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Potential Use of Industrial Effluents through Drip Irrigation for Crop Production and its Impact on Soil Properties

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Industrial effluents generated from various industries contains organic matter, nutrients, salts and dissolved chemicals that can significantly influence agricultural productivity and soil health. The reuse of treated effluents in agricultural through drip irrigation has emerged as a sustainable approach to address water scarcity and nutrient management in crop production. Drip irrigation provides precise and controlled application of effluent directly to root zone, thereby minimizing runoff, evaporation and environmental contamination risks. Several researches reported improvements in crop growth, yield, quality and nutrient uptake due to treated effluent application through drip irrigation. It also improves soil fertility by increasing organic matter and nutrient availability. However, continuous or untreated application may lead to salts buildup, heavy metal accumulation and land degradation. Compared to surface and sprinkler irrigation, drip irrigation reduces these risks. Therefore, proper treatment, dilution, monitoring and management are essential for safe and sustainable use of effluent in agriculture.

Key words: Industrial effluent, Drip irrigation, Crop production, fertilizer

Introduction

Industrial effluent refers to the liquid waste or wastewater discharged from industries during various processes. It often contains an organic and inorganic substances, heavy metals, oils, chemicals, dissolved and suspended solids depending on the type of industry. The characteristics of industrial effluent vary widely across industries such as distilleries, tanneries, paper mills, textile, dairy and fertilizer plants. These effluents, if untreated, can cause serious soil degradation, water and air pollution, causing adverse effects on people health and the environment. At the same time, treated effluent can be a potential resource for irrigation, as it may supply water and nutrients to crops. Proper treatment, safe disposal and reuse of industrial effluent in agriculture are emerged as viable solution of wastewater pollution and water scarcity in agriculture. Drip irrigation offers a promising method to applying industrial effluents due to its high efficiency and precision. By delivering water directly to root zone, it minimizes runoff and contamination risk.

Sources of industrial effluent and its characteristics

No.	Effluent	Characteristics
1	Sugar mill & Distillery	✓ Spent wash, molasses effluent ✓ Acidic, dark brown colour, extremely high COD, BOD and organic matter

		✓ Potential as fertigation after dilution & treatment (N & K rich)
2	Textile industry	✓ Coloured, saline, chemical-rich wastewater ✓ High TDS, colour, chlorides, surfactants, salts (NaCl, Na_2CO_3), heavy metals ✓ Limited potential after advanced treatment; saline-tolerant crops
3	Food processing industry	✓ Organic rich wastewater ✓ High BOD & COD, sugars, fats, oil, suspended solids ✓ Good nutrient source (N, P, K) enhances crop growth ✓ suitable after secondary treatment
4	Paper and pulp industry	✓ Dark coloured lignin rich effluent ✓ High suspended solids, BOD, COD ✓ Provides organic matter; can improve soil structure if diluted
5	Dairy processing industry	✓ Generated during milk reception, pasteurization. ✓ Lactose, sugars, fats, suspended solids, carbohydrates. ✓ Provides N, P, K and organic matter to soil that improves fertility
6	Sewage treatment plant	✓ Municipal sewage, industrial-mixed sewage ✓ Grey/black colour, high suspended solids, BOD/COD, pathogens ✓ Supplies nutrients, valuable in water-scarce areas, only safe after treatment (secondary + disinfection).

Scope of industrial effluent in agriculture

- Application of treated wastewater with fertilizer substitutes chemical fertilizers.
- It also increase fertilizer use efficiency and reducing losses.
- 10 - 38% increases yield when effluent use with the normal water for irrigation.
- It is act as a combine source of water and plant nutrients in crop production.
- Effluent like spent wash is also used as amendment for reclamation of sodic soils due to high calcium and magnesium concentration.
- Nutrient rich effluents also used for cultivation of bio-fertilizers like algae, spirulina, azolla.
- Effluents can support forest plantations and bio-fuel crops (Jatropha, Casuarina, Eucalyptus, Bamboo *etc*.) that are less sensitive to effluent toxicity.

Impact of industrial effluent on soil

➢ **Positive Impacts (if treated & diluted) :-**

- Adds nutrients (N, P, K, Ca, Mg) and organic matter that improves fertility.
- Organic matter enhances aggregation, porosity and water holding capacity.
- Stimulates microbial growth and enzymatic activity due to organic carbon.
- In some cases, *i.e.*, Distillery spent wash help neutralize alkaline soils.

