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Pulp and papermill wasterwater: can it solve the irrigation water scarcity problem

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ABSTRACT: changes in physico-chemical properties of soils and crops grown with pulp and paper mill wastewater in field lysimeters were carried out for three years at the integrated pulp and paper mill, madhya pradesh (india). lysimeters were prepared by excavating pits of 5 m x 2 m x 2 m, lined with polyethylene sheet and filled with sandy loam, clay and loamy sand soils and provided with percolate collection system. treated wastewater was used for crop irrigation containing high salinity and specific ion toxicity. with respect to sodium adsorption ration (sar), it was categorized under group `no restriction on use'. sandy loam & loamy sand soils in lysimeter i and iii percolate was 17% and 20% of irrigation while clay soil in lysimeter ii it was only 15%. sandy loam & loamy sand soils respectively showed 97 & 96% removal of chemical oxygen demand (cod) while clay soil removed 99% of cod and the color removal in both cases was 100%. percolate initially showed leaching of calcium and magnesium and retention of sodium, which got adsorbed in soil matrix. application of wastewater resulted in increase in water holding capacity, ph (0.6 - 1.3 units), electrical conductivity of saturated extract (ece - 0.6 - 2.1 ms cm^{-1}) and exchangeable sodium percent (esp - 8.1 - 11.6). organic carbon and available nitrogen, phosphorus and potash content of soils were also increasing. however, there was decrease in bulk density. the results showed that the application of wastewater increased the grain and straw yield of jowar, wheat and moong as compared to plain water respectively. there was slight variation in micro and macro nutrient content of grains of crop irrigated with wastewater, but it did not affect the nutrient quality and there was no accumulation of toxic heavy metals in the food grain. we measured nutrient input by wastewater and output by leaching and harvest export on unfertilized crop. a semi quantitative nutrient balance showed that all lysimeters had negative balance of micronutrients, indicating open nutrient cycles on these soils. these results showed that the pulp and paper mill wastewater might be successfully utilized for crop production.

Key words: Yield, Pulp and paper mill wastewater; Lysimeter; COD; ESP

INTRODUCTION

The pulp and paper industry is an important part of the Indian Economy and witnessed a steady increase in installed capacity and production over the past decade. There are 380-paper mill with an installed capacity of 3.84 million tons per annum (TPA) (India, 2000). The actual production was only 2.57 million TPA. The demand was estimated to be around 5.48 million tons in 2005-06. Paper mill is one of the major wastewater generating industry and the volume of wastewater generated is normally governed by technology adopted, effectiveness of treatment process and amount of treated wastewater recycled (Wiseman and Ogden, 1996; Robertson and Schwinget, 1997; Norris, 1998). Paper mill consume large quantities of water and generates wastewater as low as 1.5 m^3/ ton of paper (Szolosi, 2003) to as high as 60 m^3/ ton of paper produced (Thompson et al., 2001). In most of cases this wastewater is disposed into water bodies creating social and environment concern among the downstream users (EPR, 1988).

The pulp and paper mill wastewater comprises of high suspended solids (SS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), dark brown color due to lignin, and high pH (Hammer, 1998). This creates problems in disposal of wastewater in water bodies (Ali and Srikrishnan, 2001). It is reported that on average, one ton of paper production produces 1.5-50 m3 waste wastewater depending on the nature of raw materials and extent of water use (European Commission, 2001). Conventional wastewater treatment methods reduce SS, BOD, and to some extent COD but color remains more or less unchanged, because of no biodegradability of lignin. The presence of halogenated organic compounds in wastewater is toxic to aquatic life. Available treatment methods for color removal i.e. use of adsorbents (activated carbon), coagulants (lime and alum) and as bleaching agent (ozone), are not so effective or economical.

Land application is considered to be most acceptable and cost effective method for pulp and paper mill wastewater management as soil provides physical, chemical, and biological treatment to wastewater and removes the color completely (Anderson, 1979). Besides helping the growth of crops and forest trees (Juwarkar and Subrahamanyam, 1987; Fazeli et al., 1991, 1998; Al Jamal et al., 2002; Phukan and Bhattacharya, 2003; Khan et al. 2007 and NEERI-UNEP Report, 1994) it is beneficial for soil properties (physico-bio-chemical) (Kannan and Obliswami, 1990). This paper highlights the characterization of pulp and paper mill wastewater, COD and color removal capacity of soil, changes in percolate quality, soil property and crop growth. Kannan and Obliswami (1990) reported the beneficial effect of pulp and paper mill wastewater on soil and crops. As a result of the pulp and paper industry has a growing concern regarding cost effective methods for its disposal, the land treatment of pulp and paper mill wastewater has become an essential prerequisite.

MATERIALS AND METHODS

Study area

The laboratory studies were carried out at National Environmental Engineering Research Institute (NEERI), Nagpur and the field lysimeter unit was established at integrated large pulp and paper mill at Madhya Pradesh (India) which lies on 21-22^o North latitude and 75-76^o East longitudes. The study area comes under semi-arid ecoregion and the climate of the area is characterized by hot and dry summers and mild winters. The annual precipitation ranging from 600 to 700 mm covers 40 to 50% of annual potential evapotranspirative (PET) demand of 1600 to 2000 mm, resulting in gross annual deficit of 800 to 1200mm.

Wastewater

The mill produces 150 tons of paper per day employing Kraft process and generates about 220-320 m^3 of wastewater for the paper manufactured. In Kraft process, wood is cut in parts called chips and these are cooked in caustic soda to remove most of the lignin but preserving the remaining cellulose. The wastewater generated from various sections in the mill is collected and treated in aerated lagoons before its discharge to the river. The wastewater from different stages were taken in which the residual BOD, COD was removed using aerobic process and plain (river water) was used as control. The characteristics of wastewater and plain water are presented in Table 1.

Crops

Jowar (*Sorghum vulgare*), wheat (*Triticum aestium*) and moong (*Vigna radiata*) crops were selected and tested for germination study and response to wastewater application. These crops were grown in each lysimeter respectively for three years.

