Final Report

UTILISATION OF TREATED EFFLUENT FROM AGRO-BASED PAPER MILLS FOR CROP IRRIGATION

Submitted to:

DEVELOPMENT COUNCIL FOR INDIAN PULP, PAPER AND ALLIED INDUSTRIES
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FOREWORD

The compulsion to meet the ever increasing food, fuel, fodder and fibre requirements of the burgeoning human and animal population has overburdened the shrinking per capita availability of land and water. This has also led to an adverse impact on the environment. Water is the single most vital input in agriculture and has made a very significant contribution in ensuring self sufficiency and stability in food production. However, mismanagement of this crucial and finite resource has resulted in shortage of good quality water and unabated pollution of water resources.

Although the irrigation sector will always be a major share holder of the water resources in India, the share allocated to irrigation is likely to decrease by 10 to 15 per cent by the year 2025 A.D. The demand of the domestic, power and industrial sectors is likely to double by that year. Since agricultural production has to keep pace with the increasing demands, it will have to depend more and more on the waste waters of the other sectors.

The Indian Agro Paper Mills Association (IAPMA) along with the Indian Agricultural Research Institute, initiated a project at three locations in the country to explore the possibility of using the agro paper mills effluent for agricultural purposes without any detrimental effect on the environment. This publication is the outcome of the dedicated efforts put in by the scientists of the Water Technology Centre and Division of Environmental Sciences, IARI, New Delhi with technical and financial support by IAPMA. The results obtained in this study will contribute in developing guidelines for judicious utilization of paper mills effluent for crop irrigation. However, for wider applicability and significant strategic technological development, the study need to be continued for a duration of 2-3 years.

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Dated : 31.12.2001

ACKNOWLEDGEMENTS

The availability of water, to cater the needs of agriculture, urban and rural population, accelerated growth in industries and other sectors is becoming more and more scarce with passage of time both in quantity and quality. This necessitates to explore the possibility of using waste waters from industries to mitigate the irrigation water requirement of crops and to evaluate the associated changes taking place, if any in the soil & crop health and environmental quality. In view of this, the Indian Agro Paper Mills Association (IAPMA), New Delhi with the support of Development Council initiated a collaborative study on "Utilization of treated effluent from agro based paper mills for crop irrigation" at three locations, namely Shamli (U.P.), Rajahmundry (A.P.), and Aurangabad (M.S.) under different agro climatic regions for different types of crops.

I want to express my sincere gratitude to the Development Council for Pulp, Paper and Allied Industries, Ministry of Industry, Government of India for providing the financial help from the Cess Fund for this study. The Indian Agriculture Research Institute (IARI), New Delhi with their highly qualified and experienced scientists, sophisticated laboratories and other facilities has put in their expertise in carrying out the methodological and scientific study to arrive at definite pattern of trend in growth and yield of the crops with effluent irrigation. I wish to extend my sincere thanks to the IARI and the team of principal scientists associated with the project.

I also want to record my sincere thanks to the Management and Staff of M/s. Sikka Papers Limited, Shamli (Muzaffarnagar) U.P., M/s. Coastal Papers Limited, Rajahmundry (East Godavari District), A.P. and M/s. Nath Pulp and Paper Mills Limited, Aurangabad, Maharashtra for their willing cooperation and providing the necessary facilities for the study at the respective centres.

I also acknowledge the help and suggestions provided during the study by the Directors and Staff of Central Tobacco Research Institute, Rajahmundry and Water and Land Management Institute, Aurangabad. I express my heartfelt thanks to the team of the Indian Agro Paper Mills Association for their untiring efforts made during planning, supervision, execution and monitoring of the project study and preparation of the reports.

I wish to record my thanks to all those who have helped directly or indirectly in successful completion of the study.

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EXECUTIVE SUMMARY

Paper industry is one of the high water consuming and effluent generating industries. Effluents generated from the mills have to be treated to bring down toxic effects to stipulated limits before disposing off into natural water bodies. Alternatively these may be treated partially and used for irrigating field and plantation crops which beside mitigating water scarcity to some extent will economize the cost of effluent treatment. Keeping this in view the present project "Utilization of Treated Effluent from Agro based Paper Mills for Crop Protection" was undertaken with the objectives : (i) to analyse and evaluate the characteristics of effluent from agro based paper mills for its utilization for crop irrigation; (ii) to observe changes in characteristics of the soil in respect of particle size distribution, chemical composition, porosity and fertility before and after application of effluent for irrigation to different crops; (iii) to identify the characteristics of growth and yield of different crops with paper mills effluent irrigation; (iv) to evaluate change, if any, in heavy metal concentration in the grain and biomass; (v) to work out the hydraulic loading of the effluent on the land for optimum results and (vi) to identify other favourable or unfavourable factors for crop growth, soil health and sub-soil water.

The project was sanctioned by the Development Council for Pulp, Paper and Allied Industries under Cess Fund Scheme for Research and Development, Ministry of Industry, Government of India vide their letter No. 8 (3)/95-Paper dated 2nd April, 1998. The studies in field were started from *Kharif* (rainy) season, 1998 under a tripartite agreement

between Indian Agro Paper Mills Association (IAPMA), New Delhi, Indian Agricultural Research Institute (IARI), New Delhi and Paper Mills at three locations in different agro-climatic regions, namely, M/s Sikka Papers Limited, Shamli (U.P.); M/s Coastal Papers Limited, Rajahmundry (A.P.) and M/s Nath Pulp and Paper Mills Limited, Aurangabad (M.S.)

Soil samples collected from the selected fields were analysed for their physico-chemical characteristics. In some cases *in situ* determinations were also made. Samples of effluents from agro based paper mills were also collected and analysed for assessing their irrigation suitability. Crops were grown in fields with recommended agronomic practices for three years (1998-2001). Irrigation treatments comprised of (a) Effluent (100%), (b) mixed water (50% effluent + 50% fresh water) and (c) fresh water (100%). To characterize and to quantify the effects of irrigation treatments, various growth and yield attributes of plants were recorded, besides grain and total biomass yields. Samples of the soil and also plants and grains were collected after the harvest of crops to assess the effect of mill effluent irrigation on the soil and quality of the produce. Ground water quality was also monitored. Hydraulic loading was worked out for optimizing the use of effluent for crop irrigation.

M/s Sikka Papers Limited, Shamli, U.P.

- Effluent of M/s Sikka Papers Limited was of medium salinity (2.2 dSm^{-1}) and sodicity (SAR=12.4, HCO_3^{-1} = 10.8 me l^{-1}) level. Rice-wheat and maize-mustard cropping sequences were followed for three consecutive years of 1998-99, 1999-2000 and 2000-2001. Maximum yield was obtained with mixed effluent (50% Tube Well water + 50% effluent) in case of all the crops, namely rice, maize,

wheat and mustard. Crop yields with fresh water and effluent were practically similar. Initial better growth of rice and wheat plants with effluent irrigation resulted in partial lodging of crops at later stages. No significant difference was noted in the quality of sugarcane juice due to effluent irrigation.

- Fertility status of the soil irrigated with paper mills effluent was improved. Amounts of organic carbon, available phosphorus and available potash were higher in effluent irrigated plots as compared to only tubewell water irrigated one. Physical properties and water transmissibility of soil were also improved with effluent irrigation.
- No change in ground water quality was observed due to effluent irrigation.
- Heavy metal contents in grain and straw of rice and maize plants receiving effluent irrigation were very low or negligible.
- Hydraulic loading for wheat and rice crops has been worked out for optimum utilization. TSS loading was maximum in plots irrigated with effluent only.

M/s Coastal Papers Limited, Rajahmundry (A.P.)

- Average grain yield of *kharif* rice was more with fresh water irrigation and comparatively lower grain yield was harvested from effluent irrigated plots. However, there was no difference in biomass yields. Growth of effluent irrigated plants was initially better than fresh water but due to lodging grain yield decreased.
- In the *rabi* season when practically there was no lodging during

grain setting and ripening stages of rice crop both grain and biomass yields with effluent irrigation were more as compared to fresh water or mixed effluent. Mixed effluent also was better in yield than fresh water treatment.

- In case of sugarcane ratoon (December 1999-January 2001) effluent irrigation resulted in better plant growth and higher millable cane yield (Av. 81.0 tonnes/ha) followed by mixed effluent and fresh canal water.
- Quality of sugarcane juice in terms of purity, polirization, brix and CCS per cent was best under effluent irrigation. This was followed by mixed effluent and fresh water.
- Organic carbon, available phosphorus and available potash contents in the soil were increased with effluent irrigation after the harvesting of the rice and sugarcane crops.

M/s Nath Pulp and Paper Mills Limited, Aurangabad

- Average grain and biomass yields of wheat and mustard were best when crop was irrigated with mixed effluent. This was followed by fresh water and effluent alone. Grain and biomass yields of maize, sorghum and seed cotton with fresh water, mixed effluent and effluent (100%) during *kharif* 2000-01 were practically similar.
- Soil samples collected and analysed after the harvest of wheat and mustard in *rabi* 2000-01 reflected that irrigation treatments had not resulted in any significant change in chemical characteristics of the irrigated soil.

- Effluent irrigation in area near the mills had beneficial effects on establishment and growth of eucalyptus whereas teak and other tree crops could not survive. *Acacia nilotica* had also good establishment and growth.

The results emanating from studies conducted evinced that treated paper mills effluent is usually of low to moderate salinity with medium level of sodium (SAR) and very low concentration of heavy metals. Mills' effluent had no conspicuous adverse effect on grain and biomass yields of rice, wheat, maize mustard, sorghum and cotton. Improvement to some extent in yield and quality of sugarcane was noticed. Mixed effluent (50% fresh water + 50% effluent) invariably had favourable effects on crop growth and yield. Heavy metals in plants and grains of rice and maize were very low. Physico-chemical characteristics and fertility of the soil improved with effluent irrigation. No adverse effect in ground water quality was observed.

To assess and quantify the effects of accumulation of sodium, organic matter and nutrients in the soil on growth and yield of crops and soil characteristics, a study of longer duration is required. Appropriate usage technology for treated effluent needs to be developed and standardized for irrigating field and plantation crops.

1.0 INTRODUCTION

Land and water resources are becoming limiting factors in meeting the food, fodder, fibre, oil, paper, firewood, timber and other demands of the ever increasing population in India which presently has crossed the level of 100 crores and is expected to be 140 crores by 2025 AD and 170 crores by 2050 AD. Besides quantitative availability, degradation in land productivity and deterioration in water quality have assumed alarming situation. Industrial pollutants are considered as one of the major sources of environmental deterioration. Paper industry is one of the high water consuming and effluent generating industries in the country. Effluent generated from pulp and paper mills have to be treated to reduce the pollutants load to stipulated limits before disposing it off into water bodies. Alternatively it may be treated partially and used for irrigating field and plantation crops which will mitigate the water scarcity in the semi-arid and arid parts of the country to some extent and will economise the cost of effluent treatment.

Some earlier reported results by workers within the country and outside indicate that treated effluents could be used succesfully for raising crops. Organic matter enriched paper mills effluent is likely to improve the physico-chemical properties of the soil and thereby crop production provided the primary treatment is given to reduce the toxicities. Keeping these in view the present project " Utilisation of Treated Effluent from Agro based Paper Mills for Crop Irrigation" was initiated.

2.0 OBJECTIVES

The objectives of the project under study are enumerated below :

(i) To analyse and evaluate the characteristics of the effluent from agro based paper mills for its utilisation for crop irrigation.

(ii) To observe changes in characteristics of the soil in respect of particle size distribution, chemical composition, porosity and fertility before and after applicastion of effluent for irrigation to different crops.

(iii) To identify the characteristics of growth and yield for different varieties of crops with paper mills effluent irrigation.

(iv) To evaluate change, if any, in heavy metal concentration in the biomass and grain.

(v) To work out the hydraulic loading of the effluent on the land for optimum results.

(vi) To identify any other favourable or unfavourable factor for crop growth, soil health and subsoil water.

