groundwater recharging.

In irrigated agriculture, one of the most practical fertilizers management methods is injecting them directly into the irrigation water. This process is known as fertigation [1]. Some important advantages of fertigation in comparison with traditional fertilizer application methods include flexibility and manageability, cost-effectiveness, the potential for improved fertilizer distribution uniformity and application efficiency (which results in more uniform crop growth along the field), lower losses due to reduced osmotic pressure (low fertilizer concentration), and the possibility to split nutrients application during the growing season. Fertigation can be effectively used to control fertilizer losses and the resulting pollution risk.

The Ballalpur Industrial Packaging Company Limited (Bipco), located at the foothills of Western Ghats of Thekkampatty Village, Coimbatore District is producing fine quality duplex paper and paperboard from waste papers discharges around 2100 – 2600 m3 d-1 wastewater which is being used to irrigate about 40 ha of high water requirement crop like banana crop through surface irrigation that led to groundwater contamination. Moreover, another 60 ha of land is left uncultivated due to a lack of water facilities. This area could possibly be brought under cultivation if the crop is drip irrigated with treated effluent without any impact on groundwater quality. Hence an attempt was made to study the effect of ferttigation on groundwater quality under effluent irrigation under banana cultivation.

The process of industrialization is widely acknowledged to result in the issue of pollution, affecting water, soil, and air. The pulp and paper sector, in particular, consumes a significant amount of water, most of which is discharged as effluent that requires appropriate treatment and disposal measures. Since this water is on the borderline as saline water, it can be considered a potential source for irrigation [2]. These effluents not only contain nutrients that enhance the growth of crop plants but also have toxic materials, especially sodium, which increases the exchangeable sodium percentage (ESP) to a harmful level during land disposal. The effect of high ESP is manifested by reduced soil permeability and specific ion toxicity to crops. Further wastewater having appreciable concentrations of carbonate and bicarbonate alkalinity exhibits a tendency to precipitate calcium in the soil as $CaCO_3$ [3].

Heavy metals tend to accumulate in the soil and plants in undesirable amounts and proportions as a result of the disposal of paper mill effluents [4]. Therefore, it is essential that the impact of effluent on crop yield and its effect on soil properties should be assessed before they are recommended for irrigation.

According to Mohamedharoon (1991) [5], trickle irrigation has the highest potential for increasing crop yields while saving water and nutrients compared to other traditional methods. Furthermore, brackish water has been found to be suitable for use in drip irrigation. When brackish water is applied frequently under drip irrigation the salinity and sodicity of the soil especially in the root zone of the crop are maintained at a low level [6] suggesting that the treated paper mill effluent which is saline in nature and devoid of heavy metal pollutants as per State Pollution Control Board (SPCB) norms could possibly be used in drip irrigation for high water requiring crops like banana and sugarcane to alleviate soil salinity hazards in the root zone and to prevent the possible groundwater contaminations with organic and inorganic pollutants. Several studies have also indicated that the irrigation water with a total salt concentration of 2 g L-1 could safely be utilized in drip irrigation. Fertigation is a technique that combines irrigation with fertilization through any micro irrigation system, especially through drip irrigation. Fertigation could bring an accurate control of water and nutrients in the immediate vicinity of the root system. Hence, it is easy and efficient to fertilize the crop and prevents fertilizer contamination of groundwater through leaching below the crop root zone. Watering crops slowly and frequently under drip irrigation helps to minimize wide fluctuations in soil moisture, leading to improved growth and yield [7-12].

Banana is a fruit crop that is well-known for its high water requirement, high evaporative demand, high transpiration rate, shallow root system, poor ability to draw water from soil beneath field capacity, and high sensitivity to soil water deficiency. Consequently, it needs adequate irrigation water throughout its life cycle, emphasizing the significance of proper irrigation scheduling. Fertigation has been shown to be highly effective in bananas, with increased water use efficiency, labor savings, and early cropping with heavy yields [13]. This technology is also environmentally safer and helps prevent groundwater contamination [14].

The advantage of micro-irrigation over surface irrigation is the application of water and nutrients only to the part of the soil volume, where active roots are concentrated, enhances the fertilizer use efficiency, and reduces the leaching of nutrients to deep groundwater by seasonal rains. The main advantage of N micro-fertigation over broadcast N fertilization in orange was reduced nitrate leaching below the soil root volume. The nitrate concentration remained higher in the root zone with frequent trickle irrigation to sweet corn than with flood irrigation. Feign *et al*. (1982) [15] reported a decrease in NO_3 leaching with increased fruit yield and quality in tomato and celery crops under micro-fertigation.