Installation of field Lysimeter

Field lysimeters were prepared at the site (undisturbed soil) by excavating pit of size 5mx2mx2m lined with polyethylene sheet to avoid the seepage of water. Soils of different texture were used in the lysimeter as depicted (Fig 1) and analyzed for various physico-chemical properties (Table 2). Soils were collected from three different locations around the mill and bulk samples were collected separately from different layers. The soil collected from each location was filled into duplicate lysimeters. During filling care was taken to make soil layers in lysimeters resemble those in the field conditions. Bulk density of soil in each layer was adjusted to field values by compaction. Lysimeters I, II and III were filled with sandy loam (Typic Ustropepts), clay (Vertic Ustropepts) and loamy sand (lithic Ustropepts) respectively (Soil Survey Staff, 1975). In all six lysimeters installed channels were provided length wise by placing half cut pipe to collect percolate from lysimeters in central percolate collection chamber. One set of 3 lysimeters was used for wastewater application while other for plain water application, which served as control. Schematic of a field lysimeter is depicted in Fig 2.

Operation of field lysimeter

Crops were irrigated with wastewater and plain water at 5 cm/hectare i.e. 500 litre / lysimeter / irrigation and allowed to grow till maturity. Irrigation frequency was adjusted to crop water demand. Post harvested soil samples were collected in the different cropping seasons and tested for changes in physico-chemical properties. The amount of percolates collected daily were measured and analyzed for chemical characteristics.

Table1. Characteristics of wastewater and plain water used in lysimeter study

Parameters	Wastewater			Plain water		
	Minimum	Maximum	Average	Minimum	Maximum	Average
pH	7.2	8.2	7.7	7.5	8.4	7.9
ECw (mS cm^{-1})	1.6	2.6	2.1	0.2	0.4	0.3
Ca^{++} (mmolc)	7.2	9.9	8.5	0.65	1.56	1.10
Mg^{++} (mmolc)	3.0	4.8	3.9	0.24	0.53	0.38
Na^{+} (mmolc)	7.5	11.0	5.7	0.32	1.97	1.14
K^{+} (mmolc)	0.4	1.0	0.7	0.02	0.35	0.18
HCO_3^{-} (mmolc)	6.4	7.2	6.8	0.26	2.01	1.13
Cl^{-} (mmolc)	13.0	16.0	14.5	0.58	1.74	1.16
SO_4^{--} (mmolc)	1.1	2.9	2.0	0.03	0.65	0.34
SAR	3.6	4.6	4.1	0.56	2.19	1.37
COD (mg L^{-1})	295.0	380.0	485.0	5.4	7.3	6.3
Lignin (mgL^{-1})	40.0	52.0	46.0	-	-	-
Color (Pt-Co units)	560.0	680.0	620.0	-	-	-

SAR: Sodium Adsorption Ratio
COD: Chemical Oxygen Demand

Table2.Physico-chemical characteristics of soils used in field lysimeters

Parameters	Soil Depth,	Lysimeter I	Lysimeter II	Lysimeter III
Texture	0-30	Sandy loam	Clay	loamy Sand
Sand (%)		60.8	21.9	70.8
Silt (%)		23.2	30.0	17.2
Clay (%)		16.0	48.0	12.0
M.W.H.C. (%)		31.0	46.9	25.0
B.D. (g cc^{-1})		1.29	1.41	1.30
pH		6.8	7.3	6.5
ECe (mS cm^{-1})	0.2	0.6	0.2	
CEC (meq 100 g^{-1})	12.8	40.8	9.8	
Texture	30-90	Sandy loam	Clay	Loamy sand
Sand (%)		63.5	28.0	70.8
Silt (%)		20.4	26.8	13.0
Clay (%)		16.0	45.2	16.2
M.W.H.C. (%)		30.0	43.8	23.8
B.D. (g cc^{-1})		1.30	1.46	1.31
pH		6.7	7.2	6.4
ECe (mS cm^{-1})	0.3	0.5	0.2	
CEC (meq 100 g^{-1})	9.8	38.4	11.1	
Texture	90-160	Sandy loam	Clay	Loamy sand
Sand (%)		64.0	34.0	64.6
Silt (%)		21.0	26.0	20.2
Clay (%)		15.0	40.0	15.1
M.W.H.C. (%)		32.1	38.0	28.0
B.D. (g cc^{-1})		1.31	1.48	1.33
pH		6.9	7.4	6.3
ECe (mS cm^{-1})	0.5	0.3	0.2	
CEC (meq 100 g^{-1})	10.8	30.1	12.8	

M.W.H.C. - Maximum water holding capacity (M_{water}/M_{total} x 100), B.D. - Bulk density, ECe - Electrical conductivity of saturation extract, CEC - Cation exchange capacity

METHODS OF ANALYSIS

Soil samples were collected at 0 – 20 cm in depth using a manually operated Auger tool. Each sample was a composite sample of seven sub-samples, which were collected based on surface features (rock or fine material, color and texture). By conning and quartering techniques the sample volume was reduced to one kg. Samples were stored in a polythene bag. After collection, the samples were shade-dried in the laboratory at room temperature (30 – 35^{0}C). Samples were slightly crushed using mortar and pestle and passed through a 2mm sieve. Methods described by Piper (1996), Black (1965) and Jackson (1973) were employed for physico-chemical analysis of soil.

Wastewater and percolate samples were analyzed as per Standard Methods for examination of water and wastewater, 17th ed. (APHA, 2005). The effect of wastewater on germination of crop seeds of jowar, wheat and moong was assessed following standard procedure (IRST, 1966). The COD and color of wastewater was determined by open reflux method and potassium chloroplatinate method (APHA, 2005).

Experimental design

The experiment consists of three types of treatments. The main treatment consists of three types of soils: S1, S2 and S3. The sub treatment consists of two types of irrigation: Plain water (PW), and pulp and paper mill wastewater (WW) and the experiment were conducted in eight replication (number of samples) while design adopted was split plot design. Analysis of variance was carried out as described by Panses and Sukhatme (1967).