3.0 ASSOCIATED AGENCIES

The project was taken up for the field study by Indian Agro Paper Mills Association (IAPMA) after its approval/sanction by the Development Council for Pulp, Paper and Allied Industries under Cess fund scheme for Research and Development, Ministry of Industry, Government of India vide their letter No. 8(3)/95-paper dated 2nd April, 1998. The joint

studies in field were started from *Kharif* (rainy) season, 1998 under a tripartite agreement between Indian Agro Paper Mills Association, Indian Agricultural Research Institute, a leading Institution in the field of agricultural research and training in the country and Paper Mills at three locations (Fig. 1) in different agro-climatic regions, namely:

(a) Shamli (Uttar Pradesh)

(b) Aurangabad (Maharashtra)

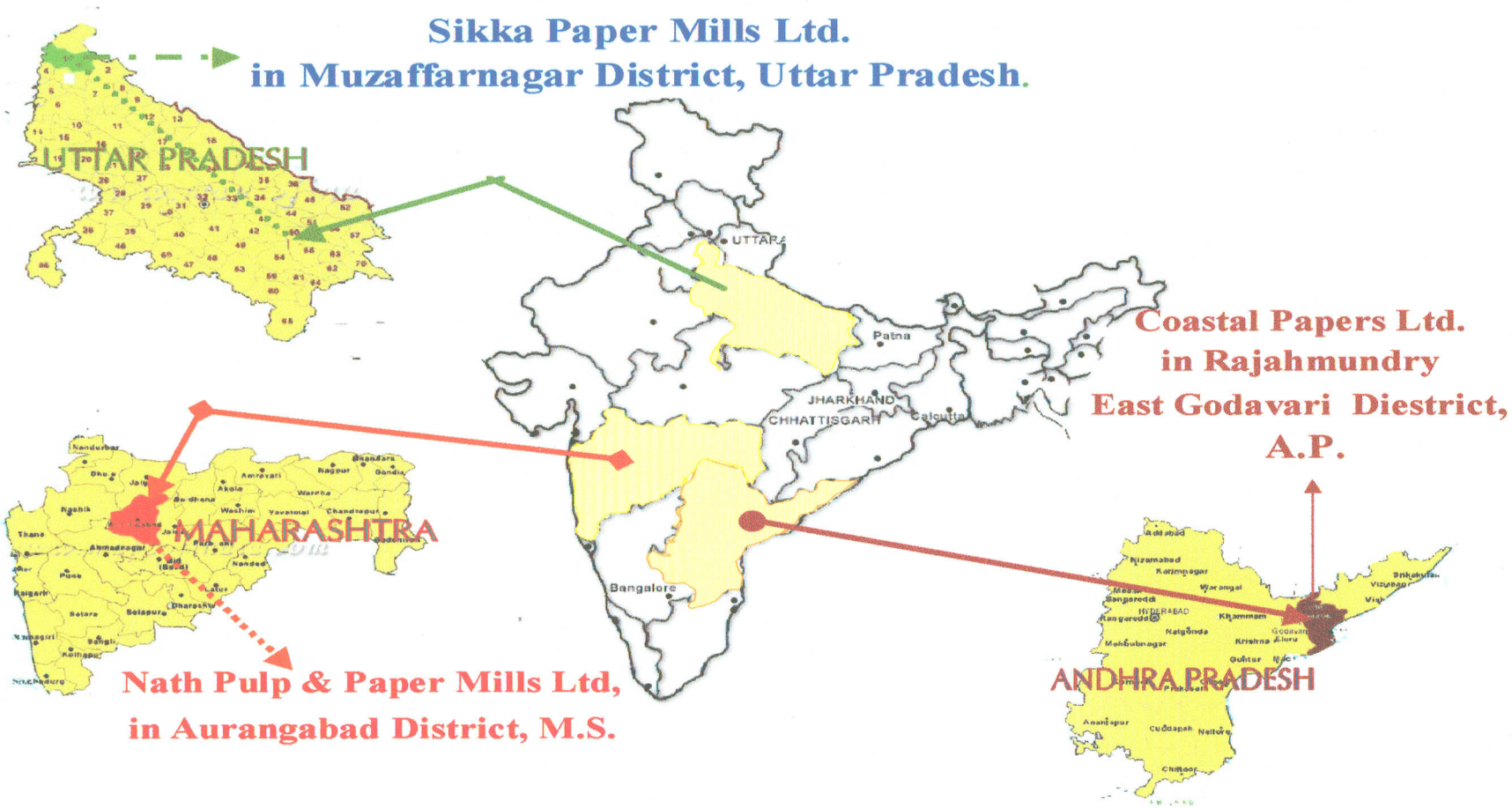
(c) Rajahmundry (Andhra Pradesh)

4.0 AGRO-CLIMATIC REGIONS OF THE STUDY CENTRES

M/s Sikka Papers Limited, Shamli is located in the North-Western part of Upper Gangetic Plains of India in Muzaffarnagar district of Uttar Pradesh (U.P.). The average rainfall of this zone is 970 mm and the climate is dry sub-humid to semi-arid. The soils are good ranging from loam to silt loam. The important raw materials for paper making are rice and wheat straw. Waste paper is also in use.

M/s Coastal Papers Limited, Rajahmundry is situated in agro-climatic zone XI, East Coast Plains and Hill region under sub-group 3-South Coastal Andhra Pradesh (A.P.) Average rain fall of this zone is 940 mm and climate varies from semi-arid to sub-humid. The soils are coastal alluvial and fertile. However, at some places upland soils are red lateritic in nature and relatively less fertile. The machines No. I and II are using mostly rice straw to make kraft paper. The newly established machine No. III is using waste paper to manufacture newsprint and writing papers.

LOCATION MAP OF PAPER MILLS WHERE THE CROP IRRIGATION STUDIES HAVE BEEN CONDUCTED



- Muzaffarnagar District, Uttar Pradesh
- Aurangabad District, Maharashtra
- East Godavari District, Andhra Pradesh

M/s. Nath Pulp and Paper Mills Ltd., Aurangabad falls in the IXth Agro-climatic region, namely Western Plateau and Hill region and the sub group 3-Central Plateau. Average rain-fall of the region is 874 mm and climate is dry semi-arid. Soils are medium to deep black, clay loam to clayey. However, in some parts they are shallow red and light. Soil pH is neutral to alkaline. Soils are impregnated with gravels and *kankar* nodules. The mill uses bagasse as agro raw material and also the waste paper. It manufactures mostly the *kraft* papers.

5.0 METHODOLOGY

A team consisting of Scientists from Indian Agricultural Research Institute, New Delhi and IAPMA visited Shamli (Uttar Pradesh), Rajahmundry (Andhra Pradesh) and Aurangabad (Maharashtra) in three agro-climatic regions for selection of sites for field oriented research studies. Soil samples were collected from the selected field areas from 0-30 and 30-60 cm depths from the surface before planting the experimental crops. Samples were analysed for determining the particle size distribution and other physico-chemical characteristics of the soil. In some cases *in situ* determinations have also been made. Samples of effluents generated from agro based paper mills were collected and analysed for assessing their chemical characteristics and irrigation suitability.

Crops selected for the area were raised in fields with their recommended agronomic package of practices. Irrigation treatments

comprised of (a) Effluent (100%), (b) Mixed water (50% effluent + 50% fresh water), and (c) Fresh water (100%).

To characterize and to quantify the effects of irrigation treatments on crops, various growth and yield attributes of plants have been recorded besides grain (produce) and total biomass (grain + straw) yields of experimental crops. Soil and grain samples were collected after the harvest of the crop for laboratory analysis purpose. Hydraulic loading of the effluent on land was also worked out. Ground water quality was determined periodically at M/s Sikka Papers Limited, Shamli.

6.0 EXPERIMENTAL RESULTS

The results obtained from field studies and analysis made in the laboratory are presented in this section.

6.1 M/s Sikka Papers Limited, Shamli (Muzaffarnagar), U.P.

Experimental site was selected well within the premises of the M/s Sikka Papers Limited located on main Delhi - Saharanpur road at a distance of about 110 km from Delhi and 10 km from Shamli towards Saharnpur city. Experimental field extended on a land area of about 7-8 acres. Out of this, the area of rice and maize experimental plots in *kharif* season was 1.5 acre each and in *rabi* (winter) season same was used for wheat and mustard, respectively. Remaining area of about 4-5 acres was under sugarcane cultivation.

Weather parameters in respect of mean monthly temperature, Relative-humidity and rainfall for the period of 1998-2000 are given in Table 1.

Table 1. Mean monthly temperature, Relative humidity and rainfall of Muzaffarnagar (U.P.) near to Shamli during 1998-2000

Month	Temperature (°C)			Relative humidity (%)			Rainfall (cm)		
	1998	1999	2000	1998	1999	2000	1998	1999	2000
January	12.23	12.79	12.60	85.94	88.73	86.48	0.51	6.19	3.89
February	15.92	16.53	14.32	81.74	82.92	81.66	1.71	1.13	6.34
March	18.24	21.57	21.13	77.57	74.16	75.92	5.19	-	0.25
April	26.19	28.21	29.08	68.95	65.27	70.19	1.32	-	0.25
May	31.07	32.47	31.66	70.28	69.84	73.36	0.50	2.84	3.74
June	31.31	34.43	31.84	78.77	73.95	79.65	7.49	9.31	14.00
July	24.88	22.18	30.87	84.38	81.59	82.53	34.70	14.25	19.78
August	28.56	29.83	29.98	87.69	81.69	82.66	24.59	3.90	11.90
September	25.57	28.93	28.07	83.08	86.13	84.18	10.84	9.15	2.97
October	24.27	24.95	33.19	81.84	81.59	83.86	11.92	2.28	-
November	18.40	19.08	19.72	82.80	81.12	84.63	-	-	-
December	14.21	15.00	14.58	88.76	87.50	85.66	-	0.40	0.40

6.1.1 Soil properties before experimentation

6.1.1.1 Soil Texture : Surface (0-30 cm) and sub-surface (30-60 cm) soil samples were collected from the experimental area and analysed for particle size distribution and other physico-chemical characteristics. Based on the sand, silt and clay percentage, the texture of soil was loam to silt loam (Table 2). Surface texture of rice plot was little coarse (loam) than that of the maize plot. The average sand, silt and clay percentage in the soil was 36, 47 and 17, respectively.

Table 2. **Particle size distribution of soil samples at M/s. Sikka Papers Ltd., Shamli (Muzaffarnagar), U.P.**

Location	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Maize field,	0-30	32.64	50.44	16.92	Silt loam
(Mill site)	30-60	40.64	44.44	14.92	Loam
Rice field	0-30	39.64	47.44	12.92	Loam
(Mill Site)	30-60	29.64	47.44	22.92	Silt loam

6.1.1.2 Physico-chemical characteristics of the soil : Chemical characteristics of experimental soil near M/s. Sikka Papers Limited are presented in Table 3. In general, soil was non-saline and non-calcareous in nature both in rice and maize plots. However, pH value of the maize plot was slightly higher (8.1) particularly in surface layer (0-30 cm) due to presence of kankar nodules as compared to rice plot. Subsurface pH was near to neutral.

Table 3. **Chemical characteristics of soil samples at M/s. Sikka Papers Limited, Shamli, Muzaffarnagar (1:2 soil - water extract)**

Location	Depth (cm)	pH	EC (dS/m)	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}	HCO_3^- (me/l)	Cl^-
Rice field	0-30	7.7	1.7	7.0	10.2	0.2	6.0	5.4
(mill site)	30-60	7.4	0.7	4.0	4.1	0.1	3.0	5.4
Maize field	0-30	8.1	0.7	3.5	3.2	0.3	6.0	3.6
(Mill site)	30-60	7.5	0.3	2.8	2.5	0.4	3.0	5.4

Salt content in terms of electrical conductivity (EC) of 1:2 soil-water extract of rice field was 1.7 dSm^{-1}. Therefore, soil may be classified as non-saline. Contents of soluble $Ca^{2+}+Mg^{2+}$ and Na^{+} in rice field were more than that in maize field. On the other hand soluble K^{+} showed reverse trend. However, contents of HCO_3^- were equal in both the cases.

6.1.2 Effluent Characteristics

Chemical constituents of fresh (tubewell) water and effluent flowing from M/s. Sikka Papers Limited are shown in Table 4. It is clear from data that the salinity in terms of electrical conductivity of the effluent was 2.2 dSm^{-1}. Tubewell water had the salinity of 1.2 dSm^{-1}. The pH of effluent was 7.5 and that of tubewell water 7.2. $Ca^{2+}+Mg^{2+}$ was 7.5 mel^{-1} in effluent of M/s Sikka Papers Limited as compared to 6 mel^{-1} of tubewell water. Effluent of M/s Sikka Papers Limited had the values of SAR moderately safe from crop production point of view. Detailed analysis of effluent generated from the mill with respect to BOD, COD and heavy metals is given in Table 5 and Table 6. It is evident that effluent has only negligible concentration of toxic heavy metals such as cadmium and nickel.

Table 4. Chemical analysis of effluent of M/s Sikka Papers Limited and others at Shamli U.P.

S. No.	Sample	EC (dS/m)	pH	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}	HCO_3^-	Cl^-
				(me/l)				
1.	Tubewell	1.2	7.2	6.0	9.5	0.4	12.8	5.6
2.	Sikka Papers Limited	2.2	7.5	7.5	23.5	5.4	10.8	12.4

Table 5. Characteristics of effluent from M/s. Sikka Papers Limited, Shamli (U.P.)

S. No.	Characteristics	Amount
1.	EC dS/m	2.16
2.	pH	7.92
3.	TSS mg/l	97
4.	BOD mg/l	68
5.	COD mg/l	258

Table 6. Chemical constituents in the effluent from M/s. Sikka Papers Limited, Shamli (U.P.)

S. No.	Characteristics	Amount (mg/l)
1.	*TKN	50
2.	Sodium	546
3.	Calcium	240
4.	Magnesium	400
5.	Potassium	74
6.	Nickel	0.070
8.	Lead	0.023
9.	Zinc	0.14
10.	Copper	0.049
11.	Manganese	0.45
12.	Iron	1.02

* Total Kjeldahl Nitrogen

6.1.3 Field Experiments during first year (1998-99)

Kharif (1998)

Field experiments with treated effluent from M/s Sikka Papers Limited were started during *Kharif* season of 1998 with rice and maize crops. As mentioned in earlier section, the main treatments were :

(a) Tubewell water, 100%

(b) Treated effluent 50% + 50% Tubewell water

(c) Treated effluent, 100%

Two separate experiments in field were laid out. Recommended agronomic practices suitable for the region were adopted for both the crops. Tubewell water was used up to crop establishment in all the treatments in both the crops.

The varieties of the crops grown were :

a) Rice - Pusa 834

b) Maize - Pro-Agro 3974

After first irrigation, effluent was used as per treatments up to the harvest of the crops. During crop growth, observations related to plant growth and yield attributes were recorded in both the crops. After crop harvest grain yield and total dry matter yield of rice and maize were also recorded and are presented in Table 7 and Table 8, respectively.