Hagin and Lowengart (1996) reported that the intensification of agriculture by irrigation and enhanced use of fertilizers may generate pollution by increasing levels of nutrients in underground and surface waters. Most of the irrigation is by an open system having a relatively low efficiency of water application. A higher efficiency may be gained by the pressurized irrigation system. Drip irrigation generates a restricted root system requiring frequent nutrient supply that may be satisfied by applying fertilizers in irrigation water (fertigation). Maximization of crop yield and quality and minimization of leaching below the root volume may be achieved by managing fertilizer concentration in measured quantities of irrigation water, according to crop requirements.

Fertigation treatments invariably increased the efficiency of applied nutrients in bananas over manual application. The fertilizer applied in solution form directly to the active root zone in small quantities has been efficiently absorbed and utilized showing reduced possibilities of leaching and utilization by banana plants in a better way than those under a conventional system. The efficiency of fertigation has been exhibited by lower nutrient status (N and K) corresponding to higher leaf nutrient status over control during the peak vegetative stage and at harvest. On the other hand, high volatilization and leaching are commonly associated with the conventional system of fertilization wherein a large quantity of fertilizer was applied at wider intervals causing every possibility of leaching below the crop root zone leading to groundwater contamination of applied nutrients. Hence, conventional fertilizer application in huge quantities at longer intervals can be replaced with fertigation at small quantities at shorter intervals to prevent groundwater contamination and maintain soil health. Finally, they concluded that fertigation could be taken up as an environmentally safer technology to prevent groundwater contamination.

The above foregoing literature reveals that either saline water or treated industrial effluents having salt concentration <2 g L-1 could be used for drip irrigation without any adverse effect on yield and quality of crop produce, soil, and groundwater. Use of drips for effluent irrigation will increase the area under cultivation, reduce labour consumption, reduce fertilizer losses, and prevent soil and groundwater contamination. The literature pertaining to effluent irrigation to banana through drip irrigation are meager. So, the present study was proposed.

Materials and methods

The investigation on the effect of fertigation of treated paperboard mill effluent and solid amendments on groundwater quality besides improving soil characteristics, crop growth, quality of crop production and are carried out at the ITC paper board industries Pvt. Ltd, Thekkampatti village, (Mettupalayam taluk) and in the Department of Environmental Sciences, TNAU, Coimbatore located in the Coimbatore district of Tamil Nadu, India from May 2002 to April 2003. The experiment was conducted in a Randomized block design with two replications and a banana (Robusta) was selected as the test crop. The treatments were assigned in an RBD. Irrigation treatments were assigned in the main plot that consisted of seven treatments 1. Farmer's practice as control (Surface Irrigation with river water (RW)+ 100% NK), 2. RWF75%NK (RW + Drip irrigation (DI) + 75% NK thro' fertigation,3. RWF 50% NK (RW + DI + 50% NK thro' fertigation, 4. EBI 100% NK (Treated effluent (TE) +Basin irrigation (BI)+100% NK thro' soil application) 5. EBI 75% NK- TE + BI + 75% NK thro' soil application, 6. EF 75%NK (TE + DI + 75% NK thro' fertigation), EF50%NK (TE + DI + 50% NK thro' fertigation). Amendments were applied in the sub-plot. Three types of amendments were applied in the soil FA (Fly ash @ 6 t ha –1 , BC (Biocompost @ 5 t ha -1), FC+BC+GM (Fly ash @ 6 t ha –1 + Biocompost @ 5 t ha –1 + Green manure @ 6.25 t ha-1) Recommended 100% NPK is 110: 35:330 g of NPK plant –1 y-1). The entire P was applied through single super phosphate as basal dressing in the pit before planting the suckers uniformly for all the treatments. The experimental area was irrigated with river water obtained from River Bhavani and treated paperboard mill effluent from Bipco according to the treatments. The treated effluent was neutral in reaction with high salinity, contained appreciable amounts of nutrient cations namely, Na, Ca, Mg, and anions namely Cl, SO_4 and HCO_3 with less sodium hazard (SAR <10). The percent sodium was well below the tolerance limit of 60 and the parameters recorded were well within the range of permissible limit prescribed by the Tamil Nadu State Pollution Control Board norms (TNSPCB). The effluent was rich in microbial load with the dominance of bacteria over fungi and actinomycetes. The characteristics of the effluent and river water used for the study were given in [Table-1].