RESULTS AND DISCUSSION

Evaluation of wastewater quality for irrigation

In view of management of irrigated crop production “Scientific Approach” which includes design of lysimeter, hydraulic loading of wastewater, selection of crops plays important role in evaluation of suitability of water/ wastewater for crop irrigation. In general, quality of water used for irrigation has been evaluated with respect to salinity, SAR and specific ion toxicity. The pulp and paper mill wastewater categorized as “Moderate Restriction to Severe Restriction” on their use with respect to salinity and specific ion toxicity (ECw, 1.6 - 2.6 mS cm^{-1} and Chloride, 13 - 16 meq L^{-1}) as depicted in Table 1. Considering the combined effect of EC and sodium adsorption ratio (SAR) the impact on infiltration rate the wastewater was observed to belong to category `No Restriction’ (SAR, 3.6 - 4.6) as per Kandiah (1987). The plain water was used under control treatment grouped in $C_1S_1$ and $C_2S_2$ class as per USSL classification (USSL staff 1954) and in `No Restriction’ class as per Ayers and Westcot (1976).

Removal of COD and Color

Percolate quality and quantity from field lysimeter was monitored for 3 years to evaluate COD and color assimilation through soil-wastewater interaction. Results indicated that sandy loam and loamy sand soil in lysimeter I and III gave a percolate of 17 & 20% respectively, while clay soil in lysimeter II was only 15% because of its maximum water holding capacity due to which higher retention of wastewater was possible. Out of 52.5 m^3 wastewater applied, 4.341. 4.462 and 4.178 m^3 of wastewater was retained in soil of lysimeter I, II and III respectively. Quantitative assessment of percolate from soils irrigated with plain water did not show much variation in quantity compared to soil which was received from wastewater irrigated soil. This indicates that hydraulic conductivity of soil remained unaffected due to wastewater application. The proportions of water existing as percolate were calculated to include only the volume of applied irrigation water. Loamy sand and sandy loam soils showed 96 & 97% removal of COD respectively, while clay soil removed 99% of COD because of high CEC and presence of calcium carbonate in clayey soil. Since soil can degrade certain pollutants, land treatment is feasible for removal of color due to lignin, which would reduce the cost of wastewater treatment (Nutter and Red, 1985). The color removal in both control and experiment were about 100%. Similar findings were reported by Malo (1967), Narum et al. (1979) and Thawale *et al.,* (1999).

Changes in Percolate quality

Percolate initially showed leaching of calcium and magnesium and retention of sodium, which gets adsorbed subsequently. The results reported by Juwarkar and Subhramanayam (1987) and Narum et al., (1979) also support the phenomena of retention of sodium and leaching of calcium and magnesium in the soil as a result of soil-wastewater interaction. The magnitude of removal varies from soil to soil. Sandy loam and loamy sand soil reach equilibrium after 50 applications, while clay soil required 80 application to reach the equilibrium state because clayey soil has higher percentage of CEC than sandy loam and loamy sand soil (Fig

3, 4 & 5). Results further indicate that chlorides were not retained in the soils as the chlorides in wastewater and percolate did not show much variation.

Table3.Values of Bulk density and Water Holding Capacity

Lysi-meter	B.D (Mgm^{-1})		W.H.C (%)	
	PW	WW	PW	WW
I	1.29±0.182	1.06±0.072	31±3.1	30.7±1.11
II	1.41±0.175	1.12±0.192	47±5.4	40.2±1.34
III	1.30±0.126	1.04±0.08	25±1.7	24.1±1.29

Table4.Values of Electrical Conductivity, ESP and organic carbon of surface soil samples for eight sets of measurement

Lysi-meter	PH		Conductivity (ms/cm)		ESP		Organic carbon (%)		N (mg $100g^{-1}$)		P (mg $100g^{-1}$)		K (mg $100g^{-1}$)	
	PW	WW	PW	WW	PW	WW	PW	WW	PW	WW	PW	WW	PW	WW
I	6.8±0.63	7.2±0.31	0.291±0.15	1.71± 0.09	5.2±0.010	8.1±0.062	0.622±0.323	0.211±0.034	2.45±0.32	3.80±0.09	1.52±0.06	2.68±0.08	5.01±1.23	22.62±2.45
II	7.3±0.44	8.5±0.34	0.613±0.18	2.34± 0.21	6.2±0.013	11.8±0.51	1.284±0.412	0.601±0.067	3.79±0.95	7.21±1.21	4.01±1.10	6.00±2.34	6.00±2.90	26.30±4.33
III	6.4±0.32	7.0±0.22	0.202±0.06	1.53± 0.07	4.1±0.041	7.6±0.042	0.473±0.121	0.182±0.051	2.38±0.05	3.21±0.04	1.32±0.03	2.02±0.05	4.50±1.39	22.11±3.45

Changes in physico-chemical properties of soil

The texture of soil under study was found to be sandy loam and loamy sand and clay. Clay soil is more suitable for agricultural purposes due to its higher nutrient and water retention capacity (White, 1987). There was slight decrease in maximum water holding capacity (MWHC) and bulk density of soils irrigated with wastewater, which was due to the deposition of lignin present in wastewater (46.0 mg L^{-1}) (Table-3). Such type of variation in soil physical characteristics might be attributed to the addition of organic materials in the soil through the wastewater and interaction between the various constituents as suggested by Baver *et al.* (1972). Among soil constituents having maximum influence on soil physical conditions, the organic carbon takes a prominent position (Low, 1955; Russel, 1971). Organic carbon influences soil compatibility, soil bulk density and porosity (Davies, 1975). Bulk density and water holding capacity are the important physical properties, which regulate the flow dynamics of salt, nutrients and water through soil. The bulk density values are dependent on type of organic matter present in soil and normally it is expected that accumulation of comparatively light organic matter will lead to a decrease in bulk density (White, 1987). Slight decrease in water holding capacity is because the pulp mill irrigated soil accumulates and form a hydrophobic layer coating over the soil (Bossert and Bertha, 1985; Miler and Donahue, 1992).

Changes in chemical characteristics of soil are presented in Table-4 and depicted in Fig 6. Average values are given along with their Standard deviation. The samples irrigated with wastewater for the past three years showed increase in pH, EC, ESP, organic carbon and available nutrient content, which might be due to the alkaline nature of wastewater since it had high soluble salt. Irrigation with the wastewater over period of three years clearly increases the soil accumulation of Na and other soluble salts. Na ions are predominant in the soil, while carbonates are also present in the soil and alkalinity formed as shown in earlier reported by Juwarkar and Subramaniyam (1987) and Thawale et al. (1999). In the present study higher concentration of suspended solids in the wastewater led to increased organic carbon content in soils. Irrigation with wastewater containing organic and inorganic compound increased the N, P and K content of soil. Irrigation with pulp and paper mill wastewater increased soil pH, ESP, EC, organic carbon, N, P and K content over control were also reported by other worker (Kannan and Oblisami, 2004), (Phukan and Bhattacharya, 2003; Chatterjee et al. 2003; Das et al., 2006, and Wang et al., 2006).