6.1.3.1 Rice Crop

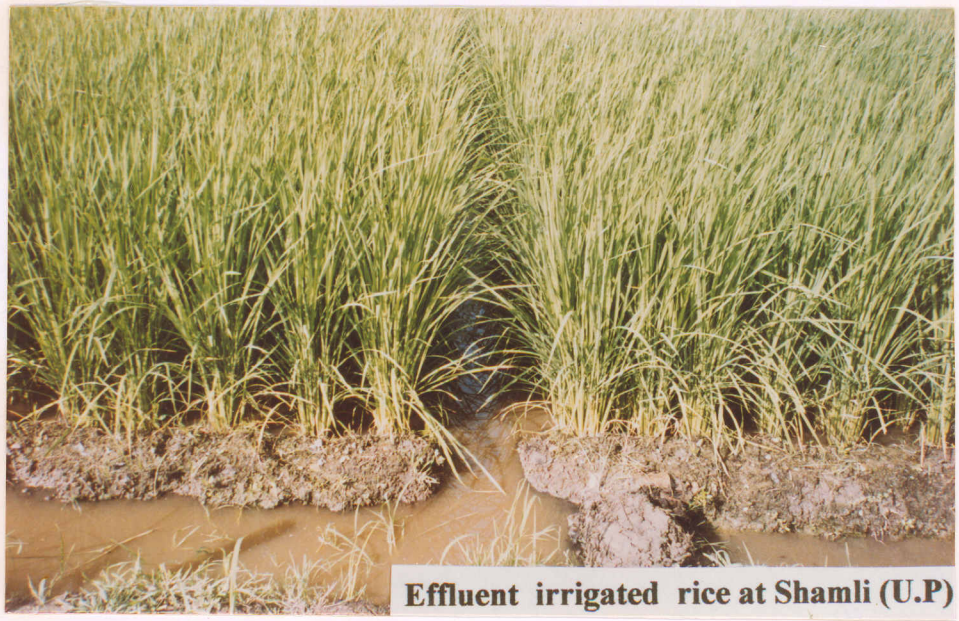
It is clear from the data given in Table 7 that irrigation with paper mills effluent induced better growth of rice as compared to that with

Table 7. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of rice (1998)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant Height (cm)	111.9	118.4	122.1
2.	No. of tillers/hill	19.5	16.5	22.5
3.	No. of hills/m row length	9.0	8.7	6.8
4.	No. of panicles per hill	17.8	15.3	19.5
5.	Length of panicles (cm)	26.3	26.6	27.5
6.	No. of spikelets/ear	11.3	11.9	12.1
7.	No. of grains/ear	172.0	206.0	205.0
8.	Test weight (g)	22.4	21.5	20.1
9.	Grain yield (q/ha)	43.7	46.7	36.5
10.	Biomass yield (q/ha)	104.5	107.5	101.5
11.	Harvest index (%)	41.8	43.4	36.0

mixed (tubewell + effluent) water (1:1) and tubewell irrigation. It is reflected in the form of plant height, number of tillers per hill, number of panicles per hill, length of panicle, number of spikelets per panicle and number of grains per panicle. However, similar trend was not observed in grain yield and dry matter yield of rice crop. Higher grain yield (46.7 qha^{-1}) and biomass yield (107.5 qha^{-1}) of rice were obtained with mixed irrigation (tubewell + effluent) as compared to that with tubewell water (43.7 and 104.5 qha^{-1}) and mill effluent irrigation (36.5 and 101.5 qha^{-1}), respectively. Reduction in grain and dry matter yield in effluent irrigated plots was actually due to lodging by intense rains and storm during the month of September, 1998. This adversely affected the boldness of grains (test weight) which was ultimately reflected in reduced yield. Therefore, based on yield data effectiveness of different treatments was rated as :

Mixed water > tube well water > effluent



Effluent irrigated rice at Shamli (U.P)

6.1.3.2 *Maize crop*

Growth of maize crop var. Pro-Agro 3974 in terms of different growth characters and yield is given in Table 8. It is reflected from the data that trend in variation of different yield attributes was similar to that of rice crop. Height of plant, number of leaves per plant, number of cobs per plant, weight of cob and test weight were higher with mixed irrigation as compared to effluent and tubewell irrigation. Similarly, highest grain yield of 36.8 qha^{-1} was recorded with effluent + tubewell irrigation as compared to tubewell irrigation (31.5 qha^{-1}) and effluent irrigation (30.5 qha^{-1}). Biomass yield and harvest index also followed similar trends. Therefore, effectiveness of different treatments was in the order of

Mixed water > tubewell water > effluent

Based on these results of one crop season, it is inferred that effluent in lesser quantity (50%) was helpful for crop growth and yield. However, results are to be confirmed in subsequent crop seasons.

Table 8. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of maize (1998)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	198.8	201.8	176.0
2.	No. of leaves	11.5	11.8	10.5
3.	No. of cobs/plant	1.1	1.0	1.0
4.	Length of cob (cm)	18.0	18.5	16.5
5.	Weight of cob (g)	205.0	212.5	185.0
6.	No. of grains/cob	545.5	580.9	500.0
7.	Test weight (g)/100 grains	23.8	26.5	21.6
8.	Grain yield (q/ha)	31.5	36.8	30.5
9.	Biomass yield (q/ha)	71.8	81.0	69.0
10.	Harvest index (%)	43.9	45.4	44.2

6.1.4 *Field Experiments During Rabi (1998-99)*

6.1.4.1 *Mustard Crop*

Field experiments were continued with mustard and wheat crops during *rabi* 1998-99 and effect of the treatments on yield and yield attributes of mustard is shown in Table 9. It is evident from the data that the height of plant and number of primary branches per plant in case of mustard crop were not affected adversely with paper mill effluent since the values were nearly equal under all the three treatments. Similarly, dry weight per plant and total seed yield (qha^{-1}) were also not adversely affected. Effluent irrigation as a matter of fact slightly improved the seed and stalk yield of mustard. In seed yield increment was 0.3 qha^{-1} while in biomass yield it was 0.8 qha^{-1} with effluent irrigation as compared to that under tubewell irrigation. Mixed irrigation (50% tubewell + 50% effluent) was more effective particularly in case of biomass yield.

Table 9. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of mustard (1998-99)

Treatment	Plant height (cm)	No. of Branches/ Plant	Dry wt./ plant (g)	Grain yield (q/ha)	Biomass yield (q/ha)
Tubewell water	46.5	11.0	11.6	10.2	54.9
Mixed (T.W. + Effluent)	46.8	11.0	11.8	11.5	58.0
Effluent	46.6	11.0	11.5	10.5	55.7

6.1.4.2 *Wheat crop*

Effect of these treatments on grain yield and yield attributes of wheat is shown in Table 10. Similar to that of mustard, plant height, number of tillers and dry weight per plant in wheat were not affected

Effluent irrigated mustard at Shamli (U.P)

adversely with effluent irrigation. However, grain and straw yields were decreased slightly with effluent irrigation as compared to tubewell irrigation. Highest values of grain and biomass yields were noted under mixed (tubewell water + effluent) irrigation system.

Table 10. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of wheat (1998-99)

Treatment	Plant height (cm)	No. of tillers/ 50 cm row length	Dry wt./ plant (g)	Grain yield (q/ha)	Biomass yield (q/ha)
Tubewell water	46.5	96.0	33.5	22.9	79.3
Mixed (T.W. + Effluent)	45.4	108.0	36.6	23.8	93.2
Effluent	45.8	98.0	33.5	21.5	75.8

Note : Crop sowing was delayed

6.1.5 Field Experiments During Second Year (1999-2000)

Kharif 1999

During second year (*Kharif* 1999) the crops of rice and maize were grown in the same experimental plots as in previous year by adopting the standard recommended agronomic practices.

6.1.5.1 Rice crop

Effect of treatments on yield and yield attributes of rice (var. Pusa Basmati No. 1) is shown in Table 11. It can be seen from data that irrigation with paper mill effluent in rice crop has improved the yield attributing parameters namely plant height, number of tillers, number of panicles per plant, number of spikelets and number of grains per panicle as compared to irrigation with tube well water. However, improvement was more with mixed effluent in comparison to either tube well water or

effluent. Number of tillers per hill was 25, 32 and 28 in tubewell, mixed and effluent irrigated plots, respectively. Similarly, number of grains per ear was 196, 217 and 208 in plants irrigated with tubewell, mixed and effluent waters, respectively. Grain yield of rice under the respective treatments was 49.0, 54.0 and 47.4 qha^{-1}. Total biomass yield also exhibited a similar trend.

Table 11. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of rice (1999)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	125.6	126.1	128.4
2.	No. of tillers/hill	25.1	31.6	28.4
3.	Dry weight/plant	44.7	57.7	67.7
4.	No. of panicles/hill	22.8	29.1	26.2
5.	Length of panicle (cm)	29.5	31.4	31.1
6.	No. of spikelets/ear	12.6	13.5	13.2
7.	No. of grains/ear	196.0	216.6	207.8
8.	Test weight (g)	21.0	22.1	21.8
9.	Grain yield (q/ha)	49.0	54.0	47.4
10.	Biomass yield (q/ha)	129.8	131.2	129.6
11.	Harvest index	37.8	41.2	36.6

It is clear from these results that effluent irrigation did not induce any significant harmful effect either on yield attributes or on the grain yield of rice crop. Mixed irrigation (50% effluent + 50% tubewell water) was more beneficial from plant growth and grain yield point of view. Effluent irrigation was as good as tubewell irrigation.

6.1.5.2 *Maize crop*

Crop yield and plant growth characters in case of maize hybrid Ganga Safed 2 crop as influenced by different treatments are shown in Table 12. It is evident from data that in general, effluent irrigated plants exhibited lower values of growth parameters as compared to those irrigated with tubewell and mixed water. Plant height , cob length, weight of cob, number of grains in each cob were of higher magnitude in plants irrigated with tubewell water or fresh water compared to effluent irrigation. However, from test weight, grain yield and dry matter yield point of view mixed irrigation again proved beneficial as compared to fresh water and effluent irrigation.

Table 12. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of maize (1999)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	277.6	267.0	265.0
2.	No. of leaves/plant	15.8	15.2	16.0
3.	No. of cobs/plant	1.1	1.2	1.2
4.	Length of cob (cm)	27.6	26.5	25.9
5.	Weight of cob (g)	168.2	166.6	153.0
6.	No. of grains/cob	458.0	461.0	437.0
7.	Test weight (g)/100 grains	25.0	26.2	24.6
8.	Grain yield (q/ha)	30.2	33.8	29.7
9.	Biomass yield (q/ha)	86.9	93.0	85.6
10.	Harvest index (%)	34.8	36.3	34.7

6.1.6 Field Experiments During *Rabi* (1999-2000)

Experiments with same treatments were continued during *rabi* season of 1999-2000 as in previous year. Wheat (HD 2285) and mustard (Pusa Bold) were grown in rice and maize plots respectively with the recommended agronomic practices. Data related to growth and yield of both the crops are presented here.

6.1.6.1 Wheat crop

It is clear from data in Table 13 that the growth characteristics of wheat plants irrigated with paper mills effluent were not affected adversely to a significant level. Experimental values recorded for different growth characteristics like plant height, number of tillers, length of ear, number of grains per ear, test weight of grains were quite comparable with those of plants irrigated either with fresh water or mixed effluent (fresh water + effluent). Grain yield of wheat was 43.3, 44.4 and 42.1 qha^{-1} under fresh water, mixed and effluent irrigations, respectively. Biomass yield and

Table 13. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of wheat (1999-2000)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	92.8	96.0	92.4
2.	No. of tillers/plant	4.0	5.0	5.0
3.	Length of ear (cm)	9.6	9.6	9.8
4.	No. of grains/ear	38.0	42.0	41.0
5.	Test weight (g)	49.0	46.0	37.5
6.	Grain yield (q/ha)	43.3	44.4	42.1
7.	Biomass yield (q/ha)	108.3	113.4	107.1
8.	Harvest Index (%)	40.0	40.2	39.3

harvest index also followed the similar trend under all the three treatments indicating no adverse effect of paper mills effluent on wheat growth and yield.

4.1.6.2 Mustard crop

It is evident from the data given in Table 14 that the effluent irrigation in mustard did not cause any adverse effect on any of the plant growth characteristics and yield parameters like plant height, number of primary and secondary branches, number of pods per plant, number of grains per pod and test weight of seeds. Grain yield of mustard in case of fresh water, mixed (1:1 fresh water and effluent) and effluent irrigated plots was 10.6, 11.6 and 10.5 q ha^{-1}, respectively.

Table 14. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of mustard (1999-2000)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	170.6	175.4	170.3
2.	No. of primary branches	9.0	9.0	9.0
3.	No. of secondary branches	23.0	27.0	23.0
4.	No. of pods/plant	457.0	482.0	463.0
5.	No. of grains/pod	14.0	14.0	14.0
6.	Test Weight (g)	5.5	5.6	5.6
7.	Grain yield (q/ha)	10.6	11.6	10.5
8.	Biomass yield (q/ha)	56.8	69.1	56.0
9.	Harvest index	18.7	16.8	18.7

6.1.7 Field Experiments During Third Year (2000-2001)

Kharif 2000

During third year the crop of rice (var Pusa Basmati-1) and maize (var. Kanchan) were grown in the same experimental plots with similar agronomic practices.