Table-1 *Characteristics of treated effluent and river water used for irrigation*

Characteristics	Treated effluent	River water
pH	7.5	7.05
Electrical conductivity (EC) (dS m^{-1})	1.8	0.05
Biological oxygen demand (BOD) (ppm)	18	4.2
Chemical oxygen demand (COD) (ppm)	90	4.5
Total dissolved solids (TDS), (ppm)	900	47
Total suspended solids (TSS) (ppm)	90	20
NH_4-N (ppm)	155	Nil
NO_3 N (ppm)	42	Nil
Total P (ppm)	1.7	Nil
Total K (ppm)	6.6	1
Ca (cmol L^{-1})	11.6	0.84
Mg (cmol L^{-1})	6.03	0.53
Na (cmol L^{-1})	11.5	0.09
SAR	3.87	0.11
CO_3 (ppm)	Nil	Nil
HCO_3 (ppm)	117	1.4
Cl (ppm)	350	37
SO_4 (ppm)	127	42
Bacteria ((x10^6ml^{-1}CFU))	33	7
Fungi (x10^4ml^{-1}CFU)	10	5
Actinomycetes (x10^3ml^{-1}CFU)	20	2

The drip system was installed as described by Udayasoorian and Prabakaran (2010) [16]. Piezometers were installed as per the procedure described by Latha *et al*. (2013) [17] in each plot to study the groundwater quality.

Water samples were collected from the reated effluent out let and piezometers of the respective plots and 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. 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 [18]. The pH was measured on the spot itself. Carbonates and bicarbonates were analysed immediately after bringing the sample from the field to the laboratory. Samples were analysed for various properties like BOD, COD, total hardness, CO_3, Cl, SO_4, Na, Ca, Mg, K contents, and percent sodium values by following standard procedures.

The data on the observation recorded and the characters studied were statistically analyzed by the procedure described by Gomez and Gomez (1984) [19] using AGRES software. Wherever the results are significant, the critical difference at the 5 percent level was presented.

Results

The pH values of the groundwater samples collected from the piezometer varied from 6.59 to 7.42 at the harvest stage [Table-2]. Neither the irrigation treatments nor the amendments and their interactions were effective in influencing significant changes in pH of the groundwater

Table-2 *Effect of effluent irrigation and amendments on pH of piezometer water samples at the harvest stage*

I/A	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	7.31	7	6.9	7.07
RWF 75 % NK	7	7	7	7
RWF 50 % NK	7.01	7	6.99	7
EBI 100 % NK	7.42	7.33	7.31	7.35
EBI 75 % NK	7.33	7.3	6.59	7.07
EF 75% NK	7.01	7	7.12	7.04
EF 50 % NK	7.12	7.02	7	7.05
Mean	7.17	6.99	7.09	
	I	A	IxA	A X I
SEd	0.26	0.19	0.48	0.49
CD (0.05)	NS	NS	NS	NS

Significant increase in ground water EC [Table-3] was observed in effluent irrigation treatments over river water irrigation. It varied from 0.02 to 1.75 dS m-1 at harvest stage. Among the irrigation treatments, basin irrigation of effluent significantly increased the EC, while river water fertigation significantly reduced it. Among the amendments, lower EC values were recorded in combined application of fly ash + compost + green manure, while higher values were recorded in fly ash alone. The interaction effects were significant.

Table-3 *Effect of effluent irrigation and amendments on EC (dS m-1) of piezometer water samples at harvest stage*

I/A	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	0.13	0.11	0.06	0.1
RWF 75 % NK	0.02	0.02	0.02	0.02
RWF 50 % NK	0.02	0.02	0.02	0.02
EBI 100 % NK	1.75	1.4	0.84	1.33
EBI 75 % NK	1.64	1.31	0.78	1.24
EF 75% NK	0.21	0.17	0.11	0.16
EF 50 % NK	0.32	0.25	0.15	0.24
Mean	0.58	0.47	0.29	
	I	A	I at A	A at I
SEd	0.07	0.04	0.1	0.09
CD (0.05)	0.17	0.08	0.23	0.2

The BOD of piezometer water samples significantly increased due to basin irrigation of effluent, while it was decreased due to fertigation treatments either through effluent or river water (Table 4). Application of fly ash alone increased the BOD values, whereas it was decreased due to incorporation of fly ash + compost + green manure .

