Performance of Bitter Gourd under Industrial Effluent Irrigation Using Matric Suction Irrigation Technique

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ABSTRACT
Water is an important natural resource, but due to industrialization and agricultural activities, there has been contamination of water resources. With the rise in the global population and climatic changes, there has been a need for sustainable water use in agriculture. Thus, reuse of treated industrial wastewater for irrigation purposes has become imperative.
The current study was carried out to determine the effect of treated paper board industry effluent in various concentrations mixed with rainwater on the growth, yield, and quality attributes of bitter gourd grown using soilless culture technique. In the study, there were five treatments consisting of rainwater irrigation (T_1), 25% effluent concentration (T_2), 50% effluent concentration (T_3), 75% effluent concentration (T_4), and 100% effluent concentration (T_5).
All the treatments were replicated five times, and each received equal fertigation dose of 100:25:25 g $N:P_2O_5$: K_2O. Results obtained from observations such as vine length, nodes per plant, leaf area, leaf area index, vine dry weight, root dry weight, fruit dry weight, and total dry weight showed no significant difference between the treatments. Quality attributes of bitter gourd fruits also revealed minor variations, which were not statistically significant. This implies that treated paperboard industrial effluents may be used as an additional irrigation source for growing bitter gourd without any harm to the yield. Nonetheless, there is a need for further studies to determine proper effluent concentrations as well as their impact on crop production.
Keywords: Paper board industry effluent, Matric suction irrigation, Fruit yield and Bitter gourd

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INTRODUCTION

The industries are key elements that contribute to the economic development of a country since they create jobs, develop infrastructure and generate income for the nation. Unfortunately, the increased growth in industries has also contributed to environmental degradation because of the pollution of soil, water, and air resources by effluents. Industrial effluents that contain harmful substances are potential hazards for both ecosystems and humans if proper measures are not undertaken (Bharagava *et al*., 2017). Many industrial sectors contribute to the pollution of the environment, but among them, the pulp and paper industries are known to be one of the most important sources of environmental pollution since they produce high-strength wastewater that contains large amounts of organic matter, suspended solids, chlorinated compounds, and other contaminants (Singh *et al*., 2019). The improper handling of these effluents or their untreated release may negatively affect the quality of soil, aquatic environments, and agriculture. Today, there is an increase in efforts that focus on the sustainable use of industrial effluents by reusing them in agriculture. This process helps conserve fresh water supplies and reduce environmental pollution (Kumar and Chopra, 2021; Sharma *et al*., 2023).

Treated wastewater has recently become a very significant option for irrigating plants because of water scarcity and growing needs of agriculture sector. Treated industrial effluent usually contains large quantities of nutrients necessary for plant development, thus, minimizing the need to use artificial fertilizers (Sahai *et al*., 1985; Mishra and Behera, 1991). The reuse of treated industrial effluent in agriculture has become a very relevant topic nowadays as far as it is considered to be one of the most effective ways of water resource management. However, the quality of industrial effluent significantly depends on the type of industry, thus, not all types of industrial effluents are applicable for agricultural purposes. Hence, the appropriate evaluation of effluents is critical in order to use them for crop irrigation. The uncontrolled application of industrial effluents may be harmful to plants and soil and cause contamination of agricultural lands. At the same time, soils have an ability to adsorb and convert some pollutants via physical, chemical, and biological mechanisms. It is known that soil microorganisms are capable of breaking down organic wastes and converting them into products beneficial to soils (Udayasoorian *et al*., 2004).