6.1.7.1 Rice Crop

Yield and yield attributing characteristics of Pusa Basmati-1 as influenced by effluent irrigation are presented in Table 15. It is clear that the results with paper mill effluent were encouraging with respect to all growth characteristics of the rice. Plants were of maximum height (110.5 cm) with mixed effluent. Further mixing of effluent (50% + 50%) also induced better grain bearing ears (higher weight, length and no. of grains) as compared to tube well (fresh water) irrigation. However, grain and

Table 15. Effect of effluent of M/s Sikka Papers Limited on yield and yield attributes of rice (2000)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	103.8	110.5	106.2
2.	No. of tillers	19.2	19.8	20.6
3.	Length of ear (cm)	28.4	30.0	29.7
4.	Weight of ear/hill (g)	58.0	59.2	58.5
5.	No. of grain/ear	145.0	158.0	150.0
6.	Test weight (g)	25.8	26.5	26.3
7.	Grain yield (q/ha)	42.2	44.6	42.5
8.	*Biomass yield (q/ha)	108.6	112.5	110.2
9.	Harvest index	38.9	39.6	38.6

*Air dry weight

biomass yields of the rice crop were highest (44.6 qha^{-1} and 112.5 qha^{-1}, respectively) with mixed effluent irrigation followed by effluent irrigation (42.5 qha^{-1} and 110.2 qha^{-1}) and tubewell irrigation (42.2 qha^{-1} and 108.6 qha^{-1}). Based on these results it may be stated that mixed effluent irrigation had increased rice yield as compared to that with tubewell irrigation or effluent irrigation during 2000.

6.1.7.2 Maize crop

Yield and yield attributing characteristics are presented in Table 16. It is obvious that effluent irrigation had induced better growth of maize plants in terms of height, no. of cobs/plant, girth of cob, weight of cob, no. of grains/cob and test weight of grains. Average weight of each cob and no. of grain/cob in effluent irrigated plants was 190 g and 442.3 grains as compared to 193.0g and 444.3 grains in tubewell irrigated plants.

Table 16. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of maize (2000)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	205.0	211.0	204.0
2.	No. of cobs/plant	1.8	1.9	1.7
3.	Girth of cob (cm)	19.0	19.8	19.6
4.	Weight of cob (g)	193.0	198.2	190.0
5.	No. of grains/cob	444.3	461.0	442.3
6.	Test weight (g)/100 grain	25.3	26.0	25.2
7.	Grain yield (q/ha)	31.2	32.6	30.8
8.	*Biomass yield (q/ha)	92.8	94.2	92.8
9.	Harvest index	33.6	34.6	33.2

* Air dry weight

Mixed irrigation had induced characteristics upto highest level. Test weight of grains was maximum (26 g /100 grains) in mixed effluent irrigated plots and due to this grain and biomass yields were maximum (32.6 qha^{-1} and 94.2 qha^{-1}) with mixed irrigated followed by tubewell irrigation (31.2 qha^{-1} and 92.8 qha^{-1}) and effluent (30.8 qha^{-1} and 92.8 qha^{-1}) irrigation.

4.1.8 Field Experiment during *Rabi* 2000-2001

Wheat (var HD 2285) and mustard (var. Pusa Bold) were grown during *rabi* season (2000-2001) with same treatments and agronomic practices as in previous year in the rice and maize fields, respectively.

4.1.8.1 Wheat crop

Yield and yield attributes of wheat as influenced by effluent treatments are presented in Table 17. Growth attributes of wheat have been improved with mixed effluent irrigation (1:1). Plant dry weight was

Table 17. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of wheat (2000-2001)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	103.0	104.0	104.5
2.	No. of tillers/m	58.0	59.0	59.0
3.	Dry weight of plants (g)/m	281.0	340.0	285.0
4.	Length of ear (cm)	9.7	10.0	10.0
5.	No. of grain/ear	50.0	57.0	52.0
6.	Test weight (g)/1000 grains	48.0	50.0	48.1
7.	Grain yield (q/ha)	46.7	48.3	47.2
8.	Biomass yield (q/ha)	106.8	109.6	108.7
9.	Harvest index	43.7	44.1	43.4

maximum (340 g) in mixed effluent irrigated plots as compared to tubewell irrigated plots. Irrigation with mixed effluent (1:1) was very effective in enhancing the number of grains/ear and the test weight of the grains. Effluent irrigated plots gave 47.2 qha^{-1} grain yield as compared to 48.3 and 46.7 qha^{-1}) in mixed and tubewell irrigated plots, respectively. Simiarly, biomass yield was maximum (109.6 qha^{-1}) with mixed effluent irrigation as compared to 106.8 qha^{-1} with tubewell irrigation.

6.1.8.2 Mustard crop

Effect of different treatments on growth characteristics of mustard crop is given in Table 18. It is clear from the table that effluent irrigation did not affect significantly the growth of mustard crop adversely and all growth parameters such as height, number of primary branches, number of pods/plant, number of grains/pod were on par with those under tubewell irrigation. However, mixing of effluent (1:1) induced better growth characteristics of the plants as compared to tubewell and effluent irrigation. Grain yield of mustard was 12.1, 12.5 and 12.0 qha^{-1} with tubewell, mixed and effluent irrigation, respectively.

Table 18. Effect of effluent from M/s Sikka Papers Limited on yield and yield attributes of mustard (2000-2001)

S. No.	Characteristics	Tubewell Irrigation	Tubewell + Effluent	Effluent Irrigation
1.	Plant height (cm)	155.0	160.0	150.0
2.	No. of primary branches	10.0	11.0	10.0
3.	No. of pods/plant	435.0	450.0	440.0
4.	No. of grains/pod	12.0	14.0	10.0
5.	Test weight (g)	4.5	4.5	4.2
6.	Grain yield (q/ha)	12.1	12.5	12.0
7.	Biomass yield (q/ha)	56.8	58.0	55.0

Based on the results of three years experimentation it is inferred that diluted paper mill effluent (1:1) had more favourable effects on growth and yield of the crops. This may possibly be due to better nutritional and lesser salt stress conditions in mixed effluent irrigated plots as compared to tubewell and effluent irrigated plots. Moreover, growth and development of BGA (blue green algae) was more prominent in mixed and effluent treated plots which might have contributed partially towards the nitrogen requirement to the rice crop.

6.1.9 Effect on Soil Properties

The most common apprehension about industrial effluents is that these damage the soil productivity and its properties to the appreciable extent. To examine this aspect physical and chemical analysis of the soil samples collected from the field after harvest of the crop was carried out.

Soil samples were collected with the help of the core cutter sampler from each treatment and bulk density as well as hydraulic conductivity of the samples were determined as per prescribed standard laboratory methods. Soil samples were also collected depthwise (0-30 cm and 30-60 cm) from each plot for determining the chemical characteristics of the irrigated soil.

Effect of paper mill effluent on physical and chemical properties of irrigated soil after harvest of rice crop in 1998 is shown in Table 19 and 20, respectively. It is evident from the data in Table 19 that bulk density of the soil (0-30 cm) of surface plough layer decreased from 1.51 g cm^{-3} with 100% fresh water (tube well) to 1.47 g cm^{-3} with 100% paper mill effluent irrigation. Similarly bulk density of subsurface layer (30-60 cm) was also decreased from 1.52 g cm^{-3} under tubewell irrigation to 1.49 g

Table 19. Effect of effluent from M/s Sikka Papers Limited on soil properties after rice harvest (1998)

A. Physical properties

Treatments	Depth (cm)	Bulk density (g/cm^3)	Hydraulic conductivity (cm/hr)
Tubewell water (T.W.)	0-30	1.51	0.45
	30-60	1.52	0.46
Mixed Water (T.W. + Effluent, 50:50)	0-30	1.48	0.59
	30-60	1.49	0.48
Paper Mill Effluent	0-30	1.47	0.58
	30-60	1.49	0.49

cm^{-3} on using mill effluent. Irrigation with mixed effluent (50% effluent + 50% fresh water) affected the changes in bulk density of intermediate magnitude. Water transmission properties of irrigated soil in terms of hydraulic conductivity were also influenced favourably by the use of paper mill effluent. Hydraulic conductivity of surface soil (0-30 cm) with fresh water, mixed effluent and 100% effluent was 0.45, 0.59 and 0.58 cm hr^{-1}, respectively. This reflects that organic carbon rich paper mill effluent might have improved the physical characteristics of the soil.

Chemical characteristics of the soil extract (1:2) were also influenced by paper mill effluent as is evident from data in Table 20. Total salt content of irrigated soil measured in terms of EC dSm^{-1} increased on use of effluent for irrigation of the rice crop.

Average value of electrical conductivity (EC) of soil extract (1:2) of surface soil (0-30 cm) increased from 0.38 dSm^{-1} with fresh water (control) to 1.0 dSm^{-1} when 100% effluent was used. The value of EC of the soil

Table 20. Effect of effluent from M/s Sikka Papers Limited on soil properties after rice harvest (1998)

B. Chemical properties

Treatment	Depth (cm)	EC (dSm^{-1})	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}
			me/l		
Control	0-30	0.38	5.00	1.3	0.18
(Tube well, 100%)	30-60	0.23	3.00	2.0	0.28
Mixed	0-30	0.81	9.50	4.3	0.55
(Tubewell + Effluent (50:50)	30-60	0.31	2.50	4.1	0.25
Effluent	0-30	1.00	14.00	4.8	0.58
(Paper mill, 100%)	30-60	0.56	7.50	2.5	0.22

with mixed effluent (1:1) was 0.81 dSm^{-1}. Similarly, salt content of sub-surface soil (30-60 cm) was also increased by irrigating with paper mill effluent. Cationic constituents like calcium, magnesium, sodium and potassium were increased in soil extract when paper mill effluent was used for irrigation. Concentration of Ca+Mg, sodium and potassium in extract of fresh water irrigated soil (0-30 cm) was 5.0, 1.3 and 0.18 mel^{-1} which increased to 14.0, 4.8 and 0.58 mel^{-1} when effluent was used for growing the rice crop. Sub-soil layer (30-60 cm) also accumulated higher amount of these cations on irrigation with mill effluent.

Chemical characteristics of the soil extract after the harvest of wheat crop have been given in Table 21. It is clear from the data that total salt content in terms of electrical conductivity was increased to 2.5 dSm^{-1} with 100% mill effluent irrigation from that of 0.41 dSm^{-1} under fresh water (tubewell) irrigation in surface (0-30 cm) layer of the soil. Diluted effluent (50:50%) increased the salinity upto 1.8 dSm^{-1} in this layer.

Table 21. Effect of effluent from M/s Sikka Papers Limited on soil properties after wheat harvest (1998-99)

Chemical properties (Extract 1:2)

Treatment	Depth (cm)	EC (dSm^{-1})	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}
			me/l		
Tubewell water	0-30	0.41	5.0	1.5	0.12
	30-60	0.20	3.0	1.2	0.10
Mixed effluent (T.W. + Effluent, 50:50)	0-30	1.8	12.5	5.5	0.18
	30-60	0.8	6.5	3.5	0.15
Paper Mill Effluent	0-30	2.5	16.5	8.5	0.35
	30-60	1.3	8.5	4.0	0.15

Cationic constituents in soil extract were also increased when 100% paper mill effluent was used to irrigate the crop. Concentration of Ca+Mg, Na and K in tubewell irrigated soil (0-30 cm) extract was 5.0, 1.5 and 0.12 mel^{-1} and it increased to the tune of 16.5, 8.5 and 0.35 mel^{-1}, respectively when only paper mill effluent (100%) was used for wheat irrigation. Similarly, concentration of these constituents was also nearly doubled in subsurface (30-60 cm) layer in effluent irrigated plots as compared to that irrigated with normal (tubewell) water.

Effect of effluent from M/s Sikka Papers Limited on physico-chemical characteristics of irrigated soil after rice crop during 2000-2001 was studied under all three treatments. Physical properties are shown in Table 22 and chemical properties in Table 23.

From Table 22 it is clearly indicated that irrigation with paper mill effluent has improved the physical condition of the soil. Bulk density of the surface layer (0-15 cm) decreased from 1.40 gcm^{-3} in fresh water irrigated plots to 1.12 gcm^{-3} in effluent irrigated plots. In mixed treatment

Table 22. Effect of effluent from M/s Sikka Papers Limited on physical properties of irrigated soil after rice crop (2000)

Treatment	Depth (cm)	Bulk density (gcm^{-3})	Hydraulic conductivity ($cm\ hr^{-1}$)
Tubewell Water	00-15	1.40	0.90
	15-30	1.63	0.25
Tubewell + Effluent water	00-15	1.21	1.22
	15-30	1.60	0.43
Effluent	00-15	1.12	1.74
	15-30	1.64	0.38

bulk density also showed decreasing trend. However, in sub-surface layer (15-30 cm) reduction was not very significant though it again exhibited decreasing trend with effluent irrigation. Water transmission property of the irrigated soil in terms of saturated hydraulic conductivity was increased with effluent irrigation. It increased substantially from 0.9 cm hr^{-1} in fresh water irrigated plots to 1.74 cm hr^{-1} in effluent irrigated plots. Improvement in hydraulic conductivity may be ascribed to better soil aggregation induced by higher organic matter content in the effluent.

Changes in chemical characteristics of the irrigated soil (Table 23) indicated the accumulation of soluble salts in upper soil zone due to effluent irrigation. EC of 1:2 soil and water extract increased from 0.46 dSm^{-1} in fresh water irrigated soil to 1.26 dSm^{-1} in effluent irrigated soil. However, soil pH did not exhibit any noticeable change due to effluent irrigation. There was 2-3 times increase in soluble sodium in irrigated soil but SAR of the soil solution remained within the safe limits. Soluble potassium exhibited about four times increase due to effluent irrigation.