Table-4 *Effect of effluent irrigation and amendments on BOD (ppm) of piezometer water samples at harvest stage*

Irrigation(I)/ Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	48.4	39.9	35.7	41.3
RWF 75 % NK	8.4	8.4	6.3	7.7
RWF 50 % NK	10.5	10.5	8.4	9.8
EBI 100 % NK	54.1	45.1	40.5	46.6
EBI 75 % NK	50.3	42.1	37.5	43.3
EF 75% NK	10.5	10.5	8.4	9.8
EF 50 % NK	8.4	8.4	6.3	7.7
Mean	27.2	23.6	20.4	
	I	A	I at A	A at I
SEd	2.7	1.2	3.7	3.1
CD (0.05)	6.7	2.5	NS	NS

Fertigation treatments decreased the COD of groundwater samples. It ranged from 52 to 443 ppm at harvest stages (Table 5). Among the irrigation treatments, fertigation either through river water or effluent significantly reduced the COD values, while basin irrigation of effluent increased the COD values and it was on par with farmer's practice . The addition of fly ash alone increased the COD compared to the rest of the amendments. Interaction between irrigation treatments and amendments was not significant.

Table-5 *Effect of effluent irrigation and amendments on COD (ppm) of piezometer water samples at harvest stage*

Irrigation (I)/Amendments (A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	397	328	293	339
RWF 75 % NK	69	69	52	63
RWF 50 % NK	86	86	69	80
EBI 100 % NK	443	369	332	382
EBI 75 % NK	413	345	308	355
EF 75% NK	86	86	69	80
EF 50 % NK	69	69	52	63
Mean	223	193	168	
	I	A	I at A	A at I
SEd	23	9.6	31	25
CD (0.05)	55	21	NS	NS

The Ca content of the groundwater sample at hthe arvest stage varied from 0.04 to 3.85 cmol L-1 [Table-6]. Effluent irrigation, amendments, or interaction had non-significantly influence the Ca content.

Table-6 *Effect of effluent irrigation and amendments on Ca (cmol L-1) of piezometer water samples at harvest stage*

Irrigation(I)/Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	0.29	0.24	0.13	0.22
RWF 75 % NK	0.04	0.04	0.04	0.04
RWF 50 % NK	0.04	0.04	0.04	0.04
EBI 100 % NK	3.85	3.08	1.85	2.93
EBI 75 % NK	3.61	2.88	1.72	2.74
EF 75% NK	0.46	0.37	0.24	0.36
EF 50 % NK	0.7	0.55	0.33	0.53
Mean	1.28	1.03	0.62	
	I	A	I at A	A at I
SEd	1.45	0.85	2.3	2.2
CD (0.05)	NS	NS	NS	NS

The Mg content of groundwater samples varied from 0.02 to 4.12 cmol L-1 [Table-7]. Similar to The Ca content of piezometer water samples Mg content was non-significantly different due to irrigation treatments, amendments, or its interaction.

Table-7 *Effect of effluent irrigation and amendments on Mg (cmol L-1) of piezometer water samples the at harvest stage.*

Irrigation(I)/Amendments(A)	A_1	A_2	A_3	Mean
FP (SI 100% NPK)	0.13	0.11	0.06	0.1
RWF 75 % NK	0.02	0.02	0.02	0.02
RWF 50 % NK	0.02	0.02	0.02	0.02
EBI 100 % NK	4.12	3.3	1.98	3.13
EBI 75 % NK	3.85	3.07	1.85	2.92
EF 75% NK	0.21	0.17	0.11	0.16
EF 50 % NK	0.34	0.27	0.17	0.26
Mean	1.24	0.99	0.6	
	I	A	I at A	A at I
SEd	1.5	0.72	2.23	2.18
CD (0.05)	NS	NS	NS	NS

Effluent irrigation significantly increased the groundwater Na content more than river water irrigation [Table-8]. Among the effluent irrigation treatments, basin irrigation of the effluent recorded higher values of Na than effluent fertigation. The application of fly ash increased the Na content in groundwater and the combined application of fly ash + biocompost + green manure reduced the Na content. The interaction effect was also significant.