The vegetable species *Momordica charantia* L., popularly known as bitter gourd, is an important commercially grown crop whose immature fruits have a distinctive bitter taste due to their high nutritional content. Bitter gourd fruits contain vitamins, minerals, and antioxidants, especially vitamin C, at a concentration of 88 mg/100 g edible part. Apart from the nutritional value, bitter gourd possesses some medicinal uses and is used traditionally in the treatment of diabetes, asthma, blood-related diseases, and rheumatism. Naturopathy suggests bitter gourd juice consumption, whereas Ayurveda employs different bitter gourd plant parts such as roots and stems. Bitter gourd is a fast-growing climbing vine with lobed green leaves, slender stems, and yellow unisexual flowers. The crop is widely grown in Indian states like Maharashtra, Gujarat, Rajasthan, Punjab, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, West Bengal, Orissa, Assam, Uttar Pradesh, and Bihar. In view of its economic and medicinal importance, the current study was conducted to investigate the effect of treated paper board industry effluent supplemented with rainwater on the growth and yield performance of bitter gourd.

MATERIAL AND METHODS

The experiment was carried out in the levelled wasteland plot situated at the western part of the building of Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Trichy. Geographically, the experimental field is situated at latitude 10045.205’ North and longitude 78036.141’ East at an elevation of 85 meters above mean sea level.

To evaluate the effect of paper board industry effluent irrigation on growth, yield and quality characteristics of bitter gourd through soilless culture, an experiment was carried out. In this experiment, the effect of paper board industry effluent irrigation on growth and yield of bitter gourd was studied. Coirpith and vermicompost were used as growing media. The test crop of bitter gourd was grown in pots supported by pillars and wired up structure (Pandal system) along with matric suction irrigation system.

Description of matric suction irrigation

For the present experiment, bitter gourd was cultivated in growing media where water was provided through matric suction irrigation technique. The configuration of soilless container cultivation with matric suction irrigation was carried out according to the design and material previously used for open land soilless cultivation system (Kannan and Arulmozhiselvan, 2019).

Matric suction of grow bag media can be explained as the pull force of water on the surfaces of physical components of substrate such as manure, coir-pith and vermicompost. Adsorptive forces act and result in absorption of water starting from the moist region to the dry region. Water present in unsaturated medium is under the influence of adsorptive forces and creates matric potential (Ψm). In the case of unsaturated soil, Ψm is one of the crucial factors which determines the movement of water in soil. Matric suction occurs due to interaction of water with solid matrix.

Increase in the moisture level of media causes reduction in matric suction and water gets more freedom to move in the system. Matric suction of growing media is more negative than pure water (Ψ=0). In unsaturated medium, water flows from low matric suction region to high matric suction region.

Matric suction irrigation involves the technique where water is supplied continuously to the growing media using capillary action starting from the bottom upwards. In this irrigation technique, water is constantly supplied to tubs or reservoirs located at the bottom of containers used for growing media through the piping arrangement. The lower part of the containers is always submerged in water, enabling water to move up through the media by means of matric action. Since water supply in this technique is done according to the moisture needs of the media, there is no drainage of water and leaching of nutrients; hence, water and fertilizers are efficiently utilized. Continuous availability of water in the tubs ensures that optimum moisture content is maintained in the growing media throughout the crop growth cycle.

To start the experiment, 30 concrete poles were set up in the experimental field in 6 rows and 5 columns to serve as the supports for the vines to grow and spread. Beneath this support, 30 containers containing growing media were placed and connected to the matric suction irrigation system through tubing arrangement. These were administered based on the randomization design of the experiment, and the growing medium for each treatment was filled into the respective containers. The seeds of bitter gourd were planted in each container in the ratio of five seeds per container, and continuous water supply to the growing media was ensured using the matric suction irrigation system.

The details crop, variety, duration and experimental design are as follows:

Experimental details of the pandal experiment

The experiment was conducted during the Rabi season (January–July) using bitter gourd cv. Co 1 as the test crop. The study was laid out in a Completely Randomized Design (CRD) comprising five treatments and five replications. Plants were grown at a spacing of 10 ft × 10 ft within an experimental area of 5 cents. The experiment was designed to evaluate the effects of treated paperboard industry effluent applied through a matric suction irrigation system on the growth, yield, and quality attributes of bitter gourd.mThe growth medium consisted of locally available organic substrates, namely coirpith and vermicompost, blended in appropriate proportions to provide a suitable rooting environment. Five irrigation treatments were imposed, namely: T_1 - 100% rainwater (control), T_2 - 25% treated effluent + 75% rainwater, T_3 - 50% treated effluent + 50% rainwater, T_4 - 75% treated effluent + 25% rainwater, and T_5 - 100% treated paperboard industry effluent.