Table 23. **Effect of effluent from M/s Sikka Papers Limited on chemical properties of irrigated soil after rice crop (2000)**

Location	Depth (cm)	EC (dS/m)	pH	SAR	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
					(me/l)			
Tube well Irrigation	0-15	0.46	7.6	1.2	2.0	2.0	1.6	0.1
	15-30	0.44	7.4	0.9	3.0	0.5	1.8	0.1
Tubewell + Effluent	0-15	1.05	7.4	2.2	3.0	4.0	4.0	0.4
	15-30	0.47	7.8	1.0	2.5	1.0	1.8	0.1
Effluent	0-15	1.26	7.2	2.5	5.0	3.0	5.0	0.4
	15-30	0.75	7.5	2.0	4.0	0.5	3.0	0.1

Based on these results it is inferred that effluent irrigation adds some soluble salts in soil mainly in upper soil layer but the magnitude remains below the critical level of soluble salts for crop production point of view.

6.1.10 Effect of Paper Mill Effluent on Fertility Status of Irrigated Soil

Fertility status of effluent irrigated soil after the harvest of rice and wheat crops (1998-99) in terms of organic carbon, available phosphorus and available potash under all the treatments has been given in Table 24.

After rice crop, organic carbon content in surface soil (0-30 cm) under all the three treatments, namely tubewell water, 50% Tube wells + 50% effluent and only effluent was 0.45%, 0.54% and 0.68%, respectively. Similarly, in sub-surface soil (30-60 cm) the corresponding values of organic carbon content were 0.22%, 0.38% and 0.40%. These results clearly reflect that there has been spectacular increase in carbon content of irrigated soil with paper mill effluent. Irrigation with paper mill effluent also increased the available phosphorus from 15.8 kg ha^{-1} with fresh water (tubewell) to 38.5 kg ha^{-1} with application of effluent in surface soil. In

Table 24. Fertility status of irrigated soils after rice and wheat crops at Shamli during 1998-99

Treatment	Soil Depth (cm)	After Rice crop			After wheat crop		
		Organic Carbon (%)	Available (kg/ha)		Organic Carbon (%)	Available (kg/ha)	
			P	K		P	K
Tubewell water	0-30	0.45	15.8	280.5	0.54	16.2	310.5
	30-60	0.22	10.5	270.6	0.21	10.5	285.6
Mixed (T.W.+ Effluent, 50:50)	0-30	0.54	22.6	385.5	0.65	28.6	506.5
	30-60	0.38	15.8	380.6	0.36	18.5	468.8
Effluent 100%	0-30	0.68	38.5	478.6	0.75	45.8	682.5
	30-60	0.40	25.6	510.8	0.43	25.6	580.2

subsurface soil (30-60 cm) the values of available phosphorus increased from 10.5 kg ha^{-1} in respect of fresh water to 25.6 kg ha^{-1} with effluent. Under diluted effluent (50% + 50%) irrigation the available phosphorus was 22.6 and 15.8 kg ha^{-1} in surface (0-30 cm) and subsurface (30-60 cm) layers, respectively. Similarly, the available potash status was also increased due to irrigation with paper mill effluent. It increased in surface soil from 280.5 kg ha^{-1} with fresh water to 478.6 kg ha^{-1} with effluent irrigation. Subsurface soil was also enriched in potassium content from 270.5 kg ha^{-1} when irrigated with fresh water to 510.8 kg ha^{-1} with effluent water.

It can be deduced that paper mill effluent irrigation raised the levels of organic carbon, available phosphorus and available potash and thus enhanced the fertility status of irrigated soil. Fertility of soil was also improved due to effluent irrigation in wheat crop. Organic carbon was further increased to 0.75% in surface (0-30 cm) soil after the harvest of wheat crop where as it remained at the same level (0.54%) in case of fresh

water irrigated plots. Similarly, in subsurface soil it was increased from 0.21% to 0.43% with effluent irrigation. Amounts of available phosphorus and available potash in surface soil were also increased from 16.2 and 310.5 kg ha^{-1} with fresh water irrigation to 45.8 and 682.5 kg ha^{-1} with effluent irrigation, respectively. Irrigation with 50% effluent + 50% fresh water also raised the contents of organic carbon, available phosphorus and available potash as compared to that with tube well irrigation.

Parameters of soil fertility after harvest of rice crop 2000 (Table 25) including organic carbon, available phosphorus and available potash have again shown improvement by effluent irrigation. These observations

Table 25. Effect of effluent from M/s Sikka Papers Limited on soil fertility of irrigated soil after rice crop (2000)

Treatment	Depth (cm)	Organic carbon (%)	Available P (kg/ha)	Available K (kg/ha)
Tubewell Irrigation	0-15	0.87	19.5	170.4
	15-30	0.17	16.5	163.8
Tubewell + Effluent	0-15	1.50	35.0	388.7
	15-30	0.16	22.0	209.6
Effluent	0-15	1.80	43.2	463.0
	15-30	0.50	30.2	275.0

are similar to those reported in preceding years. Organic carbon content was 0.87 and 0.17 per cent in 0-30 and 30-60 cm layer in fresh water irrigated plots and it increased to 1.8 and 0.50 per cent in the respective depths after effluent irrigation. In mixed effluent irrigated plots organic carbon content was of intermediate range. Available phosphorus and potash contents were about doubled in effluent irrigated plot as compared to fresh water irrigated one. These results clearly indicate that the paper

mill effluent containing organic residues of bagasse, straw and recycled papers is quite helpful in improving the nutrient reservoir of the irrigated soil.

6.1.11 Effect of Effluent from M/s Sikka Papers Limited on Quality of Produce

6.1.11.1 Effect of effluent on quality of rice and maize

For ascertaining the quality of maize and rice produce grown with effluent, the contents of some heavy metals like copper, zinc, iron, manganese, cadmium, lead and nickel were determined in straw and grain portion of the plants. Contents are presented in the Table 26.

Table 26. Heavy metal contents in grain and straw portion of rice and maize crops

Heavy metal	Rice grain (‰)	Rice straw (‰)	Maize grain (‰)	Maize straw (‰)
Copper	0.036	0.023	0.18	0.02
Zinc	0.032	0.032	0.036	0.051
Iron	1.23	0.94	0.97	0.75
Manganese	0.054	0.052	0.014	0.015
Cadmium	0.0006	0.0024	0.003	0.003
Lead	0.012	0.0023	0.029	0.025
Nickel	0.027	0.030	0.034	0.0065

6.1.11.2 Effect of effluent on quality of sugarcane juice

Effluent of M/s Sikka Papers Limited was also applied to nearby sugarcane field during 1999-2000. Therefore, it was thought imperative to judge its effect on quality of sugarcane juice. Analysis was done in the laboratory of Upper Doab Sugar Mills, Shamli, U.P. and quality characteristics are given in Table 27. It is clear from the data that all

Table 27. Effect of effluent from M/s Sikka Papers Limited on quality of sugarcane juice

S.No.	Treatment	Quality characteristics			
		Brix (%)	Polarisation (%)	Purity (%)	CCS (%)
1.	Tubewell water	20.32	17.42	85.73	11.33
2.	Mixed water	19.80	17.15	86.62	11.24
3.	Effluent	20.42	17.62	86.24	11.51

Date of analysis : March 14, 2000

quality parameters like Brix, polarization, purity and CCS percentage of the cane juice from effluent irrigated plots were quite comparable with those of tube well and mixed effluent irrigated plots. Purity (%) of cane juice from effluent irrigation was 86.24 against 85.73 from fresh water irrigated canes. Similarly the values of other parameters in effluent irrigated cane juice were also slightly higher than fresh water irrigated one.

6.1.12 Changes in Ground Water Quality

To study the changes in the quality of groundwater due to irrigation with treated paper mill effluent in the experimental area near M/s Sikka Papers Limited, Shamli, piezometers were installed in rice and maize fields. Sample of groundwater was collected in each month from January to December 2000 and analysed for total salt (EC dSm^{-1}) and cationic composition (Table 28).

The data on total salt (EC dSm^{-1}) and its constituents indicate that the quality of ground water is nearly the same during the months of January to December. Hence, irrigation with paper mill effluent did not have any recharging and/or deteriorating effect on ground water and its

Table 28. **Changes in groundwater quality at M/s. Sikka Papers Limited, Shamli, (U.P.) in effluent irrigated plots during 2000-2001**

Month	EC dSm^{-1}	pH	Na^{+}	$Ca^{2+}+Mg^{2+}$	SAR
January 2000	1.6	7.8	8.5	7.5	4.5
February	1.6	7.8	8.5	7.5	4.5
March	1.6	7.9	8.5	7.5	4.5
April	1.7	7.8	9.2	7.8	4.8
May	1.7	7.8	9.0	7.8	4.7
June	1.7	7.9	9.2	7.8	4.8
July	1.6	7.9	9.2	7.8	4.5
August	1.6	7.8	8.8	7.8	4.6
September	1.6	7.8	8.8	7.7	4.6
October	1.6	7.8	8.5	7.8	4.5
November	1.6	7.9	8.5	7.6	4.5
December	1.6	7.8	9.2	7.5	4.8
January 2001	1.7	7.8	9.2	7.6	4.8

quality. Moreover, depth of water level is more than 9.5 m below the ground surface and soil texture is clay loam to silty clay loam, therefore, percolation of effluent irrigation upto ground water level has not taken place so far under these experimental conditions.

6.1.13 Hydraulic Loading for Effluent Irrigation

Irrigation with treated paper mill effluent particularly in 50% + 50% proportion with fresh water (tubewell) had given better results. Therefore, it is imperative to calculate the hydraulic loading at this effluent and fresh water ratio.

Hydraulic loading rates for 100% effluent irrigation and 50% effluent irrigation + 50% fresh water under rice-mustard, rice-wheat, maize-wheat and maize-mustard crop rotations are given in Table 29 and 30. Possible contribution of rainfall during the crop season has also been taken care of.

Table 29. Hydraulic loading rates at 100% effluent application

Crop System	Total water requirement (cm)	Rainfall (cm)	Irrigation requirement (cm)	Effluent loading at 100% (cm)	Total Effluent loading m^3/ha	TDS loading kg/ha
Rice-Mustard	160	80	80	80	8000	8400
Rice-Wheat	190	80	110	110	11000	11550
Maize-Wheat	120	80	40	40	4000	4200
Maize-Mustard	90	80	10	10	1000	1050

Table 30. Hydraulic loading rates at 50% effluent application

Crop System	Total water requirement (cm)	Rainfall (cm)	Irrigation requirement (cm)	Effluent loading at 50% (cm)	Total Effluent loading m^3/ha	TDS loading kg/ha
Rice-Mustard	160	80	80	40	4000	4200
Rice-Wheat	190	80	110	55	5500	5775
Maize-Wheat	120	80	40	20	2000	2100
Maize-Mustard	90	80	10	5	500	525

Amount of total dissolved solids likely to be added through effluent irrigation under different cropping systems has also been worked out and reported in the Table 29 and Table 30.

6.2 Coastal Papers Limited Rajahmundry (Andhra Pradesh)

Field experiments were also conducted for ascertaining the suitability of paper mills effluent from M/s Coastal Papers Ltd. Rajahmundry (A.P.). This experimental site was selected because of a different agro-climatological zone. Weather characteristics of the area are given in Table 31.

Table 31. Mean monthly weather parameters recorded at Central Tobacco Research Institute, Rajahmundry, Andhra Pradesh (1989-2000)

Month	Temperature (°C)		Relative humidity)		Sun-shine hours	Total rainfall (mm)	No. of rainy days	Wind velocity Km/hr	Evapora-tion mm/day
	Max	Min	I (7H)	II (14hr)					
January	29.6	16.1	91.9	62.6	7.8	17.2(9)	2.4(9)	4.35(8)	3.2(5)
February	31.2	18.1	91.0	62.6	8.2	5.4(9)	1.8(9)	5.05(8)	3.9(5)
March	34.2	21.7	83.0	57.3	7.7	15.8(10)	2.2(10)	5.69(8)	4.6(4)
April	36.4	24.8	87.2	53.1	7.2	15.5	2.8	7.19(8)	5.1(6)
May	38.0	26.4	84.2	50.5	7.5	34.3	5.6	7.65	5.6(6)
June	35.7	2.62	85.7	59.8	5.2	132.9	5.6	7.84	4.7(6)
July	32.3	24.9	90.2	71.4	3.9	229.7	14.8	7.13	3.9(6)
August	31.7	24.8	90.6	73.1	3.2	251.8	14.6	7.11(7)	4.015
September	32.4	24.7	90.7	71.7	4.3	178.9	12.2	5.18(6)	3.8(5)
October	32.0	22.9	89.8	6.71	4.8	149.8	9.9	4.86(7)	3.7(5)
November	31.3	19.8	87.6	59.1	4.9	46.6(11)	4.7(11)	5.83(8)	3.7(6)
December	29.8	16.2	89.3	59.1	7.3	9.5(10)	2.2(10)	4.90(9)	3.2(6)

Figures in parenthesis indicate number of years of observations recorded.

6.2.1 Soil Characteristics

Soil samples were collected on July 5, 1998 from sugarcane, maize and rice cropped areas representing red and black soils. Samples were collected from surface and subsurface layers. Samples were processed and mechanical separates were determined by standard laboratory methods. Percentage of sand, silt and clay is given in Table 32 alongwith the soil type. Red soil was mostly sandy loam in texture at the sub-surface. Black soil had finer texture (clay).

