



## Impact of pulp and paper mill effluent on soil nutrient dynamics in Ludhiana, Punjab

Ashwini C Chandel, Dipali Pawar, Anilkumar Mishra, Arpula Sairam

Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi, India

\*Corresponding email: [ashwini.chandel06@gmail.com](mailto:ashwini.chandel06@gmail.com)

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#### Article Authors

Ashwini C Chandel,  
Dipali Pawar, Anilkumar Mishra,  
Arpula Sairam

#### Corresponding Author Email

[ashwini.chandel06@gmail.com](mailto:ashwini.chandel06@gmail.com)

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### ABSTRACT

This study investigates the influence of different irrigation treatments and fertilizer combinations on soil properties at Shreyans Industries Limited, Ludhiana, Punjab. Split - plot design was employed and the treatments involved varying proportions of pulp and paper mill effluent (E) and ground water (GW) (ranging from 100% E to 100% GW) as I1: 100% (E), I2: 90% (E) + 10% (GW), I3: 80% (E) + 20% (GW), I4: 70% (E) + 30% (GW), I5: 60% (E) + 40% (GW) and I6: 50% (E) + 50% (GW) in main plot and four fertilizer treatments: Control (No fertilizers) (F1), 100% FYM (F2), 100% NPK (F3), and 50% NPK + 50% FYM (F4) under sub-plot. The results indicated that soil pH remained slightly alkaline across all treatments with minimal fluctuations, while electrical conductivity (EC) values suggested low to moderate salinity levels. Soil organic carbon (SOC) content varied significantly, with the highest values observed under treatments with 60% effluent + 40% ground water (I5) and 100% ground water (I7). This combination also showed the most significant improvements in available nitrogen, phosphorus, and potassium, indicating enhanced nutrient availability compared to other treatments. These findings emphasize the importance of integrated nutrient management, showing that effluent irrigation combined with organic-inorganic fertilizers can significantly improve soil fertility and promote sustainable agricultural practices. Irrigation with a 60% pulp and paper mill effluent and 40% ground water mix optimized soil organic carbon and nutrient levels, while maintaining stable pH and EC, suggesting it as the most effective treatment for improving soil fertility and plant growth. This study highlights the potential of using effluent in sustainable agricultural practices, offering valuable insights into optimizing irrigation strategies with minimal environmental impact.

### KEYWORDS

Soil Ph, Electrical Conductivity, Organic Carbon, Nutrient Availability, Irrigation, Pulp and Paper Mill Effluent, Ground Water, Punjab

### HOW TO CITE THIS ARTICLE

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In India, the pulp and paper sector has witnessed substantial growth, fueled by increasing demand for paper products. However, the environmental impact of this growth cannot be overlooked. The advantages of utilizing pulp and paper mill effluents in agriculture, such as providing nutrients and organic matter to soil, must be balanced against the disadvantages, including potential soil and water contamination. Effluents from pulp and paper mills are often rich in nutrients such as nitrogen and phosphorus, which, in moderate amounts, can enhance soil fertility and support crop growth.

This has led to discussions about the potential use of treated effluents as a resource for agricultural irrigation (Singh and Kumar, 2022). When applied appropriately, such effluents can improve soil structure, increase microbial activity, and boost the availability of essential nutrients, potentially leading to higher crop yields (Gupta *et al.*, 2020). This research paper aims to examine the current state of pulp and paper mill effluent disposal in India, highlighting recent effluent values and their implications for the environment and agriculture.

Furthermore, we will explore future strategies for effective effluent management that prioritize sustainability and environmental protection. By addressing these issues, we hope to contribute to a more sustainable framework for the pulp and paper industry, fostering a balance between economic growth and environmental stewardship. Soil quality is particularly susceptible to degradation from industrial effluents, which can alter its physical, chemical, and biological properties. High levels of nutrients such as nitrogen and phosphorus from effluents can lead to soil eutrophication, affecting plant growth and soil biodiversity (Gupta and Kumar, 2023). Additionally, the accumulation of heavy metals like cadmium and lead, often found in paper mill waste, poses serious risks to soil health and agricultural productivity (Joshi *et al.*, 2022).