A separate storage tank with a capacity of 100 L was provided for each treatment to ensure independent water supply through the matric suction irrigation system. Water from the storage tanks was conveyed through 20 mm diameter drip tubes to water reservoirs positioned beneath the cultivation containers. The reservoirs maintained continuous hydraulic contact with the growth medium, facilitating water movement to the root zone through matric suction. This system enabled the crop to absorb water according to its moisture demand, thereby minimizing water stress and reducing evaporation losses. The water level in each tank was monitored daily using a graduated scale. Water consumption was determined based on the reduction in water level between consecutive observations and the known cross-sectional area of the tank. Treatment solutions were prepared and replenished weekly to maintain the prescribed effluent-to-rainwater ratios throughout the experimental period. Crop growth, yield, water use, and quality parameters were recorded at regular intervals and at harvest to assess the suitability of treated paperboard industry effluent for irrigation under matric suction conditions.

Fertilization for bitter gourd in soilless system

Fertilizer composition for fertigation was formulated taking into consideration the nutrient requirement of bitter gourd for its proper growth and development. The fertilizer requirement of the plant for N, P2O5, and K2O is 200:100:100 kg ha-1, respectively. However, since there is no fixation of phosphorus and potassium nutrients in the soilless culture method, only 50% of their respective dosages were considered. Thus, the fertigation schedule was formulated to give 200:50:50 kg ha-1 of N, P2O5, and K2O. Nutrient requirement for each planting container was then computed using the number of plants per hectare and fixed to be 100:25:25 g of N, P2O5, and K2O.

Observations were made on growth and yield attributes of bitter gourd grown under various irrigation treatments. Growth characters like vine length, number of nodes per plant, leaf area, leaf area index, vine dry weight, root dry weight, fruit dry weight, and dry matter production were measured. On the other hand, some of the yield characters like fruit length, fruit girth, individual fruit weight, and fruit yield per pot were observed and recorded.

RESULTS AND DISCUSSION

Characteristics of treated effluent water used for soilless culture experiment

The treated effluent derived from TNPL-II paper board industries was found to be colourless with a slightly alkaline nature having a pH of 8.0 (Table 1). The alkalinity of the effluent might be due to the use of chemicals during the process of pulping and bleaching such as caustic soda and hydrogen peroxide. The value of electrical conductivity (EC) of the effluent was determined to be 2.65 dS m^{-1}, revealing that the effluent contained some amount of dissolved salts. The total dissolved solids (TDS) were found to be 1680 mg L^{-1}, which is less than the maximum permissible limit of 2100 mg L^{-1} fixed by the Central Pollution Control Board (CPCB), making it suitable for irrigation purpose. The suspended solids concentration was 82 mg L^{-1}, which may be attributed to the presence of cellulose fibres, fillers, and residual chemical additives commonly used in paper manufacturing processes. These constituents contribute significantly to the solid load in paper mill effluents and can adversely affect water quality if discharged without adequate treatment (Singh *et al*., 2024; Sharma *et al*., 2014).

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the treated wastewater were found to be 30 mg L^{-1} and 92 mg L^{-1}, respectively. The BOD and COD values indicate the presence of biodegradable organic matter and residual chemicals originating from the paper manufacturing process (Tripathi et al., 2014; Kuzhali et al., 2012; Singh et al., 2024). Nutrient analysis of the effluent revealed appreciable concentrations of nitrogen (15.2 mg L^{-1}), phosphorus (1.3 mg L^{-1}), and potassium (12.7 mg L^{-1}). These nutrients may contribute to crop growth and can be beneficial when treated effluent is utilized for irrigation, provided that its quality complies with environmental and agricultural standards (Singh et al., 2024).