Chemical properties of these samples have been given in Table 33. It can be seen from data in the table that the soil of the experimental area was non-calcareous (low pH) and non saline (low EC) in nature. Sugarcane

Table 32. Mechanical analysis of soil samples of M/s Coastal Papers Ltd. Rajahmundry, Andhra Pradesh

Locations	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Sugarcane field I (Red Soil)	0-15	71.08	10.56	18.36	Sandy loam
	15-30	70.36	9.08	20.56	Sandy clay loam
	30-60	63.36	9.08	27.56	Sandy clay loam
	60-90	57.36	12.08	30.56	Sandy clay loam
Sugarcane field II (Red soil)	0-30	62.36	11.12	26.56	Sandy clay loam
Sugarcane field III (Black soil)	0-30	34.80	12.84	52.36	Clay
Maize area	0-30	59.36	17.08	23.56	Sandy clay loam
-do-	30-60	64.36	13.08	22.56	Sandy clay loam
Rice area	0-15	58.36	9.08	32.56	Sandy clay loam
(Mill's site)	15-30	53.08	19.56	27.56	Sandy clay loam

Table 33. Chemical characteristics of soil samples of M/s. Coastal Papers Ltd., Rajahmundry, Andhra Pradesh (1:2 soil-water ratio)

Location	Depth (cm)	pH	EC (dS/m)	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}
				(me/l)				
Sugarcane field (red soil)	0-15	6.5	0.4	5.0	4.5	0.06	6.0	3.6
	15-30	6.3	0.5	6.0	3.6	0.08	6.0	3.6
	30-60	6.5	0.7	5.0	3.5	0.05	3.0	2.8
	60-90	6.6	0.6	5.0	3.2	0.06	3.0	3.1
Sugarcane field (red soil)	0-30	6.6	0.5	4.0	3.5	0.16	3.0	3.6
Sugarcane field (black soil)	0-30	7.5	1.4	5.0	7.7	0.26	6.0	5.4
Maize field (red soil)	0-30	6.4	0.5	5.0	3.5	0.12	5.8	3.6
	30-60	6.4	0.4	4.0	2.8	0.08	3.6	3.5
Rice field (mill site)	0-15	7.6	1.8	11.0	10.0	0.70	3.0	5.4
	15-30	6.5	1.3	8.0	8.5	0.25	6.0	5.4

Date of sampling : 5-6 July, 1998

field soil which had been irrigated since last five years with effluent showed very low EC values indicating negligible build-up of salt in the rhizosphere. Analysis of soil extract indicated the dominance of sodium in black soil and both calcium and sodium in rice soil. Bicarbonate ranged from 3.0 to 6.0 me l^{-1} and potassium was very less (< 0.1 me l^{-1}) in red soil samples.

6.2.2 Effluent characteristics

Samples of effluent were collected on July 5, 1998 from three points of the dicharge system and analysed for pH, EC and other chemical constituents (Table 34). Salinity was more (> 3.0 dSm^{-1}) in primary and secondary overflow. Sodium and calcium + magnesium were present in equal proportion. Chloride content was slightly more than bicarbonate content in primary and secondary overflow.

Table 34. Effluent analysis report of M/s Coastal Papers Ltd., Rajahmundry, Andhra Pradesh

Date of sample Collection	Sample No. & source	pH	EC (dS/m)	$Ca^{2+}+Mg^{2+}$	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}
				(me/l)				
05/07/98	Secondary overflow	7.9	3.6	20.0	20.0	0.95	9.0	10.8
05/07/98	Primary over flow	7.7	3.5	19.0	24.0	0.80	9.0	12.6

6.2.3 Effect of Treated Paper Mill Effluent on Yield of Crops

Field experiments were laid out at two sites for rice in an area of 1.3 and 6.0 acres. Sugarcane was also grown in an area of 6.0 acres with three main treatments namely; 1. Effluent (100%), 2. Effluent and fresh

water (1:1), and 3. Fresh water (100%). Results of these experiments are briefly described in the subsequent sections.

6.2.3.1 Rice

Experiment I - (Area 1.3 acre)

Yield and growth attributes of Swarna variety of rice as influenced by effluent treatments during *kharif* and *rabi* seasons of 1999-2000 and 2000-2001 are given in the Table 35 and Table 36, respectively.

It is evident that the yield attributes of the crop *viz.* plant height, number of panicles/hill, no. of grains/panicle and 1000 grains weight were not adversely affected by effluent irrigation. Height of plants was maximum (114.40 cm) with effluent in comparison to mixed (112.7 cm) and fresh water (101.9 cm) treatments. However, mixed effluent (1:1) induced maximum number of panicles/hill (14.8) and grains/panicle (218.3) as compared to fresh water (14.6 and 195.0) and effluent (13.6 and

Table 35. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on yield and yield attributes of rice

Particular	Experiment - I					
	Kharif-1999 (var. *Swarna*)			*Rabi* 1999-2000 (*var. Swarna*)		
	T1	T2	T3	T1	T2	T3
Plant height (cm)	101.9	112.7	114.4	122.3	122.3	124.1
No. of panicles/hill	14.6	14.8	13.6	18.0	17.0	18.0
No. of grains/panicle	195.0	218.3	194.3	262.4	269.1	267.9
1000 grain wt (g)	19.7	18.8	21.4	28.0	31.1	29.8
Grain yield (q/ha)	65.3	62.4	56.9	49.5	51.0	58.5
Biomass yield (q/ha)	133.1	131.1	129.2	99.5	107.1	123.4

T1-Fresh water; T2-Fresh water + Effluent (1:1); T3-Effluent

Effluent irrigated rice at Rajahmundrya (A.P)

Table 36. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on yield and yield attributes of rice

Particular	Experiment - I					
	Kharif-2000 (var. *Swarna*)			*Rabi* 2000-2001 (*var. Swarna*)		
	T1	T2	T3	T1	T2	T3
Plant height (cm)	121.8	120.5	120.5	95.46	97.46	98.53
No. of panicles/hill	15.6	14.6	14.2	14.08	15.93	18.46
No. of grains/panicle	297.73	293.0	291.93	15.0	16.0	18.50
1000 grain wt (g)	22.63	19.87	19.48	25.09	26.00	26.93
Grain yield (q/ha)	64.0	61.0	59.0	51.1	55.6	59.4
Biomass yield (q/ha)	134.4	133.9	135.8	104.9	113.9	117.8

T1-Fresh water; T2-Fresh water + Effluent (1:1); T3-Effluent

194.3) treatments. But effluent was again effective in producing maximum 1000 grain weight (21.4 g). Grain yield was again maximum (65.3 q ha^{-1}) with fresh water followed by mixed (62.4 q ha^{-1}) and effluent (56.9 q ha^{-1}) treatments. Similar trend was also observed in case of biomass yield.

Based on these results it is inferred that effluent irrigation had some beneficial effect on yield attributing characteristics and hence vegetative growth was very vigorous during *kharif* season that led to lodging of plants and finally less yield with effluent irrigation. This point is more clear when we examine the yield data of rice grown during the *rabi* season. Here the effluent irrigation was very effective in enhancing the growth and yield of rice crop. Grain yield was about 17% more with effluent irrigation in comparison to fresh water. Similar increasing trend was also observed with biological yield.

During *kharif* season of 2000, grain yield of rice was reduced by 8% with effluent irrigation but the biomass yield was slightly improved.

However, there was not significant reduction in all growth attributing characteristics of the rice crop with effluent irrigation and it may be concluded that paper mill effluent was very beneficial for *rabi* rice rather than *kharif* rice. Later trend was again observed in yield of rice during 2000-2001 *rabi* season. Effluent irrigation had beneficial effect on all growth attributing characteristics. Number of panicles/hill increased from 14.1 (fresh water) to 18.5 with effluent irrigatioin. Similarly, number of grain/panicle and test weight were of higher magnitude with effluent irrigation. Grain yield and biomass yields were 51.1 and 104.8 q ha^{-1} with fresh water and 59.4 and 117.8 q ha^{-1} with effluent irrigation, respectively. Therefore, effluent irrigation was beneficial in *rabi* rice as compared to *kharif* rice.

Experiment II - (Area 1.0 acre)

Results of the second experiment (Table 37 and 38) with var. Swarna in *kharif* (1999 and 2000) and Mehsuri in *rabi* (2000-2001) were quite similar to those of first experiment. During *kharif* effluent irrigation had some adverse effect on yield and yield attributing characteristics of the rice. Grain yield was 64.4 q ha^{-1} with fresh water as compared to 55.3 q ha^{-1} with effluent irrigation indicating a decrease of about 14.5% due to effluent irrigation. However, reduction in biomass yield was insignificant.

During *rabi* 2000-2001 effluent irrigation again proved slightly better than fresh water irrigation. There was improvement in all growth characteristics of the rice crop. Plant height, panicles/hill, grains/panicle and test weight increased from 97.2 cm, 17.0, 210 and 25.3 g with fresh water to 98.7, 19.0, 218.4 and 26.1 g with effluent irrigatioin, respectively.

Table 37. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on yield and yield attributes of rice

Particular	Experiment - II		
	Kharif-1999 (var. *Swarna*)		
	T1	T2	T3
Plant height (cm)	101.9	112.7	114.4
No. of grains/panicle	14.6	14.8	13.6
1000 grain wt (g)	19.7	18.8	21.4
Grain yield (q/ha)	65.3	62.4	56.9
Biomass yield (q/ha)	133.1	131.1	129.2

T1-Fresh water; T2-Fresh water + Effluent (1:1); T3-Effluent

Table 38. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on yield and yield attributes of rice

Particular	Experiment - II					
	Kharif-1999-2000 (var. *Swarna*)			*Rabi* 2000-2001 (*var. Mehsuri*)		
	T1	T2	T3	T1	T2	T3
Plant height (cm)	122.30	122.3	119.0	97.2	98.3	98.7
No. of panicles/hill	14.50	13.0	12.3	17.0	18.0	19.0
No. of grains/panicle	294.70	275.5	268.6	210.8	216.9	218.4
1000 grain wt (g)	22.60	22.3	22.3	25.3	25.7	26.1
Grain yield (q/ha)	64.4	56.6	55.3	53.7	54.3	55.8
Biomass yield (q/ha)	133.24	132.8	131.9	112.8	115.8	117.2

T1-Fresh water; T2-Fresh water + Effluent (1:1); T3-Effluent

Grain yield and biomass yields also increased from 53.7 and 112.8 q ha^{-1} to 55.8 and 117.2 q ha^{-1} with fresh water and effluent irrigation, respectively. However, favourable effect of effluent irrigation on yield and its attributes was of higher magnitude in first experiment than that in the second experiment.

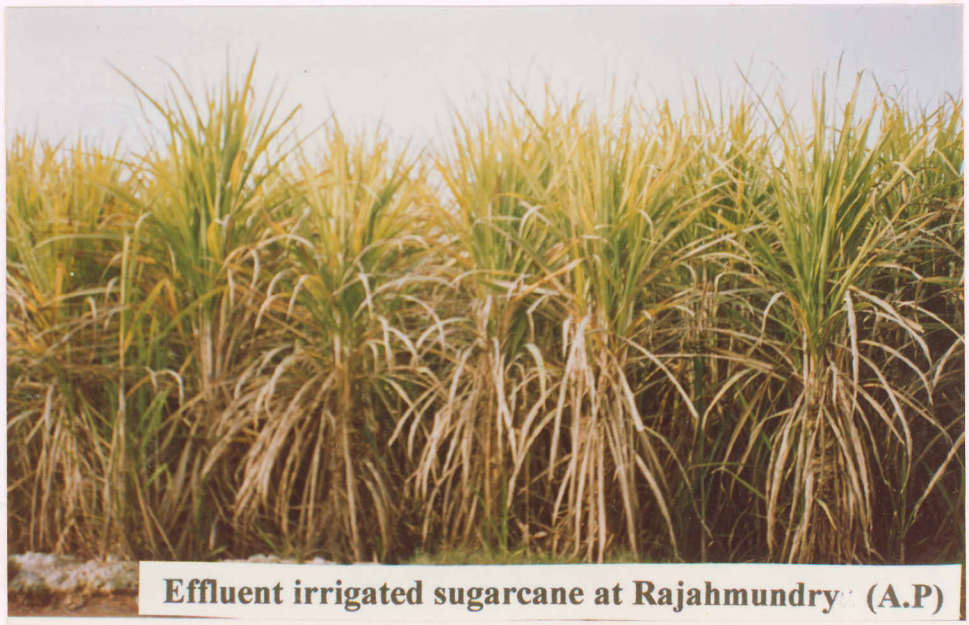
Based on the data of yield and yield attributes of rice it is clear that effluent irrigation was not much beneficial during *kharif* season. This growth behaviour was reflected in all the *kharif* seasons of 1999-2000 and 2000-2001.

6.2.3.2 Sugarcane

Two field experiments were laid out with the same effluent treatments. Yield of cane and cane characteristics are given in Table 39 (First experiment Dec. 1999- Jan 2001) and Table 40 (Second experiment - Dec. 1999 - Jan. 2001). It is clear from the table that effluent irrigation had beneficial effect on height of sugarcane plants. Average height of effluent irrigated plants was 318 cm as compared to 315 cm with fresh water. Mixing of effluent had similar effect to that of pure effluent. Moreover, other growth characters were also improved by effluent irrigation. Cane yield with effluent irrigation was 4% more as compared to that with fresh water treatment. Average cane yield was 79.0 and 81.0 and 82.0 t ha^{-1} with fresh water, mixed effluent and 100% effluent, respectively.