➢ **Negative Impacts (if Untreated) :-**

- High salts (Na, Cl, SO_4) cause dispersion, soil compaction, poor infiltration and reduced permeability.
- Toxic chemicals, heavy metals and high BOD/COD suppress beneficial microbes.
- Effluents may cause excessive acidity (*i.e.* fertilizer, tannery *etc*.) or alkalinity (*i.e.* textile, paper *etc*.).
- Ground water contamination through leaching.

Impact of industrial effluent on plant

➢ **Positive Impacts (if treated & diluted) :-**

- Nutrient-rich effluents act as **liquid fertilizer**, improving plant growth and yield.

- Improved vegetative growth due to additional organic matter and micronutrients.
- Short term yield may increase with diluted effluent use.

➢ **Negative Impacts (if Untreated) :-**

- Germination inhibition due to high salts, dyes or toxic chemicals.
- Reduced root and shoot growth from soil compaction or poor aeration.
- Heavy metal accumulation in edible plant parts, enters food chain, cause health hazards.
- Long-term continuous use often reduces yield quality and contaminates produce (metal residues).

Advantages of use of industrial effluent for irrigation

- Provide additional water source in water scares region
- Supplies nutrients (N, P, K) that reduces fertilizer requirement
- Improves soil structure and microbial activity by adding organic matter
- Encourages sustainable resource use when treated properly
- Reduce cost of fertilizers, thus minimize cost of production
- Reduce soil, water and environment pollution

Disadvantages of use of industrial effluent for irrigation

- High salinity and TDS may cause soil degradation
- Heavy metals (Cr, Pb, Cd, Ni) can accumulate in soil and crops
- May reduce crop growth and yield if not manage properly
- Risk of groundwater pollution and eutrophication in surface water
- Chances of pathogen contamination in soil and plant
- High salt load may reduce seed germination

Problems rise due to industrial effluent applied through flood irrigation in crop production

- Flooding applies large volumes of effluent at once, leading to over-irrigation and leaching of salts and contaminants into groundwater.
- High salt content in effluent accumulates on the soil surface after evaporation. Which leads to soil hardening, reduced infiltration and poor aeration.
- Due to uneven distribution of effluent, results in patchy nutrient and salt distribution which harming crop growth.
- Flooding promotes rapid leaching and lateral movement of heavy metals.
- Sensitive crops suffer from salt injury and reduced germination.
- Direct exposure to effluents during flooding causes health problems for farmers.
- Required large quantity of effluent which difficult to store and handle.

Benefits of drip over other irrigation systems to use industrial effluent

- Delivers effluent **directly to root zone**, minimizing soil and crop exposure to harmful salts and chemicals.
- Allows controlled dilution of effluent with freshwater, avoiding toxicity.
- Reducing the leaching and evaporation loss which increase the absorption efficiency of nutrients and water.
- Prevents contact of effluent with crop leaves, stems and edible parts, thus safer for food crops compared to sprinkler/surface irrigation methods.
- Reduces the chances of **salinity, alkalinity and waterlogging.**
- No effluent runoff into nearby water bodies and reduces groundwater contamination compared to surface irrigation.

Effect of industrial effluent on growth and yield of crops:-

Several studies have demonstrated the beneficial effect of industrial on crop growth and yield when applied through drip irrigation system. Hassanli *et al.* (2009) reported a 56.58% increase in corn yield (12.37 t/ha) with the application of municipal effluent through subsurface drip irrigation. Similarly, Khan *et al.* (2011) observed that irrigation with textile

wastewater at 10% concentration significantly enhanced seed germination, root dry weight, shoot dry weight and total dry weight in pea, lentil and gram compared to other effluent concentrations. Further, Goncalves *et al.* (2017) reported the highest sugarcane yield when treated domestic wastewater was applied at depth of 20 cm by subsurface drip irrigation system. In Maize, Suganthi *et al.* (2019) recorded the highest total yield (14.92 t/ha), grain yield (7.1 t/ha) and water use efficiency (2.26 kg/m^3) with the application of recycled paper board mill effluent by drip irrigation. Likewise, Mahmoudi *et al.* (2020) observed the maximum okra yield (4.59 t/ha) under treated wastewater supplied through sub surface drip at depth of 15 cm.