Sodium (616 mg L^{-1}) was the most abundant cation in the treated effluent. Calcium and magnesium were present at concentrations of 140 mg L^{-1} and 9.6 mg L^{-1}, respectively. Among the anions, bicarbonates (451 mg L^{-1}), chlorides (213 mg L^{-1}), sulphates (242 mg L^{-1}), and carbonates (24 mg L^{-1}) were detected. The elevated concentrations of these ions are primarily attributed to the chemicals used during pulping, bleaching, and paper manufacturing processes, which contribute significantly to the ionic composition of paper mill effluents (Birjandi et al., 2014; Suriyanarayanan et al., 2010; Kaur et al., 2023; Singh et al., 2024).

The irrigation water quality parameters, including Soluble Sodium Percentage (SSP), Sodium Adsorption Ratio (SAR), and Residual Sodium Carbonate (RSC), were within acceptable limits. The RSC and SAR values were 0.4 meq L^{-1} and 13.5, respectively. Furthermore, pH, electrical conductivity (EC), total dissolved solids (TDS), biochemical oxygen demand (BOD), chloride, and sulphate concentrations were within the permissible limits prescribed for treated industrial wastewater reuse. These findings suggest that the treated effluent may be suitable for irrigation purposes, subject to periodic monitoring of soil and crop responses (Kaur et al., 2023; Kumar et al., 2024).

Characteristics of media used in soilless culture experiment

The physical and chemical properties of the growing media substrates are summarized in Table 2. The bulk density of raw coirpith was relatively low (0.11 Mg m^{-3}), while vermicompost registered relatively high bulk density (0.59 Mg m^{-3}). Coirpith had extremely high water holding capacity of 426%, while vermicompost had comparatively low water retention capacity ranging from 45 to 60%. The pH of coirpith and vermicompost was 6.49 and 7.46, respectively, indicating that both substrates had suitable pH levels for crop growth.

The electrical conductivity (EC) of coirpith was relatively high (8.53 dS m^{-1}) compared to vermicompost (1.86 dS m^{-1}). This is reflected in the TDS, where coirpith recorded high TDS level (4296 mg L^{-1}), while vermicompost had relatively low TDS (886 mg L^{-1}). The organic carbon content in coirpith (28.56%) was relatively high compared to vermicompost (15.5%). The C:N ratio was relatively high in coirpith (98.30), while vermicompost had relatively low C:N ratio (10.19).

Concerning the nutrient content, vermicompost had more total nitrogen (1.52%) and phosphorus (0.77%), whereas coirpith had lesser amounts of nitrogen (0.26%) and phosphorus (0.06%). On the other hand, there was more potassium in coirpith (1.38%) than vermicompost (1.20%). The higher levels of secondary nutrients in vermicompost included calcium (5.42 g kg^{-1}), magnesium (2.65 g kg^{-1}), and sulphur (1.29 g kg^{-1}). Furthermore, there were higher amounts of micronutrients like iron (172 mg kg^{-1}), manganese (225 mg kg^{-1}), zinc (109 mg kg^{-1}), and copper (78 mg kg^{-1}) in vermicompost compared to coirpith.

The improved nutrient content and favorable characteristics of vermicompost may be attributed to the intense microbial activity and earthworm-mediated decomposition processes involved in vermicomposting. These processes facilitate the stabilization of organic matter, enhance nutrient mineralization, and increase the availability of essential plant nutrients. Significant changes in physicochemical properties such as bulk density, water-holding capacity, pH, electrical conductivity (EC), nutrient content, and C:N ratio during vermicomposting have been widely reported (Suresh and Ganesh, 2012; Kumar et al., 2023; Singh et al., 2024).