Table 39. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on sugarcane yield and other characters

Particular	Experiment - I		
	Fresh water	Fresh water+ Effluent	Effluent
Plant height (cm)	315.0	318.0	318.0
Girth of cane (cm)	4.4	4.5	4.5
Leaf length (cm)	130.0	132.0	132.0
Leaf width (cm)	4.6	4.6	4.7
Cane yield (t/ha)	79.0	81.0	82.0



Effluent irrigated sugarcane at Rajahmundry (A.P)

Results of second experiment (Table 40) also revealed the similar trend. Average height of plants was 270 cm in fresh water and mixed treatment plots while it was 274 cm in effluent irrigated plots. Girth of the plants was also more (4.8 cm) with effluent as compared to fresh water treatment (4.4 cm). Cane yield was 80.0 t ha^{-1} with effluent treatment as compared to 76.2 t ha^{-1} with fresh water treatment indicating an increase of more than 5% in cane yield.

Table 40. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on sugarcane yield and other characters

Particular	Experiment - II		
	Fresh water	Fresh water+ Effluent	Effluent
Plant height (cm)	270.0	270.0	274.0
Girth of cane (cm)	4.4	4.5	4.6
Leaf length (cm)	130.0	132.0	132.0
Leaf width (cm)	4.3	4.5	4.5
Cane yield (t/ha)	76.2	77.3	80.0

6.2.4 Quality of Sugarcane Juice

Quality of sugarcane juice as affected by effluent irrigation in terms of its different ingredients is given in Table 41 and Table 42 analysed on December 22, 2000 and January 14, 2001, respectively. Percentage of juice in cane did not decrease due to effluent irrigation rather it improved slightly in the later case. The most striking effect of effluent irrigation was on enhanced purity (%) and CCS (sucrose) (%) of sugarcane irrigated with effluent as compared to fresh water. Moreover, Pol (%) was also increased

Table 41. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on quality of sugarcane juice

Particular	Experiment - I (14 January 2001)		
	Fresh water	Fresh water+ Effluent	Effluent
Juice (%)	63.73	64.22	64.22
Purity (%)	86.52	90.36	91.66
Pol. (%)	17.31	18.82	18.73
Brix (%)	19.00	18.34	19.83
CSS (%)	10.29	12.20	12.10

Table 42. Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on quality of sugarcane juice

Particular	Experiment - II (22 December, 2000)		
	Fresh water	Fresh water+ Effluent	Effluent
Juice (%)	63.64	62.12	63.07
Purity (%)	86.46	89.54	91.65
Pol. (%)	16.29	16.87	18.00
Brix (%)	18.86	18.84	19.64
CCS (%)	10.79	11.44	12.39

with effluent application particularly in second experiment. Effect of mixed effluent irrigation (1:1) was of intermediate nature.

Based on these results, it is hereby concluded that quality of sugarcane juice improves with effluent irrigation particuarly from purity and sucrose content point of view.

6.2.5 Effect on Properties of Irrigated Soil

Effect of paper mill effluent on physico-chemical characteristics and fertility status of irrigated soil after rice and sugarcane crops is shown in Table 43 and 44, respectively. It is evident that pH of irrigated soil did not change due to effluent irrigation. However, there has been some addition of salts in soil profile and electrical conductivity of soil hence showed some increasing trend. EC dSm^{-1} of surface layer (0-15 cm) under rice crop increased from 0.6 dSm^{-1} with fresh water to 1.5 dSm^{-1} with effluent irrigation. Sub-surface layers of 15-30 and 30-60 cm also exhibited some amount of salt added through effluent application. Fertility ingredients of organic carbon, available phosphorus and avaialble potash were increased significantly on addition of effluent. Organic carbon increased from 1.23% in fresh water irrigated soil to 1.86% in mixed effluent irrigated and 1.71% in effluent irrigated soil. Available phosphorus and potash also increased from 13.5 and 432 kg ha^{-1} in fresh water irrigated soil to 20.25 and 861 kg ha^{-1} in effluent irrigated soil.

Similarly, changes in physico-chemical characteristics and fertility status of the irrigated soil were again observed after sugarcane crop. Conductivity of the soil increased from 0.72 dSm^{-1} in fresh water irrigated soil to 1.48 dSm^{-1} in effluent irrigated plots. Fertility status was improved due to effluent irrigation. Organic carbon, available phosphorus and available potash in 0-15 cm soil layer were increased from 0.52%, 11.25 kg ha^{-1} and 148 kg ha^{-1} in fresh water irrigated plots to 1.47%, 22.5 kg ha^{-1} and 177 kg ha^{-1} in effluent irrigated plots, respectively.

Table 43. **Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on physico-chemical characteristics and fertility of the soil after rice (April 2001)**

Treatment	Soil depth (cm)	pH	EC (dSm^{-1})	Organic carbon (%)	Available Phosphorus (kg/ha)	Available Potash (kg/ha)
Fresh water	00-15	7.7	0.60	1.23	13.50	432
	15-30	7.9	0.30	0.48	9.00	335
	30-60	7.7	0.30	0.30	9.00	250
Fresh water + Effluent	00-15	7.5	1.20	1.71	18.25	612
	15-30	7.8	1.00	0.30	13.25	433
	30-60	7.8	0.50	0.30	11.15	297
Effluent	00-15	7.7	1.50	1.86	20.25	861
	15-30	7.8	1.20	0.45	14.50	505
	30-60	7.9	0.92	0.30	9.50	335

Table 44. **Effect of effluent from M/s Coastal Papers Limited, Rajahmundry on physico-chemical characteristics and fertility of the soil after sugarcane (January 2001)**

Treatment	Soil depth (cm)	pH	EC (dSm^{-1})	Organic carbon (%)	Available Phosphorus (kg/ha)	Available Potash (kg/ha)
Fresh water	00-15	6.6	0.72	0.52	11.25	148
	15-30	7.0	0.36	0.36	9.0	136
	30-60	7.4	0.16	0.36	4.50	128
Fresh water + Effluent	00-15	7.4	1.28	0.66	29.15	167
	15-30	7.5	0.75	0.48	13.50	157
	30-60	7.8	0.18	0.36	9.00	148
Effluent	00-15	7.6	1.48	1.47	29.25	177
	15-30	7.1	1.00	0.63	22.50	168
	30-60	7.8	0.45	0.39	13.50	148

6.3 Nath Pulp and Paper Mills Ltd., Aurangabad (M.S.)

Field experiments were also conducted to study the suitability of effluent generated from M/s Nath Pulp and Paper Mills Ltd. Aurangabad (M.S.) for crop production. This experimental site was selected with the aim of ascertaining effluent effect on heavy textured vertisols under a different set of agro-ecological zone. Climatic parameters of the area are given in Table 45.

Table 45. Mean monthly weather parameters recorded at Water and Land Management Institute, Aurangabad (MS)

Month	Temperature (°C)		Relative humidity		Sun-shine hours	Total rainfall (mm)	Wind velocity (Km/hr)	Evapora-tion (mm/day)
	Max	Min	I (7H)	II (14hr)				
January	29.2	13.0	68.2	39.3	9.32	1.35	2.13	4.1
February	31.6	14.4	60.3	30.9	9.90	1.99	2.09	5.1
March	35.3	18.3	51.4	23.4	9.88	4.47	2.13	6.9
April	38.0	21.4	47.5	22.4	9.74	3.47	2.40	8.7
May	39.7	23.6	56.0	23.1	9.71	15.76	4.02	9.9
June	35.0	22.8	78.0	45.2	6.54	143.88	4.57	7.2
July	3.02	21.7	89.5	65.8	3.34	158.54	3.88	4.4
August	29.0	20.8	90.6	70.1	3.16	141.29	3.20	3.6
September	30.2	20.6	90.7	62.1	5.73	146.80	2.37	4.1
October	31.2	19.3	80.7	50.6	7.81	106.08	2.08	4.7
November	30.0	16.1	69.0	46.0	8.62	21.98	2.06	4.8
December	28.6	11.9	67.6	44.1	5.38	11.39	2.09	4.1

6.3.1 Soil Characteristics

On July 7, 1998 soil samples were collected from the experimental area No. 1 and No. 2 to study the initial physico-chemical characteristics before the use of effluent for crop growing. Based on the percentage of sand, silt and clay fractions (Table 46), the texture of surface (0-15 cm) and (15-30 cm) in plot No. 1 was sandy clay loam and of 30-60 cm as sandy silt loam. Soil texture of subsurface layer (60-90 cm) was coarser as sandy loam. In plot No. 2 surface soil texture (0-15 cm) was sandy clay loam but a sandy layer (sandy loam to loamy sand) was present just below 15 cm depth.

Table 46. Mechanical analysis of soil samples from fields of M/s Nath Pulp & Paper Mills Limited, Aurangabad (M.S.)

Location	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Plot No. 1	0-15	51.00	25.64	23.36	Sandy clay loam
	15-30	48.72	23.92	26.36	Sandy clay loam
	30-60	61.00	21.64	17.36	Sandy silt loam
	60-90	73.00	16.64	10.31	Sandy loam
Plot No. 2	0-15	56.80	22.84	20.36	Sandy clay loam
	15-30	73.00	15.64	11.36	Sandy loam
	30-60	81.00	14.64	4.36	Loamy sand
	60-90	84.00	12.64	3.36	Loamy sand

Plot No. 1 : Eucalyptus Plantation; Plot No. 2 : NSF Project Area.

6.3.2 Effluent Quality

Quality of the treated effluent in terms of pH, EC dSm^{-1}, total dissolved solids (TDS) and suspended solid (SS) is given in Table 47. It is clear that pH value of the effluent did not change significantly over a period of 7 to 8 months starting from July 2000 to Feb. 2001 with its maximum value of 7.4 in the month of January 2001. Total salt concentration (EC dSm^{-1}) ranged from 1.24 to 1.71 dSm^{-1} during the months of July to December indicating fairly safe water quality class from crops irrigation point of view. Total dissolved solid (TDS) ranged from 284 to 769 mg l^{-1} during the month of Juy 2000 to Feb. 2001 indicating variable quality of inputs and degree of its effluent treatment. From irrigation point of view TDS concentration is within the safe limits and not likely to affect either the crops or irrigated soil adversely. Amount of suspended solids varied from 63.3 mg l^{-1} to 96.0 mg l^{-1} over a period of 7-8 months.

6.3.3.1 Effect of Effluent Irrigation on Growth and Yield of Crops

Table 47. Analysis of effluent from M/s Nath Pulp and Paper Mills Ltd. Aurangabad (MS)

Month	pH		EC (dSm^{-1})		T.D.S. (mg l^{-1})		SS (mg l^{-1})	
	Average value	No. of samples	Average value	No. of samples	Average value	No. of samples	Average value	No. of samples
July 2000	7.22	16	-	-	284	16	63.3	16
August 2000	7.21	26	1.24	7	308	26	75.5	25
September 2000	7.24	13	1.48	4	318	12	88	12
October 2000	7.35	11	1.40	5	382	10	96	10
November 2000	7.20	17	-	-	415	17	92	16
December 2000	7.40	15	1.71	3	598	15	96	15
January 2001	7.50	25	-	-	567	25	91	25
February 2001	7.20	9	-	-	769	9	86	9

6.3.3.1 *Maize*

Effect of treated effluent on yield and other yield attributes of maize (Var. Nath Samrat-112) is shown in Table 48. It is evident that the treated effluent did not affect any of the growth characteristics adversely, thereby their values were nearly the same under all the three treatments. Average height of the plants was 209.3, 208.9 and 207.3 cm under fresh water, mixed and pure effluent (100%) irrigated plots, respectively. Similarly, other growth parameters like stem girth, number of leaves and their length/width, size and girth of cob did not change significantly on using effluent for irrigation. Grain yield and biomass yield of the crop was 24.5, 24.8, 24.0 and 60.3, 60.8 and 58.9 q ha^{-1} under fresh water, mixed effluent and 100% effluent, respectively.

Based on these results it is hereby concluded that irrigation with

Table 48. Effect of effluent from M/s Nath Pulp and Paper Mills Ltd., Aurangabad on growth and yield of maize (*Kharif*, 2000)

Particular	Treatment		
	Fresh water	Fresh water + effluent	Effluent
Plant height (cm)	209.3	208.9	207.3
Girth of plants (cm)	9.5	10.6	11.3
No. of leaves/plant	9.0	9.0	8.0
Length of leaf (cm)	75.5	76.4	74.8
Width of leaf (cm)	8.6	8.2	8.8
Length of cob (cm)	24.0	23.6	23.8
Girth of cob (cm)	16.4	16.5	16.0
Grain yield (q/ha)	24.5	24.8	24.0
Biomass yield (q/ha)	60.3	60.8	58.4

Effluent irrigated maize at Aurangabad (M.S)

treated effluent did not affect the yield and other characteristics of maize adversely. Yield and other growth characteristics of maize crop were at par in effluent and fresh water irrigated plots.

6.3.3.2 *Sorghum*

Yield and yield attributing characteristics of sorghum (var. Amar Nath-101) as influenced by fresh water, mixed effluent (1:1) and effluent alone (100%) are given in Table 49. It is clear from the table that height of the sorghum plants slightly increased in effluent irrigated plots (187.3 cm) as compared to that in fresh water irrigated ones (179.5 cm). However, other growth characteristics like no. of leaves/plant, girth of plants, length and girth of earhead of the plants were not significantly different in both the plots. Grain yield and biomass yield were 21.0, 21.2, 20.5 and 68.5, 72.2 and 67.8 q ha^{-1} in fresh water, mixed effluent and 100% effluent irrigated plots, respectively. Grain yield and biomass yield were thus

Table 49. Effect of effluent from M/s Nath Pulp and Paper Mills Ltd., Aurangabad on growth and yield of sorghum during *Kharif*, 2000

Particular	Treatment		
	Fresh water	Fresh water + effluent	Effluent
Plant height (cm)	179.5	185.8	187.3
Girth of plants (cm)	9.2	9.2	9.1
No. of leaves/plant	9.7	9.5	9.5
Length of earhead (cm)	30.7	32.5	32.2
Girth of earhead (cm)	11.4	12.5	10.9
Grain yield (q/ha)	21.0	21.2	20.5
Biomass yield (q/ha)	68.5	72.2	67.8

higher due to mixed effluent (1:1) irrigation than others. Results of sorghum yields also indicated the parity between fresh water and effluent irrigations.