Table 5.Effect of pulp and paper mill wastewater on grain and straw yield of crops grown in field lysimeters

Lysimeters and crops	Grain Yield (q ha^{-1})						Straw Yield (q ha^{-1})					
	Ist year		IInd year		IIIrd year		Ist year		IInd year		IIIrd year	
PW	WW	PW	WW	PW	WW	PW	WW	PW	WW	PW	WW	
Jowar												
Lysimeter I	33.20	40.00	29.62	33.52	31.31	39.19	52.10	58.30	48.13	51.19	50.96	58.19
Lysimeter II	37.80	42.21	34.25	37.31	35.42	42.32	56.12	61.12	53.62	57.16	55.82	61.15
Lysimeter III	42.41	50.43	37.73	42.42	41.31	50.72	62.01	66.32	56.25	61.13	60.15	67.32
Soil												
SEm +	0.215		0.410		0.468		0.412		0.562		0.391	
CD 5%	0.813		1.222		1.315		1.241		1.679		1.221	
Wastewater												
SEm +	0.328		0.272		0.391		0.419		0.415		0.432	
CD 5%	0.956		0.745		1.143		1.331		1.213		1.392	
Interaction												
SEm +	0.571		0.450		0.698		0.730		0.712		0.779	
CD 5%	1.700		NS		NS		NS		NS		NS	
Wheat												
Lysimeter I	23.46	24.95	20.61	21.31	25.18	27.18	26.30	27.31	22.52	23.52	27.31	29.75
SEm +	0.241		0.213		0.248		0.250		0.218		0.362	
CD 5% NS	0.639		NS		0.891		NS		NS			
Wastewater												
SEm +	0.198		0.213		0.179		0.191		0.216		0.152	
CD 5% 0.588	0.616		0.531		0.539		0.651		0.451			
Interaction												
SEm +	0.361		0.312		0.317		0.321		0.381		0.266	
CD 5% 1.111	1.132		0.913		0.932		1.099		0.719			
Moong												
Lysimeter I	6.94	8.51	5.31	6.12	7.23	8.93	8.16	9.62	6.28	7.15	8.16	9.22
Lysimeter II	7.85	8.93	5.52	6.47	7.624	8.31	8.31	9.32	6.27	7.32	8.39	9.82
Lysimeter III	8.32	9.84	5.63	8.61	9.12	9.11	9.44	10.01	8.11	9.12	10.12	10.03
Soil												
SEm +	0.132		0.121		0.169		0.121		0.160		0.212	
CD 5%	0.371		0.362		0.513		0.373		0.331		0.637	
Wastewater												
SEm +	0.114		0.131		0.113		0.127		0.112		0.120	
CD 5%	0.314		0.253		0.283		0.399		0.312		0.253	
Interaction												
SEm +	0.182		0.146		0.163		0.234		0.176		0.145	
CD 5%	NS		NS		NS		NS		NS		NS	

Lysimeter II	21.97	27.46	19.46	23.12	23.32	27.32	24.25	29.30	21.31	25.31	25.17	29.72
Lysimeter III	23.32	27.33	20.31	23.71	24.14	27.19	25.13	29.11	22.11	25.69	26.32	29.21

Soil

PW - plain water, WW - wastewater, NS - non significant (1 q = 100 kg)
SEm – Standard Error mean, CD 5% – Critical difference at 5% level

Table6.Effect of pulp and paper mill wastewater on nutritional quality of food grain of crops grown in field lysimeters

Lysimeters and Treatments	Macronutrient, %						Micronutrient, mg Kg^{-1} (grain dry weight)			
	N	P	K	Na	Ca	Mg	Zn	Cu	Fe	Mn
JOWAR										
Lysimeter I (Sandy Loam)										
With Wastewater	1.75	0.31	0.39	0.033	0.17	0.26	25.9	8.4	82.5	19.4
With Plainwater	1.64	0.33	0.34	0.029	0.20	0.31	26.3	10.3	99.8	21.3
Lysimeter II (Clay)										
With Wastewater	1.71	0.33	0.36	0.037	0.17	0.32	25.1	8.0	74.3	23.3
With Plainwater	1.65	0.35	0.36	0.038	0.19	0.35	26.9	8.9	81.5	24.2
Lysimeter III (Loamy Sand)										
With Wastewater	1.70	0.29	0.36	0.034	0.13	0.29	24.1	7.0	83.2	22.6
With Plainwater	1.60	0.33	0.40	0.029	0.12	0.36	26.3	9.0	96.2	24.4
WHEAT										
Lysimeter I (Sandy Loam)										
With Wastewater	2.28	0.35	0.23	0.034	0.12	0.28	37.4	9.1	73.1	49.2
With Plainwater	2.29	0.34	0.29	0.033	0.16	0.30	43.3	11.5	79.5	52.3
Lysimeter II (Clay)										
With Wastewater	2.23	0.33	0.24	0.037	0.22	0.29	39.3	12.7	95.6	51.1
With Plainwater	2.29	0.24	0.23	0.024	0.18	0.31	44.9	16.2	97.2	59.4
Lysimeter III (Loamy Sand)										
With Wastewater	2.37	0.33	0.32	0.036	0.30	0.34	29.1	9.5	92.2	53.1
With Plainwater	2.25	0.25	0.23	0.025	0.17	0.40	35.9	12.7	97.1	53.5
MOONG										
Lysimeter I (Sandy Loam)										
With Wastewater	3.22	0.43	1.40	0.050	0.24	0.20	23.3	12.3	58.1	23.3
With Plainwater	3.37	0.49	1.61	0.051	0.23	0.26	26.2	13.7	60.3	26.7
Lysimeter II (Clay)										
With Wastewater	3.23	0.40	1.61	0.061	0.23	0.20	26.2	11.8	60.3	24.7
With Plainwater	3.03	0.40	1.58	0.063	0.24	0.24	29.2	13.3	62.1	26.2
Lysimeter III (Loamy Sand)										
With Wastewater	3.20	0.35	1.43	0.050	0.23	0.15	21.4	10.1	56.1	22.1
With Plainwater	3.01	0.35	1.43	0.053	0.18	0.20	23.2	13.1	57.8	23.2