Effect of paper board industry effluent on growth and growth attributes of bitter gourd

The effect of effluent from the paper board industry on the growth characteristics of bitter gourd was analyzed during harvest. These included measurements of vine length (Fig. 1), number of nodes per plant (Fig. 2), total leaf area (Fig. 3), leaf area index (Fig. 4), vine dry weight, root dry weight, fruit dry weight, and total dry weight (Table 4). Vine length varied from 434.5 cm to 435.5 cm with an average of 434.8 cm. Number of nodes per plant varied from 120.3 to 121.1 with an average of 120.7. Total leaf area varied from 3458.01 to 3458.25 cm^2 with an average of 3458.13 cm^2. Leaf area index was from 1.230 to 1.239 with an average of 1.235. Similarly, vine dry weight, root dry weight, fruit dry weight, and total dry weight were from 1.25 to 1.65 g, 2.02 to 2.74 g, 3.02 to 3.76 g, and 6.29 to 8.15 g, respectively.

Although there were slight differences between the values in the different treatments, statistical analyses did not show any significant difference. The plants watered with treated effluent exhibited similar results compared to those irrigated with rainwater, suggesting that even 100% treated effluent (T_5) did not have any negative impact on the growth of crops as compared to the control treatment (T_1). This could be due to the consistent fertigation schedule followed for all the treatments, where 100:25:25 g of N, P_2O_5, and K_2O was used, thus ensuring sufficient nutrient availability during the crop growth period.

The presence of potassium in the fertigation schedule may have played a significant role in plant growth due to its essential functions in nutrient transport, carbohydrate (sugar) translocation, maintenance of cell turgidity, and stimulation of meristematic activity. Similar findings were reported by Singh et al. (2020), who observed enhanced growth and yield of bitter gourd with the application of treated sewage effluent combined with microbial inoculants. Recent studies have further confirmed that nutrient-rich treated wastewater and potassium availability can improve crop physiological performance, biomass production, and yield attributes under fertigation systems (Kumar et al., 2023; Sharma et al., 2024; Patel et al., 2025).

Effect of paper board industry effluent on yield and yield attributes of bitter gourd

The impact of the effluent from paper board industry on yield and yield attributes of bitter gourd was assessed during harvesting (Table 4). The recorded fruit length was found between 23.1 and 24.5 cm with a mean of 23.9 cm, and fruit girth was measured between 11.5 and 12.8 cm with a mean value of 12.4 cm. Number of fruits per plant was found between 12.0 and 15.5 with a mean value of 14.1 fruits per plant. Fruit weight was recorded between 104.54 and 106.25 g with a mean value of 104.93 g, and fruit yield was measured between 2.34 and 2.85 kg pot^{-1} with a mean yield of 2.57 kg pot^{-1}.

It was evident that there was a little variation among treatments regarding yield and yield attributes, but these were statistically insignificant. It was revealed that the performance of the plant grown by applying treated effluent was similar to that grown by applying rainwater irrigation. This indicates that the use of 100% treated effluent (T_5) does not have any negative impact on the yield of the crop when compared to the control treatment (T_1). This might be due to the consistent fertigation regimen used for all the treatments where the plants received 100:25:25 g of N, P_2O_5, and K_2O, respectively, ensuring sufficient supply of nutrients during the whole growth cycle of the plants.

Phosphorus and nitrogen nutrients play a crucial role in flower initiation and fruit development. Phosphorus availability promotes flower formation, while nitrogen supports vegetative growth and overall plant vigor without adversely affecting the reproductive phase when maintained at optimum levels. The improved flower and fruit formation observed under treated effluent irrigation may be attributed to the presence of essential nutrients such as phosphorus and potassium in the effluents. In addition, micronutrients such as potassium, iron, magnesium, and manganese are essential for chlorophyll synthesis, enzyme activation, and photosynthetic efficiency, thereby enhancing crop productivity. Similar observations were reported by Singh et al. (2020). The findings are also supported by Akhther et al. (2021), who reported improved growth performance of *Brassica nigra* under treated contaminated soil conditions. Recent studies have further confirmed that nutrient-enriched wastewater irrigation enhances flowering, fruit set, and yield attributes through improved nutrient uptake and physiological efficiency in crops (Kumar et al., 2023; Sharma et al., 2024; Singh et al., 2025).