Soil health and fertility are paramount to the productivity of agricultural lands. Soil properties such as pH, organic carbon, and nutrient content (including nitrogen, phosphorus, and potassium) directly affect plant growth and crop yields. Among these properties, soil pH influences nutrient availability and microbial activity, while electrical conductivity (EC) indicates the salinity level, which can affect plant water uptake and soil structure. Organic carbon is crucial for soil structure, water retention, and nutrient supply (Kekane *et al.*, 2015). Pulp and paper mill effluent irrigation, combined with ground water, has emerged as a potential solution to water scarcity, but its impact on soil health requires careful investigation. This study examines the effects of different irrigation combinations of effluent and ground water on soil pH, EC, organic carbon, and available nutrients at Shreyans pulp and paper Industries Limited in Ludhiana, Punjab, aiming to understand their role in soil fertility and agricultural productivity.

## Materials and Methods

The study was conducted at Shreyans Industries Limited, Ludhiana, Punjab, over a period to assess the impact of various irrigation treatments. These treatments involved the use of different combinations of pulp and paper mill effluent (E) and ground water (GW), with the following irrigation combinations:

### Main Plot (Combination of Paper Mill Effluent and Ground Water)

- I1:** 100% pulp and paper mill effluent (E)
- I2:** 90% pulp and paper mill effluent (E) + 10% ground water (GW)
- I3:** 80% pulp and paper mill effluent (E) + 20% ground water (GW)
- I4:** 70% pulp and paper mill effluent (E) + 30% ground water (GW)
- I5:** 60% pulp and paper mill effluent (E) + 40% ground water (GW)
- I6:** 50% effluent + 50% ground water (GW)
- I7:** 100% ground water (GW)

### Fertilizer Sub Plots:

- F1:** Control (No NPK, No FYM)
- F2:** 100% FYM
- F3:** 100% NPK
- F4:** 50% NPK+50% FYM

Soil samples were collected at various stages of crop growth at 0-15 cm depth, and analysed for pH, EC, organic carbon, and available nitrogen, phosphorus, and potassium, following standard procedures (Singh *et al.*, 1999). Statistical analysis was performed by using split plot design to determine the significance of differences between treatments and irrigation combinations.

## Results and Discussion

### Soil pH

The mean pH values ranged from 7.30 to 8.55 across all treatments, with slight variations observed across irrigation treatments, but all values remained in the slightly alkaline range. Among the main plots, the highest mean pH value was observed under 100% pulp and paper mill effluent (E) irrigation (I1) at 8.38, while the lowest was recorded under the combination of 50% pulp and paper mill effluent (E) and 50% ground water (I6) at 7.58. Despite these variations, the application of fertilizers particularly in sub-plots not showing any significant fluctuations in pH, suggesting that soil pH remained stable regardless of the nutrient management practices applied. The results reflect minimal impact of the effluent and ground water irrigation combinations on pH, indicating a relatively stable soil environment across the study area (table 1).

**Table 1. Soil pH Interaction at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	8.20	8.55	8.40	8.35	8.38
I2 (90% E+10% GW)	8.10	8.35	8.20	8.30	8.24
I3 (80% E+20% GW)	7.85	7.76	7.91	7.90	7.85
I4 (70% E+30% GW)	7.67	7.85	7.80	7.77	7.77
I5 (60% E+40% GW)	7.77	7.60	7.71	7.30	7.59
I6 (50% E+50% GW)	7.69	7.59	7.73	7.31	7.58
I7 (100% GW)	7.71	7.85	7.75	7.95	7.82
Mean	7.86	7.93	7.93	7.84	
Interaction	Sem±		0.08		
	CD (0.05)		NS		

**Note:** GW-Ground Water, E-pulp and paper mill effluent

The increase in pH particularly in paper mill effluent application treatments due to paper mill effluent often exhibits an alkaline nature due to the use of chemicals like sodium hydroxide and calcium carbonate in pulping processes (Sumathi and Hung 2004). This alkalinity, coupled with the presence of inorganic salts and varying organic matter content, can significantly increase soil pH upon effluent application. The salts can react with soil components, releasing hydroxyl ions, while some organic compounds may decompose into alkaline byproducts.