Table7. Annual input – output balance of nutrient (Kg. ha^{-1})

Nutrient	N	P	K	Ca	Mg	Na
Jowar						
Lysemeter-I						
Wastewater	464	19	477	2975	819	2194
Leaching	2784	ND	235	5222	2341	3210
Harvest	7000	1240	1560	680	1040	132
Balance	-9320	-1221	-1318	-2927	-2562	-1148
Lysemeter-II						
Wastewater	464	19	477	2975	819	2194
Leaching	2431	ND	200	4880	2230	729

Harvest	217	1392	1519	717	1350	156
Balance	-2184	-1373	-1242	-2622	-2761	-1309
Lysemeter-III						
Wastewater	464	19	477	2975	819	2194
Leaching	2819	ND	311	5548	2449	3593
Harvest	8573	1462	1815	655	1462	171
Balance	-10928	-1443	-1649	-3228	-3092	-1570
Wheat						
Lysemeter-I						
Wastewater	464	19	477	2975	819	2194
Leaching	2213	ND	230	5580	2456	3466
Harvest	5348	821	539	281	656	79
Balance	-7097	-802	-292	-2886	-2293	-1351
Lysemeter-II						
Wastewater	464	19	477	2975	819	2194
Leaching	2001	ND	185	4440	2140	3215
Harvest	4999	725	527	483	637	81
Balance	-6536	-706	-235	-1948	-1958	-1102
Lysemeter-III						
Wastewater	464	19	477	2975	819	2194
Leaching	2315	ND	250	6110	2511	3613
Harvest	5526	769	746	699	792	83
Balance	-7377	-750	-519	-3834	-2484	-1502
Moong						
			Lysemeter-I			
Wastewater	464	19	477	2975	819	2194
Leaching	2211	ND	275	3320	2531	3682
Harvest	2234	298	971	166	138	34
Balance	-3981	-279	-769	-511	-1850	-1522
			Lysemeter-II			
Wastewater	464	19	477	2975	819	2194
Leaching	2115	ND	198	3001	2483	3533
Harvest	2535	314	1263	180	157	47
Balance	-4186	-295	-984	-206	-1821	-1386
			Lysemeter-III			
Wastewater	464	19	477	2975	819	2194
Leaching	2320	ND	320	3440	2589	3921
Harvest	2662	291	1189	191	124	41
Balance	-4518	-272	-1032	-656	-1894	-1768

Effect of wastewater on germination, yield of crops and nutritional quality of foodgrain

Seed germination

The germination test of jowar, wheat and moong seeds irrigated with wastewater and plain water did not show significant differences. Germination percentage of jowar seeds was 72% and 71% respectively when irrigated with wastewater and plain water, while wheat showed 94% and 95% and moong showed 70% and 72% germination. These results are comparable with the data reported by Spulnik (1940), Sundermoorthy and Kunjithapatham (2000), Tanghavi and Vora (1994), Somashekar et al., (1984) and Srivastava (1991).