Table-8 *Effect of effluent irrigation and amendments on Na (cmol L-1) of piezometer water samples at the harvest stage*

Irrigation (I)/ Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	0.19	0.17	0.11	0.16
RWF 75 % NK	0.04	0.02	0.02	0.03
RWF 50 % NK	0.04	0.04	0.02	0.04
EBI 100 % NK	6.18	4.94	2.96	4.7
EBI 75 % NK	5.76	4.63	2.78	4.69
EF 75% NK	0.34	0.27	0.17	0.26
EF 50 % NK	0.5	0.4	0.23	0.38
Mean	1.87	1.5	0.9	
	I	A	I at A	A at I
SEd	0.23	0.12	0.35	0.33
CD (0.05)	0.57	0.27	0.81	0.7

The K content of groundwater samples at harvest stage ranged from 0.01 to 2.75 cmol L-1 [Table-9]. The same trend as above in Na was observed here also in irrigation treatments and amendments and interaction.

Table-9 *Effect of effluent irrigation and amendments on K (cmol L-1) of piezometer water samples at harvest stage*

Irrigation (I)/ Amendments (A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	0.11	0.08	0.06	0.08
RWF 75 % NK	0.02	0.02	0.01	0.02
RWF 50 % NK	0.02	0.02	0.02	0.02
EBI 100 % NK	2.75	0.34	1.66	1.58
EBI 75 % NK	2.59	0.32	1.56	1.49
EF 75% NK	0.19	0.15	0.08	0.14
EF 50 % NK	0.27	0.23	0.13	0.21
Mean	0.85	0.17	0.5	
	I	A	I at A	A at I
SEd	0.08	0.05	0.14	0.14
CD (0.05)	0.21	0.11	0.31	0.29

Basin irrigation with effluent recorded higher SSP values than fertigation treatments either through effluent or river water indicating the possibilities of polluting ground water. The SSP of water samples collected in the piezometer varied from 43.54 to 80.31 [Table-10]. The SSP of ground water samples was not significantly influenced by the incorporation of amendments and their interactions with irrigation treatments.

Table-10 *Effect of effluent irrigation and amendments on SSP values of piezometer water samples at harvest stage*

Irrigation(I)/ Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	51.63	52.86	56.24	53.58
RWF 75 % NK	60.66	43.54	43.54	49.24
RWF 50 % NK	60.66	60.66	43.54	54.95
EBI 100 % NK	80.19	80.18	80.18	80.18
EBI 75 % NK	80.1	80.18	80.31	80.2
EF 75% NK	54.02	54.11	52.86	53.67
EF 50 % NK	53.63	53.96	53.07	53.55
Mean	49.23	49.24	49.09	
	I	A	I at A	A at I
SEd	1.1	21	22.1	22.1
CD (0.05)	2.2	NS	NS	NS

The ground water chloride content was significantly increased due to effluent irrigation compared to river water irrigation [Table-11]. Among the effluent treatments, fertigation with effluent reduced the Cl contamination than basin irrigation. Among the amendments, incorporation of fly ash + compost + green manure decreased the chloride content, whereas addition of fly ash increased the chloride content of ground water samples.

Table-11 *Effect of effluent irrigation and amendments on Cl (cmol L-1) of piezometer water samples at harvest stage*

Irrigation(I)/Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	2.96	2.37	1.78	2.37
RWF 75 % NK	0.59	0.59	0	0.39
RWF 50 % NK	0.59	0.59	0.59	0.59
EBI 100 % NK	9.48	7.76	4.68	7.3
EBI 75 % NK	8.88	7.28	4.38	6.85
EF 75% NK	5.33	4.15	2.37	3.95
EF 50 % NK	5.13	4.34	2.37	3.95
Mean	4.71	3.87	2.31	
	I	A	I at A	A at I
SEd	16.9	6.9	22.7	18.4
CD (0.05)	41.4	14.9	52.5	39.6

The sulphate content of groundwater samples varied from 0.10 to 3.74 cmol L-1 [Table-12]. The same trend as that of Cl was observed here also where the magnitude of SO_4 contamination was less compared to Cl.