CONCLUSION

The results obtained from the current soilless cultivation experiment revealed that the use of treated paper board industry effluent at varying concentrations alone or in combination with rainwater did not have any adverse effect on the growth, yield, and quality of bitter gourd. There were only slight differences observed in growth factors, yield factors, and quality factors; however, the differences were statistically insignificant. The performance of plants grown through irrigation by using treated effluent was similar to those grown by using rainwater.

It is concluded that treated paper board industry effluent can be used as an alternative water source for irrigation. The effluent also contains nutrients that can help plants grow without requiring freshwater or fertilizers. The use of matric suction irrigation along with proper growing media made sure that the optimum amount of nutrients and water was available to the plants.

Nonetheless, additional research needs to be conducted in order to identify the optimal concentration of effluent for irrigation, as well as the ongoing effects of such irrigation on crop yield, characteristics of the growth medium, and environmental safety.

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Table 1. Characteristics of treated effluent water used for soilless culture experiment

Particulars	**Characteristics**
Colour	Colourless
pH	8.00
EC (dS m-1)	2.65
TDS (mg L-1)	1680
TSS (mg L-1)	82
BOD (mg L-1)	30
COD (mg L-1)	92
Nitrogen (mg L-1)	15.2
Phosphorus (mg L-1)	1.3
Potassium (mg L-1)	12.7
Calcium (mg L-1)	140
Sulphate (mg L-1)	242
Magnesium (mg L-1)	9.6
Carbonate (mg L-1)	24
Bicarbonate (mg L-1)	451
Sodium (mg L-1)	616
Chloride (mg L-1)	213
RSC (meq L-1)	0.4
SAR	13.5

Table 2. Characteristics of substrates used for soilless culture experiment

Media	**pH**	**BD (Mg**	**WHC (%)**	**EC (dS**	**TDS**	**OC (%)**	**Total Nutrients (%)**	**Secondary nutrients (g kg-1)**	**Micronutrients (mg kg-1)**	**C/N Rat**

		m-3)		m-1)			N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	io
Vermicompost	7.46	0.59	254	1.86	886	15.5	1.52	0.77	1.20	5.42	2.65	1.29	172.6	225.4	109.2	78.24	10.19
Coir pith	6.49	0.11	426	8.53	4296	28.56	0.26	0.06	1.38	3.25	0.98	0.56	152.5	185.5	98.4	65.4	98.30

Table 3. Effect of paper board industry effluent on yield and yield attributes

Treatments	**Fruit length (cm)**	**Fruit girth (cm)**	**No. of fruits/vine**	**Fruit weight (g)**	**Fruit Yield (kg/pot)**
T1 – Rain water irrigation	23.1	11.5	12.0	105.25	2.34
T2 – 25% Effluent concentration	24.3	12.8	15.0	104.54	2.65
T3 – 50% Effluent concentration	24.5	13.1	15.5	106.25	2.85
T4 – 75% Effluent concentration	24.1	12.5	14.5	103.25	2.54
T5 – 100% Effluent concentration	23.5	12.1	13.5	105.35	2.49
Mean	23.9	12.4	14.1	104.93	2.57
SEd	0.40	0.01	0.20	1.64	0.02
CD=0.05	0.86	0.37	0.44	NS 3.51	0.06

Table 4. Effect of paper board industry effluent on dry matter production (DMP) of bitter gourd

Treatments	**Vine dry weight (g)**	**Root dry weight (g)**	**Fruit dry weight (g)**	**Total dry weight (g)**
T1 – Rain water irrigation	1.25	2.02	3.02	6.29
T2 – 25% Effluent concentration	1.54	2.65	3.52	7.71
T3 – 50% Effluent concentration	1.65	2.74	3.76	8.15
T4 – 75% Effluent concentration	1.47	2.45	3.46	7.38
T5 – 100% Effluent concentration	1.32	2.35	3.38	7.05
Mean	1.45	2.44	3.43	7.32
SEd	0.02	0.03	0.05	0.07
CD=0.05	0.04	0.07	0.11	0.24