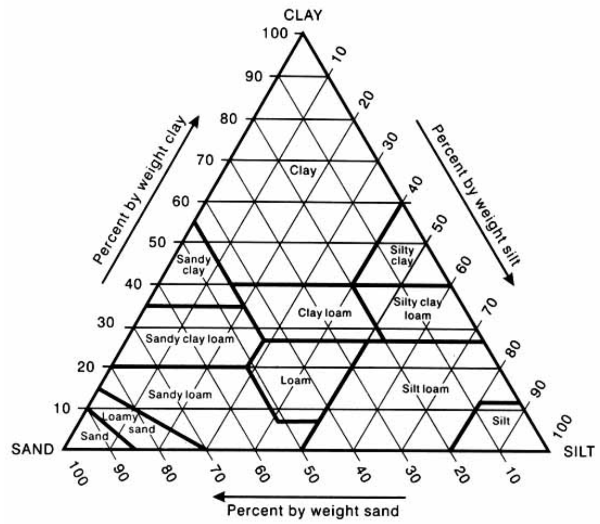

Figure1. Textural triangular diagram

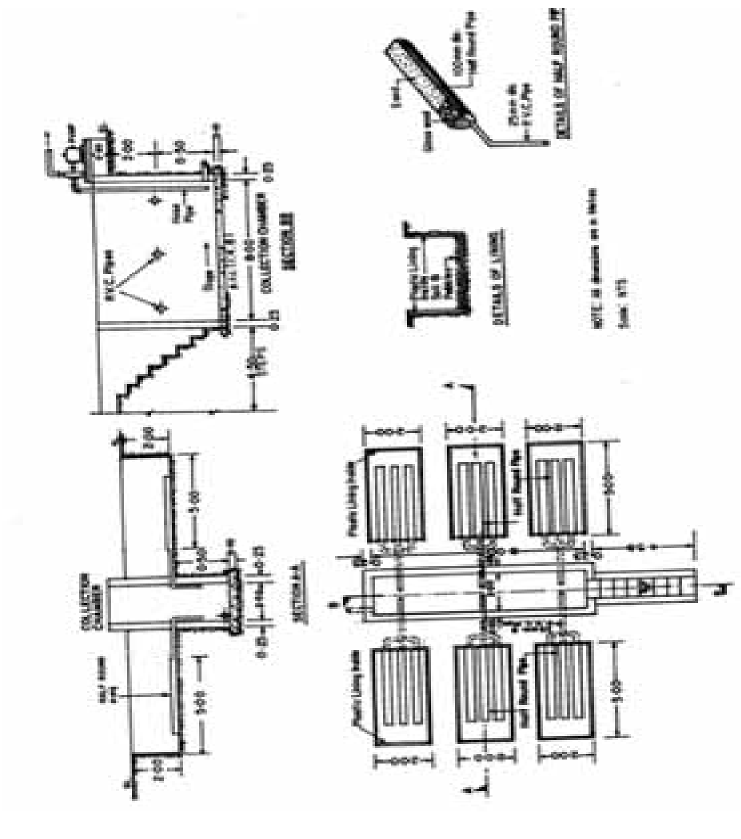

Figure2. Design of the field lysimeter

Grain and straw yield

The wastewater application resulted in an increase of crop yield (Table 5). The wastewater is rich in organic matter and nutrients, hence Jowar crop showed significant increase in grain yield grown in different types of soils irrigated with wastewater and plain water for three years respectively. Eight samples from the same lysimeter i.e. eight replications were used to generate mean and SEM values. A significant difference was observed for the first year of soil-wastewater interaction. Jowar showed 17.5% increase in grain yield with wastewater in Lysimeter I having sandy loam soil over control followed by Lysimeter III (loamy sand) and Lysimeter II (clay) with increase of 16.3 and 12.8% respectively. Straw yield of jowar also showed a significant difference for consecutive 3 years, irrigated with wastewater and plain water in three different types of soils. However, there was no significant impact of soil and wastewater interactions on jowar straw yield. Jowar straw showed maximum increase of 11.2% in sandy loam (Lysimeter I) and increase of 8.8% and 8.3% was recorded for clay (Lysimeter II) and loamy sand soil (Lysimeter III) respectively over control.

Wheat crop grown in sandy loam soil (Lysimeter I) showed maximum increase in grain yield of 18.3% with wastewater over control and followed by clay (Lysimeter II) and loamy sand soils (Lysimeter III) which showed increase of 15.1% and 6% respectively over control. For the first two years, no significant impact of soil type on the grain yield was observed. However, wastewater and its interaction with soil types showed significant difference in the grain yield in the third year. In the case of straw yield, except for third year soil-wastewater interaction had not much impact on the straw yield. Wheat showed an increase of 16.5% in straw in case of sandy loam soil (Lysimeter I), 12.2% for clay soil (Lysimeter II) and 5.3% increase with respect to loamy sand soil (Lysimeter III) respectively over control.

The difference in the grain and straw yield of moong was observed for three years grown in different types of soils and irrigated with plain water and wastewater. Except for third year grain yield, no significant effect of soil and wastewater irrigation was observed on grain and straw yield. The moong crop grown in sandy loam soils (Lysimeter I) showed increase of 20.9% while 20.6% and 12.4% was recorded in clay (Lysimeter II) and loamy sand (Lysimeter III) soils respectively over control. Increase of 14.0% in straw yield was observed as a result of wastewater application in sandy loam soil, while 12.8% and 10.0% increase was recorded for clay and loamy sand soils. Similar results were reported by Barnah and Das (1998) and Chatterjee et al. (2003), NEERI (1994) and Thawale et al., (1999). The presence of root promoting phenolic compounds in the wastewater might have played a vital role in influencing the beneficial effect on plant growth as suggested by Bose et al. (1971).

Nutritional quality of food grain

Food grain of crop from wastewater irrigated and control lysimeters were collected and analyzed for macronutrient (N, P, K Ca, Mg & Na) and micronutrient (Cu, Zn, Fe & Mn) to ascertain the changes in nutrient quality (Table 6).

The micronutrients in control grains were slightly higher as compared to wastewater application. A marginal decrease in micronutrient in food grains which received wastewater may be due to addition of organic matter, which forms insoluble chelates. The lignin incorporated in soil through wastewater forms insoluble complexes with these micronutrients and reduced their bioavailability. However, at no stage of crop growth nutrient deficiency was observed. This substantiates the fact that a slight variation in mineral nutrition will not affect normal physiological functioning of crops. Further there were no accumulations of toxic heavy metals like Cd, Ni, Pb, Cr etc. in food grains as it was found below detectable level. Pulp and paper mill wastewater used for crop irrigation do not affect the nutritional quality of grains (McCormic, 1959). Similar results were reported by Juwarkar *el al.,* (1987) on nutritional quality of pulses, cereals, vegetables and cash crops, which received paper mill wastewater for 16 years.

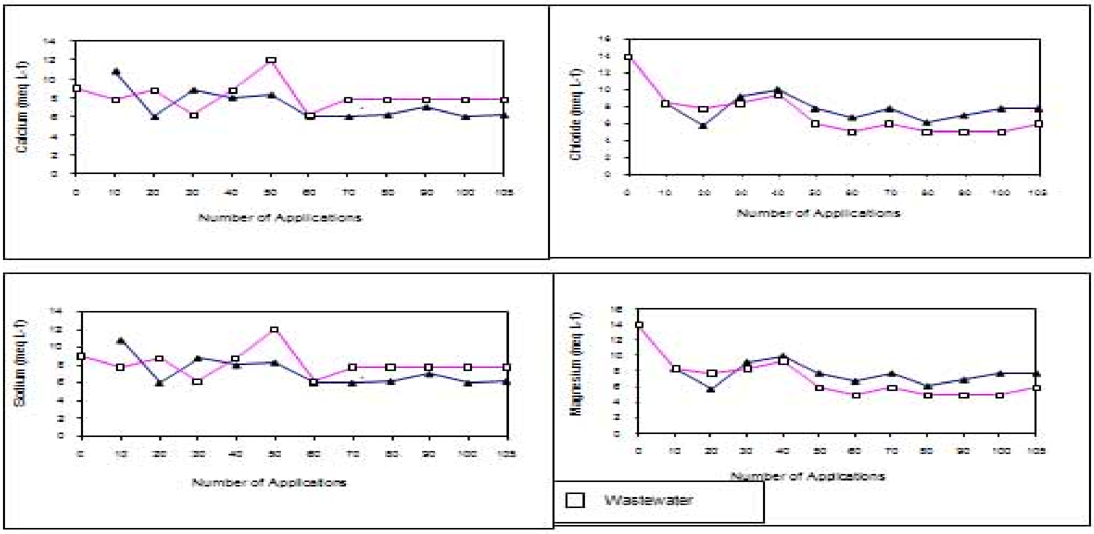

Figure3. Concentration of cations and anion in wastewater applied and percolate collected from field lysimeter I

Input-Output Balance of major nutrient

Input nutrients by wastewater and output by harvest and leaching losses were calculated for crops and results are presented in Table 7. In general the result showed that, leaching losses for loamy land soils in lysimeter III was higher than, sandy-loam soil in lysimeter-I. Clay soil is lysimeter-II showed least leaching loss. It seems that differences in leaching losses depended more on soil texture than on crop grown. Leaching losses were highest for N, Ca and Mg than other nutrients. Harvest except for all the nutrients was higher for jowar followed by wheat and moong. The results of soil nutrient analysis at the harvest showed increase in the nutrient content of soil irrigated by wastewater. This signifies that although there was a negative nutrient balance for all crop grown in the lysimeter the application of wastewater is a sustainable and economic process.