Table-12 *Effect of effluent irrigation and amendments on SO_4 (cmol L-1) of piezometer water samples at harvest stage*

Irrigation(I)/Amendments (A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	1.17	0.93	0.7	0.93
RWF 75 % NK	0.23	0.23	0.1	0.19
RWF 50 % NK	0.23	0.23	0.23	0.23
EBI 100 % NK	3.74	3.06	1.85	2.88
EBI 75 % NK	3.5	2.87	1.73	2.7
EF 75% NK	2.1	1.64	0.93	1.56
EF 50 % NK	2.02	1.71	0.93	1.55
Mean	1.86	1.52	0.92	
	I	A	I at A	A at I
SEd	0.19	0.08	0.25	0.21
CD (0.05)	0.46	0.17	0.58	0.44

Fertigation treatments lowered groundwater nitrate pollution than surface irrigation. The magnitude of NO_3 pollution was higher in effluent basin irrigation than rest of the irrigation treatments. Addition of fly ash + compost + green manure reduced the groundwater nitrate pollution and fly ash alone increased the NO_3 pollution. and the values ranged from 7.6 to 79.2 ppm [Table-13].

Table-13 *Effect of effluent irrigation and amendments on NO_3 (ppm) of piezometer water samples at harvest stage*

Irrigation(I)/Amendments(A)	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	42.1	33.6	25.2	33.6
RWF 75 % NK	8.4	8.4	7.6	8.1
RWF 50 % NK	8.4	8.4	8.4	8.4
EBI 100 % NK	79.2	64.8	39.1	61
EBI 75 % NK	74.2	60.8	36.6	57.2
EF 75% NK	38	29.6	16.9	28.2
EF 50 % NK	36.6	31	16.9	28.2
Mean	41	33.8	21.5	
	I	A	I at A	A at I
SEd	3.8	1.6	5.2	4.4
CD (0.05)	9.4	3.5	12	9.3

In general, fertigation treatments recorded higher yield than basin irrigation treatments and farmer's practice. The yield obtained from the field trial varied from 21.5 to 57.5 kg plant-1 [Table- 14]. The yield was increased (57.5 kg plant-1) due to effluent fertigation with 75 percent NK on par with other fertigation treatments. Application of amendments or interaction did not show any differences in yield.

Table-14 *Effect of effluent irrigation and amendments on fruit yield (kg plant-1)*

I/A	FA	BC	FA+BC+GM	Mean
FP (SI 100% NPK)	34	30.5	38	34.2
RWF 75 % NK	53	51.5	52.5	52.3
RWF 50 % NK	51.5	50.5	53.5	51.8
EBI 100 % NK	25.5	22.5	28	25.3
EBI 75 % NK	24	21.5	24	23.2
EF 75% NK	55	56	57.5	56.2
EF 50 % NK	56.5	54.5	56.5	55.8
Mean	42.8	41	44.3	
	I	A	I at A	A at I
SEd	5.7	3	8.6	14.9
CD (0.05)	14.1	NS	NS	NS

The result obtained due to analysis of piezometer water samples collected during the harvest stage are discussed here under. The pH is the negative logarithm of the hydrogen ion concentration or simply the log of the reciprocal of the hydrogen ion concentration and indicates the degree of acidity or alkalinity of water. In the present investigation, three was no drastic change in pH of water collected in the piezometer. due to irrigation sources amendments or interaction. This might be due to buffering capacity of soil that might have prevented drastic change of groundwater pH.

The concentration of soluble salts in water can be measured in terms of electric conductivity. In the present investigation surface irrigation of treated effluent with 100 per cent NK increased the EC of groundwater. This may be attributed to the surface application of a larger quantity of effluent, which could have seeped and percolated down to the groundwater. Among the amendments, application of fly ash increased the EC. The EC was decreased in the plots applied with fly ash + biocompost + green manure. It was due to addition of organic matter by green manure that prevented the downward movement of salts. Increase in ground water EC might be due to increase in the concentration of salts like Ca, Mg, Na, K etc., present in the seepage.

BOD (biological oxygen demand) refers to the quantity of oxygen needed by bacteria to stabilize decomposable organic matter in aerobic conditions. The current study found that surface irrigation of effluent resulted in an increase in groundwater BOD levels. It might be due to the eutrophication of the groundwater with nutrients present in the effluent and applied nutrients. Similarly, the application fly ash alone increased the BOD, while decreased BOD was recorded in the plots applied with fly ash + biocompost + green manure. This might be due to the slow release of applied nutrients and continuous uptake by crops might have reduced the nutrient content of groundwater collected in the piezometers.