Fig 1. Effect of paper board industry effluent on vine length (cm)

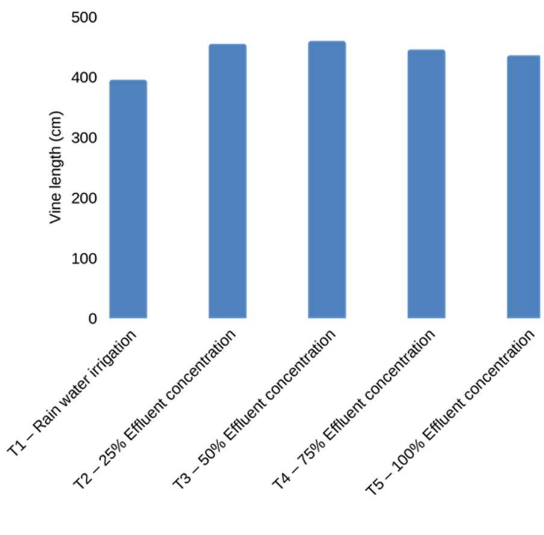


Fig 2. Effect of paper board industry effluent on number nodes per plant

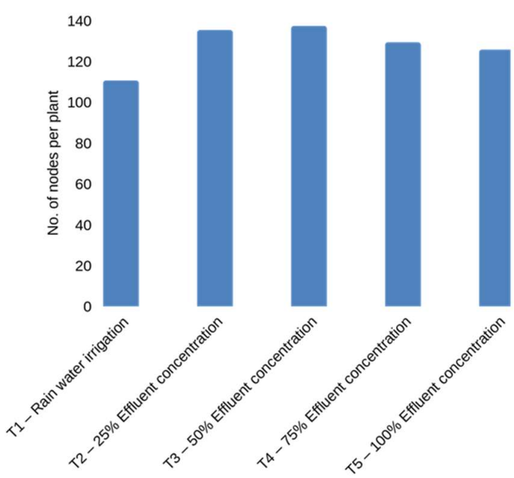


Fig 3. Effect of paper board industry effluent on total leaf area (cm2)

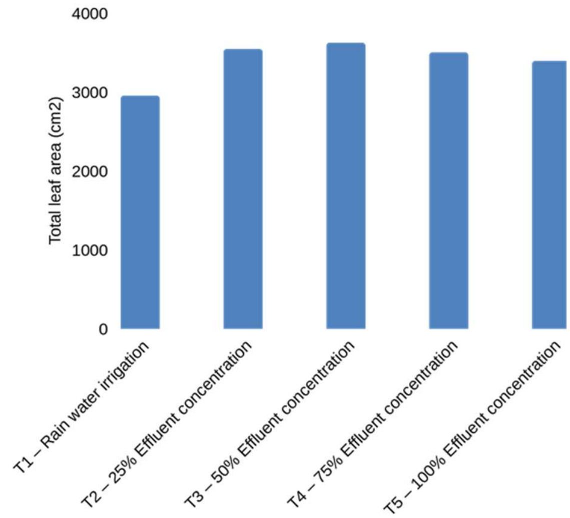
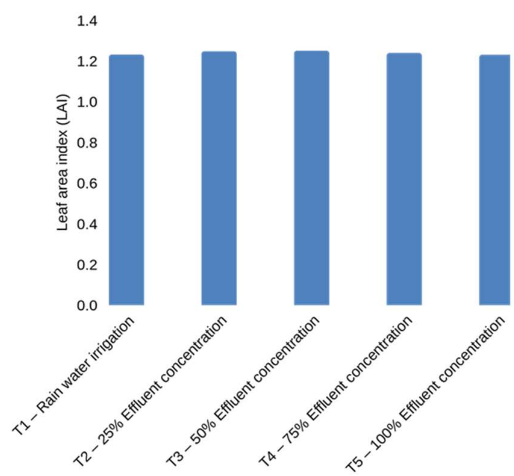


Fig 4. Effect of paper board industry effluent on Leaf area index (LAI)



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