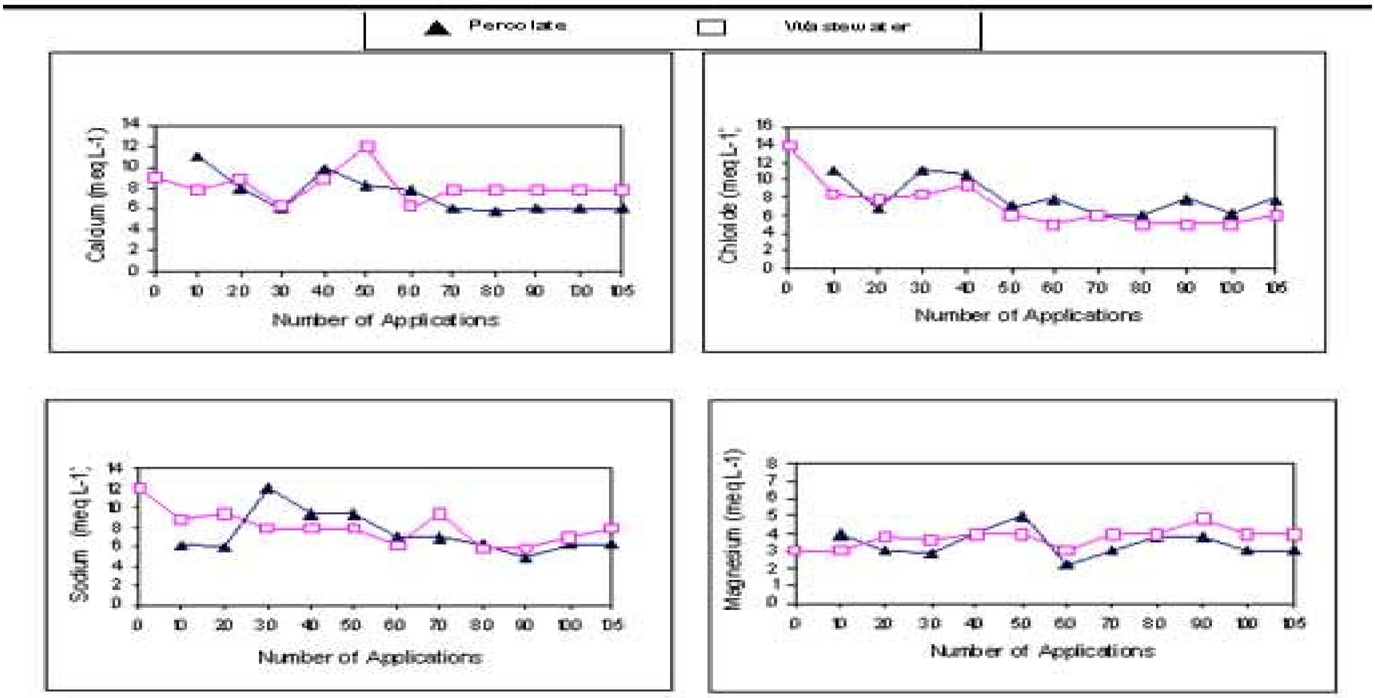

Figure4. Concentration of cations and anion in wastewater applied and percolate collected from field lysimeter II

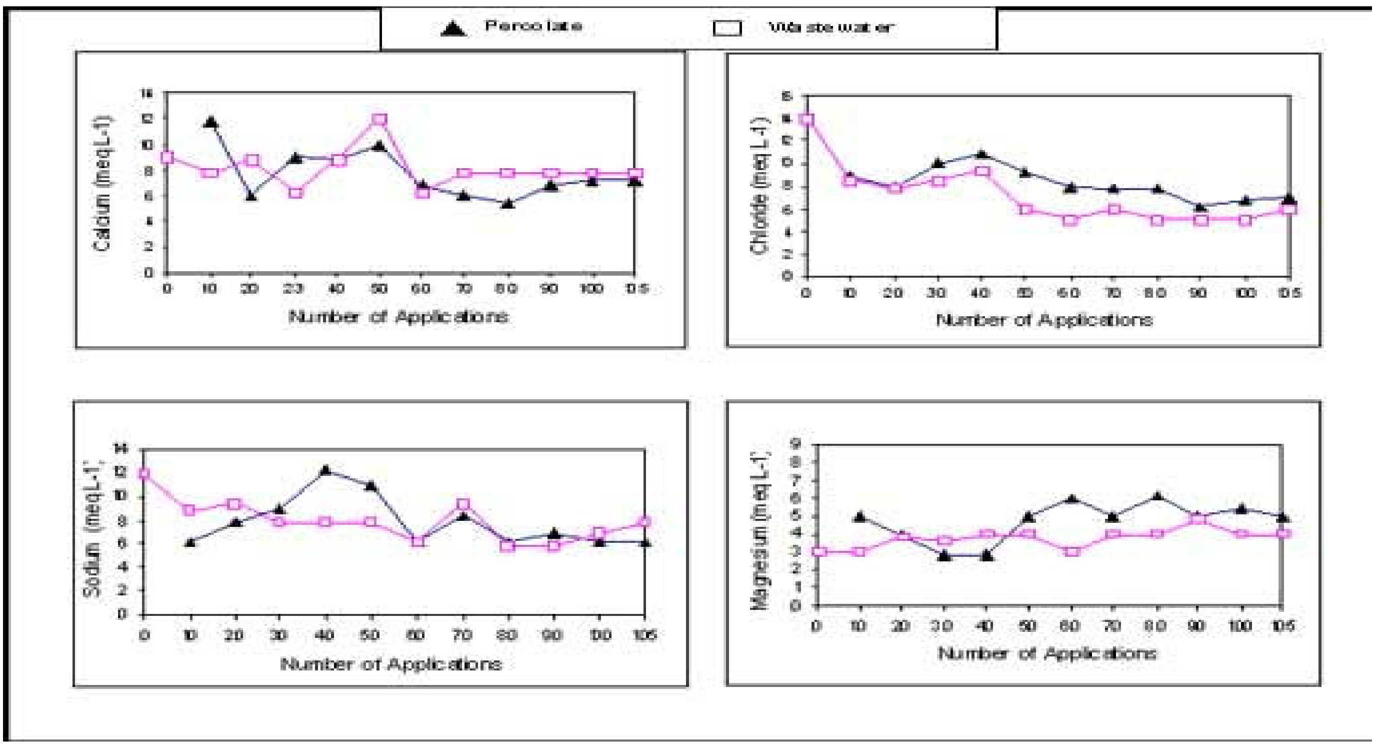

Figure5. Concentration of cations and anion in wastewater applied and percolate collected from field lysimeter III