**Electrical Conductivity (EC)**

The EC values ranged from 0.16 to 0.21 dS/m across paper mill effluent along with ground water application and fertilizer treatment combinations, suggesting low to moderate salinity across all treatments. The highest EC was recorded under the 100% pulp and paper mill effluent treatment (I1) at 0.20 dS/m, while the lowest was observed in the 60% effluent + 40% ground water treatment (I5) at 0.16 dS/m. The results indicate that increasing the proportion of ground water in the irrigation mix led to a decrease in EC, particularly in treatments with a higher proportion of ground water, which exhibited lower salinity. The mean EC values were consistent across fertilizer subplots, indicating that the applications of fertilizers were not significantly influence the salinity of the soil. These findings suggest that the irrigation treatments had a more pronounced effect on EC than the fertilizer treatments, and that soil salinity remained within acceptable limits for crop growth (table 2).

**Table 2. Soil EC(ds/m) Interaction at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	0.21	0.20	0.18	0.21	0.20
I2 (90% E+10% GW)	0.20	0.16	0.18	0.18	0.18
I3 (80% E+20% GW)	0.19	0.19	0.17	0.19	0.18
I4 (70% E+30% GW)	0.19	0.17	0.17	0.16	0.17
I5 (60% E+40% GW)	0.17	0.16	0.16	0.16	0.16
I6 (50% E+50% GW)	0.17	0.16	0.17	0.16	0.17
I7 (100% GW)	0.16	0.16	0.17	0.17	0.17
Mean	0.19	0.17	0.17	0.18	
Interaction	Sem±		0.01		
	CD (0.05)		NS		

**Soil Organic Carbon (SOC)**

Organic carbon content varied significantly across treatments in both main and sub-plots, ranging from 0.27% to 0.98%. This variation underscores the influence of both treatment and irrigation combination on organic carbon levels. The fertilizer treatments (F2, F3, and F4) significantly impacted SOC content, with the highest values typically recorded under F4 (50% NPK + 50% FYM) compared to rest of the fertilizer treatments.

**Table 3. Soil Organic Carbon Interaction (%) at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	0.27	0.35	0.49	0.54	0.41
I2 (90% E+10% GW)	0.49	0.37	0.39	0.41	0.42
I3 (80% E+20% GW)	0.52	0.43	0.47	0.51	0.48
I4 (70% E+30% GW)	0.77	0.73	0.71	0.72	0.73
I5 (60% E+40% GW)	0.62	0.80	0.98	0.76	0.79
I6 (50% E+50% GW)	0.55	0.76	0.53	0.83	0.67
I7 (100% GW)	0.53	0.75	0.46	0.83	0.64
Mean	0.54	0.60	0.58	0.66	
Interaction	Sem±		0.04		
	CD (0.05)		0.12		

**Note:** GW-Ground Water, E-pulp and paper mill effluent

The mean SOC content also significantly varied in paper mill effluent along with ground water application was higher in 60% pulp and paper mill effluent (E) and 40% ground water (I5) compared to the control I1, I2 and I3. However, I4, I5, I6 and I7 were not significantly varied. The increase in SOC in these treatments reflecting the importance of organic fertilizers and paper mill effluent enhancing organic carbon levels.

These findings suggest that effluent irrigation, especially combined with organic fertilizers, improves soil organic carbon content, which is essential for soil fertility and health (table 3).

### Available Nitrogen

Available nitrogen content ranged from 250.88 kg/ha to 633.47 kg/ha in different treatment combinations. When compared among irrigation treatments, the mean available nitrogen content ranged from 269.70 kg ha<sup>-1</sup> to 581.73 kg ha<sup>-1</sup>, with the highest values recorded under treatment I4 (70% E + 30% GW) showed best compared to other treatments. The treatments under sub-plots, particularly under fertilizer treatment F3 (100% NPK) also showing significantly higher available N compared with other fertilizer treatments. The statistical analysis showed that the variability in available nitrogen was significant across the treatments. These findings indicate that nitrogen availability is strongly influenced by both the irrigation treatment and fertilizer type applied, with higher available nitrogen associated with the combined use of inorganic and organic fertilizers (table 4).