The chemical oxygen demand (COD) is a parameter used to measure the quantity of oxygen required to oxidize the organic matter present in a wastewater sample using potassium dichromate. This is a crucial and rapidly determined metric for determining the pollution level of stream, sewage, and industrial waste samples Among irrigation treatments, higher COD values were recorded in surface irrigation treatments. Similarly, the application of fly ash alone increased the COD.

The cations *viz*., Ca, Mg, Na and K were increased due to surface irrigation of effluent with the application of fly ash alone, while river water irrigation along with the combined application of fly ash + biocompost + green manure decreased cations of groundwater. Increased cations and anions due to surface irrigation of effluent were reported by Elayarajan (2002) [20]. The decrease in ions due to the combined application of amendments might be due to the precipitation of Ca and Mg by green manure.

Among the irrigation treatments, surface irrigation of effluent with 100 percent NK increased the Na and K content. The increase in Na and K content might be due to their high mobility favored to contaminate the groundwater easily when compared to other constituents. Similarly, the application of fly ash alone increased the Na and K content. It might be due to the high Ca and Mg content of the fly ash which had replaced the native Na leach out to groundwater.

Among the irrigation sources, surface irrigation of the treated effluent increased the chloride content. Among the amendments, the application of fly ash alone increased the chloride concentration. This was due to the higher chloride content of the treated effluent. An increase in chloride content in the groundwater samples collected in and around the continuously effluent irrigated area was reported by Elayarajan (2002).

Very frequently groundwater contains a high amount of nitrate. Continuous application of such irrigation water on soil can adversely affect several physical properties, leading to poor plant growth. In the present investigation, among the irrigation sources, the surface application of treated effluent increased the concentration of nitrate. Similarly, the application of fly ash increased the concentration. The permissible limit for safe drinking water is 50 ppm above which may cause "blue baby disease". In the study, the surface application of treated effluent with fly ash and surface application of treated effluent with biocompost at the harvest stage exceeded the critical limit of 50 ppm. This indicates that surface irrigation of the effluent either with fly ash or biocompost alone should be avoided to protect the wells from nitrate pollution.

The result indicates that fertigation treatments were effective in protecting the groundwater from leaching and percolation of effluent water irrigation. The yield of banana ha−1 was increased due to effluent fertigation with 75 percent NK. Increased yield in the present study might be due to an increase in bunch weight plant−1 [21]. Banana requires very moist conditions for optimum growth and production. A decrease in soil matrix potential adversely affects its performance [22]. Robinson and Alberts (1986) [26] and Robinson and Bower (1987) [27] have noticed initiation of stress in banana plants at a soil matric potential of around −20 to −25 kpa. As the drip irrigation system maintains very high soil matric potential, at least a part of the root zone without much stress, there were probably ideal conditions eexistfor better growth and yield of a banana compared with basin irrigation where plants are liable to experience increasing stress each day following irrigation. Increased yield due to fertigation was reported in different crops *viz*., tomato [28], cotton [29], sweet corn [30], avocado [31], mandarin [32], apricot [33], sugarcane [34], orange [35-37], pomegranate [38], papaya [39], hybrid tomato [40], banana [41 and potato [42,43].

Conclusion

The groundwater quality parameters *viz*., EC, BOD, COD, TDS, Ca, Mg, Na, K, Cl, and SO_4 were increased due to basin irrigation of treated board mill effluent. Basin irrigation with effluent recorded higher SSP values and higher nitrate content than fertigation treatments either through effluent or river water indicating the possibility of a polluting groundwater source. The Surface application of treated effluent with fly ash and surface application of treated effluent with bio-compost at the harvest stage exceeded the critical limit of 50 ppm. It is evident that the fertigation treatments are more effective in protecting the groundwater and reducing leaching and percolation of effluent water in this study. The advantage of micro-irrigation over surface irrigation is the application of water and nutrients only to the part of the soil volume, where active roots are concentrated, and reduces the leaching of nutrients deep underground water by seasonal rains.

Application of research:

The treated effluent obtained shcould be treated and utilized for banana through drip fertigation to conserve precious natural resources

Research Category: Natural Resource Management

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Cultivar / Variety / Breed name: Nil

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