6.3.3.3 Cotton

Effect of effluent irrigation on plant growth characteristics and seed cotton yield (var. Rajat) is given in Table 50. It is clear from the data that the results are similar to those reported for maize and sorghum crops. All the plant parameters namely plant height, number of branches, number of bolls/plant were not affected adversely with effluent irrigation. Seed cotton yield and biomass yield were 15.8, 16.0, 16.3, and 78.4, 79.3 and 76.5 q ha^{-1} under fresh water, mixed effluent and pure effluent (100%), respectively. Based on these observations it may be concluded that treated paper mill effluent did not cause any harmful effect on cotton crop.

6.3.3.4 Mustard

Table 50. Effect of effluent from M/s Nath Pulp and Paper Mills Ltd., Aurangabad on growth and yield of cotton (*Kharif*, 2000-2001)

Particular	Treatment		
	Fresh water	Fresh water + effluent	Effluent
Plant height (cm)	165.5	168.4	164.5
No. of branches/plant	17.5	18.6	17.7
No. of squares/plant	14.5	14.8	14.4
Seed cotton yield (q/ha)	15.8	16.0	16.3
Biomass yield (q/ha)	78.4	79.2	76.5

Note : Four Pickings made on 20 Oct., 9 Nov., 19 Dec., 2000 and Jan 11, 2001.

Yield and growth characteristics of mustard (var. Nath Sona 212) crop as influenced by effluent irrigation are given in Table 51. It is clear that behaviour of growth parameters was similar to other crops. Plant height, no. of primary and secondary branches and number of pods/plant were not affected appreciably due to effluent irrigation. However, relatively taller plants with more number of primary and secondary branches were obtained with mixed effluent. Total number of pods was highest (513.2) in mixed effluent irrigated plots as compared to fresh water (487.6) and effluent (499.0) irrigated plots. Grain yield and biomass yield of mustard was 12.0, 12.54, 12.0 and 62.5, 64.2 and 63.5 q ha^{-1} under fresh water, mixed effluent and 100% effluent treatment, respectively. Based on these results it is again inferred that effluent irrigation is not harmful to growth of mustard crop.

6.3.3.4 Wheat

Table 51. Effect of effluent from M/s Nath Pulp and Paper Mills Ltd., Aurangabad on Growth and yield of mustard (*Rabi*, 1999-2000 & 2000-2001)

Particular	Treatment					
	Fresh water		Fresh water + effluent		Effluent	
	1999-2000	2000-2001	1999-2000	2000-2001	1999-2000	2000-2001
Plant height (cm)	82	129.7	93	135.1	82	129.8
No. of primary branches/ plant	6.1	6.2	6.5	7.4	5.7	7.6
No. of sub-branches/ plant	15.8	35.5	16.2	36.3	13.2	34.8
No. of pods/plant	257	487.6	274	513.2	219	499.0
Grain yield (q/ha)	4.4	12.0	4.8	12.5	3.7	12.0
Biomass yield (q/ha)	14.8	62.5	15.6	64.2	13.0	63.5

Note : Sowing in 1999-2000 was delayed for about one month

Growth characteristics of wheat crop (var. Nath wheat) along with grain and biomass yield under all the treatments are given in Table 52. It is clear that the height of plants did not differ significantly with all the three treatments though it was slightly higher with mixed effluent as compared to other treatments. Total number of tillers/plant was slightly more for mixed effluent in first year, but with 100% effluent in second year. Mixed effluent (1:1) was effective as it caused maximum height of the plants and maximum effective tillers and 1000 grains weight. Average grain yield and biomass yield were highest under mixed irrigation followed by fresh water and 100% effluent, respectively. But variations between latter two were not much.

Based on these results it may be concluded that effluent irrigation

Table 52. Effect of Effluent from M/s Nath Pulp and Paper Mills Ltd., Aurangabad on Growth and Yield of Wheat (*Rabi*, 1999-2000 & 2000-2001)

Particular	Treatment					
	Fresh water		Fresh water + effluent		Effluent	
	1999-2000	2000-2001	1999-2000	2000-2001	1999-2000	2000-2001
Plant height (cm)	61.1	105.2	62.9	107.5	62.6	104.6
No. of tillers/plant	9.3	8.5	10.2	9.5	10.1	10.8
No. of heads/plant	5.3	3.5	5.9	3.6	5.6	3.4
No. of heads/m^2	-	180.5	-	182.8	-	179.4
1000-grain weight (g)	58.8	48.5	58.6	49.2	53.2	48.8
Grain yield (q/ha)	29.6	39.4	32.5	40.0	24.1	39.5
Biomass yield (q/ha)	70.3	79.2	70.8	81.5	69.7	78.4

Note : Sowing in 1999-2000 was delayed by one month.

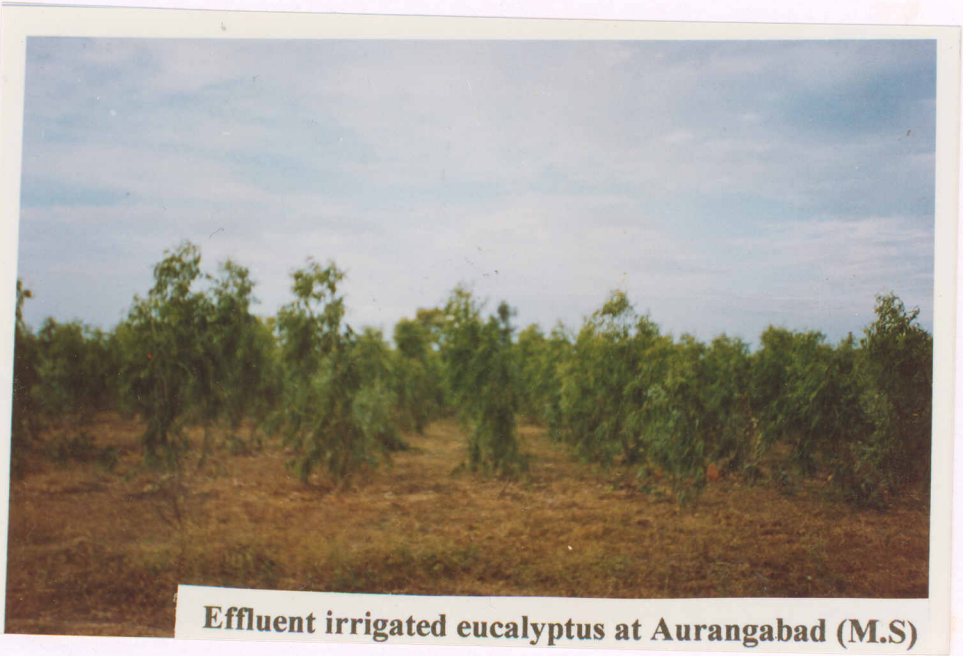
did not induce any significant adverse effect either on growth or on yield of the crops under this investigation. However, mixed effluent invariably proved better.

6.3.4 Effect of Effluent on Eucalyptus

Eucalyptus plantation has been raised for judging the irrigation suitability of the effluent. Observations on girth of the plants at 1.5 m height were recorded and are presented in the Table 53. Based on the average girth of the five plants in 5 random rows, it is concluded that in most of the plants effluent irrigation has induced better growth thereby more girth as compared to fresh water treatment. Overall, average girth of the effluent irrigated plants was 11.2 cm against 9.7 cm of plants irrigated with fresh water.

Table 53. Effect of effluent from M/s. Nath Pulp and Paper Mill Ltd. on girth of Eucalyptus plants at 1.5 m height

No. of row	Average girth (cm)	
	Fresh water	Effluent
1.	11.6	14.1
2.	9.6	13.0
3.	10.3	11.8
4.	8.5	9.3
5.	8.6	7.8
Average	9.7	11.2



Effluent irrigated eucalyptus at Aurangabad (M.S)

6.3.5 Effect of Irrigation on the Soil

Salinity build-up in irrigated soil on account of effluent irrigation in wheat crop during 2000-2001 is shown in Table 54. It is clear from the table that the total salt build up in irrigated soil in terms of EC dSm^{-1} is increased due to effluent irrigation. However, plot having freshwater irrigation also showed higher salinity (1.6 dSm^{-1}) in sub-surface layers (15-30 cm). It is possibly displacement of salts downward due to freshwater irrigation. Mixed irrigation induced similar magnitude of salinity in both the layers. In effluent irrigated plot salinity was restricted to surface layer mainly. Here presence of salts in tubewell irrigated plots might be due to previous accumulation because of disposal of effluents in this part of the field. This is further reflected in the analysis of soil extract of this field as concentration of cations of calcium, magnesium, sodium and potassium was nearly of the same magnitude as that in mixed water and effluent

Table 54. Effect of effluent from M/s Nath Pulp and Paper Mills Limited on chemical properties of the soil after wheat (2000-2001)

Treatment	Depth (cm)	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-
			(mel^{-1})					
Fresh water	0-15	0.93	3.0	1.0	9.6	0.09	8.0	10.0
	15-30	1.60	3.0	2.0	12.2	0.14	12.0	14.0
Fresh water +	0-15	1.20	4.0	2.0	10.9	0.09	12.0	10.0
Effluent	15-30	1.14	5.0	0.5	10.3	0.09	8.0	10.0
Effluent	0-15	1.13	3.0	1.5	10.6	0.11	10.0	8.0
	15-30	0.99	4.0	1.0	10.5	0.10	10.0	12.0
	30-45	0.95	2.0	1.0	9.3	0.03	6.0	10.0
	45-60	0.83	2.0	1.0	9.0	0.02	4.0	10.0

treated plots. Sodium was 9.6 and 12.2 mel^{-1} in 0-15 and 15-30 cm soil layers in fresh water irrigated plots and nearly similar concentrations was observed in mixed effluent and pure (100%) effluent irrigated plots. Concentration of anions (chloride and bicarbonate) was also the same in effluent and fresh water irrigated plots.

Salt build up in irrigated plots after the harvest of mustard crops is shown in Table 55. Pattern of salt build up in surface (0-15 cm) and sub-surface layers (15-30 cm) was similar to that in wheat field. However, EC values particularly in surface layer (0-15 cm) were comparatively higher in effluent and mixed effluent irrigated plots. Magnitude of salt build up in all three situations indicates that this plot has been the lagoon for storing black liquor or effluent for sometime. EC was 0.86, 1.2 and 1.2 dSm^{-1} in 0-15 cm soil layer on irrigation with fresh water, mixed and effluent, respectively. Distribution of cations namely, calcium, magnesium, sodium and potassium was nearly similar in the plots of all the three treatments.

Table 55. Effect of effluent from M/s Nath Pulp and Paper Mills Limited on chemical properties of the soil after mustard (2000-2001)

Treatment	Depth (cm)	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-
			(mel^{-1})					
Fresh water	0-15	0.86	2.0	1.0	8.8	0.2	12.0	12.0
	15-30	0.82	3.0	2.0	9.1	0.2	8.0	8.0
Fresh water+	0-15	1.2	3.0	1.0	10.0	0.2	12.0	10.0
Effluent	15-30	0.9	2.0	2.0	9.0	0.1	8.0	10.0
Effluent	0-15	1.2	3.0	2.0	11.0	0.2	10.0	10.0
	15-30	1.0	2.0	1.0	9.5	0.1	10.0	10.0
	30-45	0.8	5.0	1.0	8.3	0.1	6.0	8.0
	45-60	0.7	2.0	2.0	7.9	0.1	8.0	8.0

7. CONCLUSIONS

- Treated paper mill effluent is usually of low to moderate salinity with medium level of sodium (SAR) and very low concentration of heavy metals.
- There was no significant adverse effect of effluent on grain and biomass yield of most of the crops such as rice, maize, mustard, wheat and sugarcane.
- On the other hand, there was some favourable effect on yield of crops particularly with mixed effluent.
- Quality of the produce such as sugarcane juice was slightly improved with effluent irrigation.
- Content of heavy metals in grain and straw of the rice and maize plant was very low.
- Physico-chemical characteristics of the effluent irrigated soil were not adversely affected during the period of experimentation.
- Soil salinity and sodicity (SAR) increased to some extent but remained below the critical limits.
- Physical properties of the soil such as bulk density and hydraulic conductivity were slightly improved with effluent irrigation.
- Fertility status of the irrigated soil in terms of organic carbon, available phosphorus and potash was improved due to effluent irrigation

- Effluent irrigation had no deteriorating effect on quality of the groundwater at M/s. Sikka Papers Limited, Shamli (U.P.).

8. FUTURE RESEARCH

- Significant findings of this investigation are to be validated for a further period of 2 to 3 years in order to recommend the technology for farmers' use.
- Improvement in physico-chemical characteristics of the irrigated soil is to be critically examined and quantified along with organic matter loadings and nutritional requirement of crops.
- Studies should be extended to vegetable, garden and forest crops particularly from quality and nutritional point of view.
- Usage technology for treated effluent needs to be standardized.