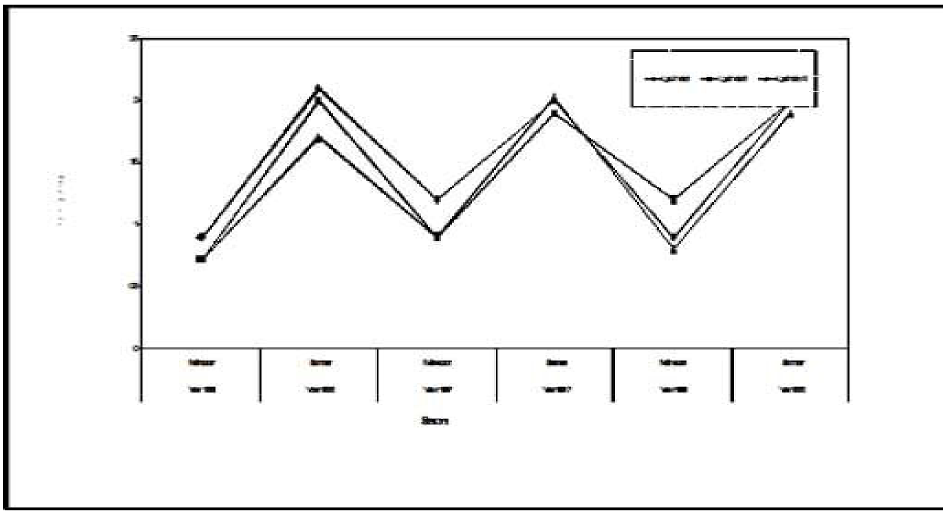

Fig 6. Changes in electrical conductivity of saturation extract of soils in field lysimeters

CONCLUSIONS

The prospect of utilizing paper mill wastewater in irrigation to certain crops was explored in this study. The results obtained indicate that irrigation using wastewater to soil improved yield of crops. Wastewater irrigated soils showed increase in pH, EC, ESP, Organic carbon and available nutrient content of soils. But decrease in water holding capacity and bulk density was observed during harvest. Accumulation of sodium and gradual increase in pH will have adverse effects on soil quality but it can be overcome by providing efficient drainage and adopting soil management practices. Monsoon rains also leached the accumulated salt beyond rhizosphere there by reducing soil EC. Soils used in the study had capacity to reduce the color and COD of wastewater. Wastewater irrigation did not affect the germination and nutritional quality of food grains of crop rather the yield of crop was improved during three years. Both nutrient balance and changes in soil nutrient content showed use of wastewater for irrigating agricultural crop becomes a cost effective alternative compared to disposal into surface water. Thus by ensuring soil and crop qualities in continuum, the study suggest that paper mill wastewater can be utilized for irrigation under decreasing availability of fresh water. This solves the problem of wastewater disposal to some extent and conserves fresh water for other use as well.

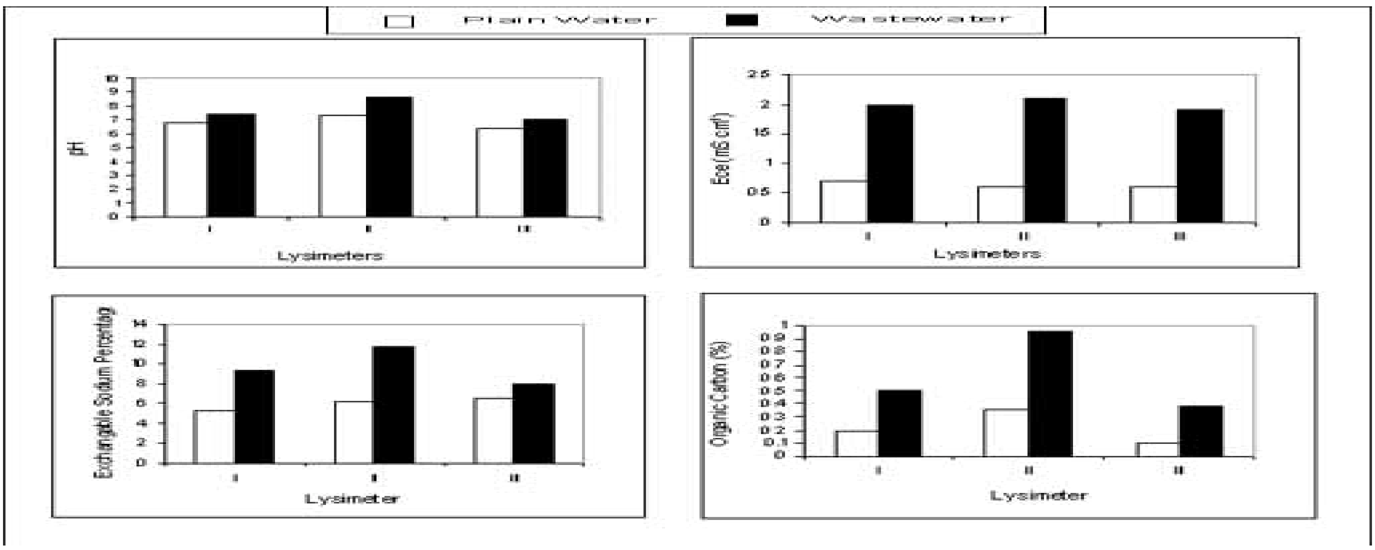

Fig 7. Chemical characteristics of soils irrigated with plain water and wastewater

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