**Table 4. Available Nitrogen (kg ha<sup>-1</sup>) at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	263.42	250.88	282.24	282.24	269.70
I2 (90% E+10% GW)	332.42	370.05	401.41	294.78	349.66
I3 (80% E+20% GW)	439.04	357.50	376.32	551.94	431.20
I4 (70% E+30% GW)	602.11	495.49	633.47	595.84	581.73
I5 (60% E+40% GW)	495.49	570.75	533.12	558.21	539.39
I6 (50% E+50% GW)	464.13	595.84	501.76	451.58	503.33
I7 (100% GW)	457.86	514.30	620.93	539.39	533.12
Mean	436.35	450.69	478.46	467.71	
Interaction	Sem±		41.15		
	CD (0.05)		117.46		

Note: GW-Ground Water, E-Effluent

### Available Phosphorus

The data highlights the significant influence of both irrigation treatments (I1 to I7) and fertilizer types (F1 to F4) on the availability of phosphorus in the soil. Available phosphorus levels ranged from 9.23 kg/ha to 20.66 kg/ha. The highest available phosphorus content was observed under treatment I3 (80% E + 20% GW) and fertilizer combination of 50% NPK + 50% FYM (F4) showing the highest phosphorus content.

Overall, the results emphasize the positive impact of organic and inorganic fertilizer combinations in improving available phosphorus levels, particularly when combined with effluent irrigation treatments that incorporate a higher proportion of ground water. These findings underscore the potential of integrated nutrient management strategies to optimize phosphorus availability for agricultural production (table 5).

**Table 5. Available Phosphorus (kg ha<sup>-1</sup>) at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	9.23	12.18	10.08	10.48	10.49
I2 (90% E+10% GW)	12.89	15.16	17.68	17.03	15.69
I3 (80% E+20% GW)	9.23	12.34	17.52	20.66	14.94
I4 (70% E+30% GW)	16.93	17.88	11.12	15.86	15.45
I5 (60% E+40% GW)	19.08	14.76	18.35	18.87	17.76
I6 (50% E+50% GW)	18.66	15.60	19.19	19.64	18.27
I7 (100% GW)	12.05	9.94	11.22	12.24	11.36
Mean	14.01	13.98	15.02	16.40	
Interaction	Sem±		0.762		
	CD (0.05)		2.1769		

Note: GW-Ground Water, E-Effluent

### Available Potassium

Available potassium levels varied between 448 kg/ha and 789.60 kg/ha across the different treatment combinations. The highest mean available potassium 686.0 kg ha<sup>-1</sup> was recorded under I3 (80% E+20% GW) followed by I6 (50% E+50% GW) at 670.0 kg ha<sup>-1</sup>.

**Table 6. Available Potassium (kg ha<sup>-1</sup>) at Shreyans Industries Limited, Ludhiana, Punjab**

Treatments	F1	F2	F3	F4	Mean
I1 (100% E)	498.40	589.87	616.00	565.60	567.47
I2 (90% E+10% GW)	548.80	632.80	464.80	560.00	551.60
I3 (80% E+20% GW)	649.60	694.40	744.80	655.20	686.00
I4 (70% E+30% GW)	666.40	694.40	604.80	604.80	642.60
I5 (60% E+40% GW)	638.40	767.20	683.20	448.00	634.20
I6 (50% E+50% GW)	582.40	548.80	789.60	761.60	670.60
I7 (100% GW)	677.60	520.80	593.60	537.60	582.40
Mean	608.80	635.47	642.40	590.40	
Interaction	Sem±		36.48		
	CD (0.05)		104.10		

Note: GW-Ground Water, E-Effluent

When compared in fertilizer treatments, while the lowest was obtained under F4 (50% NPK + 50% FYM) which was realized value of 551.60 kg ha<sup>-1</sup>.

The data reveals significant variation in potassium availability depending on the combination of effluent irrigation treatments (I1 to I7) and fertilizer treatments (F1 to F4). This variation underscores the role of both irrigation and fertilizer management in optimizing potassium availability, which is crucial for plant growth and overall soil fertility (table 6).

## **Conclusion**

The impact of various irrigation treatments and fertilizer combinations on soil properties at Shreyans Industries Limited, Ludhiana, Punjab. The study identified the treatment with 60% pulp and paper mill effluent (E) and 40% ground water (GW) (I5) as the most effective for improving soil fertility and nutrient availability. This treatment significantly enhanced soil organic carbon, nitrogen, phosphorus, and potassium levels while maintaining stable soil pH and electrical conductivity (EC). The combination of effluent irrigation and organic-inorganic fertilizer application (F4: 50% NPK + 50% FYM) showed the best results for optimizing soil properties, demonstrating the potential of integrated nutrient management practices in promoting sustainable agricultural practices. This treatment not only improves soil fertility but also supports plant growth, suggesting it as a promising strategy for sustainable farming with minimal environmental impact.

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