Effect of industrial effluent on quality of crops:-

Several studies have reported improvement in crop quality parameters by application of industrial effluent through drip irrigation. The highest leaf soluble protein (36 mg/g) in banana were observed when treated paper board mill effluent was applied through drip irrigation along with 75% recommended nitrogen and potassium fertilizer (Udayasoorian and Prabhakaran, 2010). Similarly, Kumar and Chopra (2013) evaluated the effect of different effluent concentrations on okra and observed that 25% effluent resulted the highest 15% crude proteins, 23% crude carbohydrates and 44% crude fiber content. In sugarcane, Goncalves *et al.* (2017) reported significant improvements in quality parameters such as brix (21.86%), sucrose (16.96%), purity of juice (90.69%) and fiber (11.42%) when domestic wastewater applied at 20 cm soil depth through subsurface drip irrigation. Likewise, Prabhakaran (2020) observed highest ascorbic acid (9.40 mg/100 g) and β-carotene (96 µg/100 g) with application of treated paper board mill effluent in drip irrigation with 75% recommended nitrogen and potassium levels.

Effect of industrial effluent on content and uptake in crops:-

Several researchers have reported enhanced nutrient content and uptake in crops irrigated with industrial effluent through drip irrigation Umebese *et al.* (2009) found that industrial effluent application through drip irrigation over control showed significantly higher concentration of Zn (5.50 mg/L), Fe (8.37 mg/L), Mn (4 mg/L) and Ca (2.2 mg/L) in both white and red cultivar of cow pea. Similar results were also observed that various micro and heavy metal nutrients uptake reported significantly higher in application of treated wastewater through drip irrigation system as compared to fresh water in tomato crop (Demir and Sahin, 2017). In sugarcane, Goncalves *et al.* (2017) recorded significantly higher uptake of nitrogen (20.9 g/kg), potassium 12.3 g/kg) and magnesium (2.48 g/kg) with sewage wastewater application than surface reservoir water application. Prabhakaran (2020) founded that the uptake of calcium and iron by banana was significantly 78-98% higher under treated effluent irrigation through basin irrigation along with 75-100% recommended nitrogen and potassium compared to river water irrigation. Further, Hao *et al.* (2022) observed significantly higher uptake of Cu (17.7 mg/kg), Zn (53.6 mg/kg), Mn (159.1 mg/kg), Fe (1467.9 mg/kg) and B (2.56 mg/kg) in cotton under the application of 80 % RDF along with organic wastewater through drip irrigation over control.

Effect of industrial effluent on soil properties:-

Disciglio *et al.* (2015) observed that chemical properties of soil such as EC (1.05 ds/m), SAR (3.5 me/L), NO_3^- nitrogen (12.83 mg/kg), NH_4^+ nitrogen (21.2 mg/kg) and Na^+ (1039 mg/kg) increased significantly in treated agro-industrial wastewater irrigation than ground water irrigation through drip irrigation in tomato. Demir and Sahin (2017) concluded that application of treated wastewater through drip irrigation increase the concentration of Fe (18.4 mg/kg), Zn (0.67mg/kg), Cu (0.93 mg/kg). Cd (0.37 mg/kg) and Ni (2.22 mg/kg) in tomato field. Application of treated wastewater through surface and sprinkler irrigation had significantly higher accumulation of heavy metals like Cd, Pb and Ni in corn field over surface and subsurface drip irrigation and fresh water application (Khawla *et al.*, 2019). Further, Ait-Mouheb *et al.* (2022) observed significant increases in soil chemical properties

under both treated and untreated wastewater application through drip irrigation compared to fresh water irrigation and initial soil properties in lettuce cultivation. In cotton, Hao *et al.* (2022) reported that soil organic matter, available P and K, nitrate and ammonia increased significantly with increasing levels of RDF combined organic wastewater application. Similarly, Suresh *et al.* (2024) observed significant increases in soil EC (1.03 ds/m) and organic matter content (0.78%) with basal application of spent wash combined with drip irrigation in cotton field.

Conclusion

Application of treated and diluted industrial effluent have positive impact on seed germination, growth & yield attributes, quality of crop as well as increase in soil organic matter and fertility status. However, long term or improper use of untreated effluent may cause in land degradation, salinity, heavy metal accumulation and groundwater contamination. Efficiency of effluent to supply nutrient to plant can be increased by application of diluted industrial effluent through either surface or sub surface drip irrigation which can increase yield of crop along with improving post-harvest soil chemical and biological properties. Application of treated and diluted effluent up to 10 - 40 % through surface and subsurface drip irrigation system can enhance the irrigation water use efficiency with potential to substitute 20 - 50 % RDF of crops and reduced the heavy metal accumulation in soil as well as plant.

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