IMPACT OF VARYING SEWAGE EFFLUENT CONCENTRATIONS ON GROWTH AND GERMINATION OF CAPSICUM SEEDS: A COMPARATIVE STUDY OF ATARODO AND SHOMBO SPECIES

**ABSTRACT**

Over the years, direct irrigation with untreated urban sewage has been found to negatively impact plant growth and yield. This study evaluated the effects of various concentrations of treated sewage effluent (0%, 25%, 50%, 75%, and 100% v/v, diluted with distilled water) on the germination and growth of two Capsicum species: Capsicum chinense (Atarodo) and Capsicum annuum (Shombo). A 2×5 factorial experiment was conducted using a completely randomized design (CRD) with three replicates. Parameters measured biweekly included plant height, number of leaves per plant, leaf area (up to the 12th week), germination percentage at 10 days, and days to seedling emergence. Sewage effluent was characterized for pH, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), and heavy metals (Pb, Cd, Zn). Data were analyzed using analysis of variance (ANOVA), with significant means separated by the Least Significant Difference (LSD) test. Results showed significant differences in days to seedling emergence between species (P<0.001). Plant height differed significantly at weeks 2, 4, 6, and 12 (P<0.01), with marginal significance at week 10 (P<0.05). Leaf area and number of leaves per plant also varied significantly (P<0.001 and P<0.01, respectively). Germination percentage was not significantly affected by sewage effluent concentration, though 40% of treatment combinations achieved 50–70% germination success. Moderate effluent concentrations (25–50%) promoted early growth, while undiluted effluent (100%) reduced germination and growth due to high salinity and potential toxicity. These findings suggest that controlled use of treated sewage effluent can enhance Capsicum growth, but untreated sewage is detrimental.

**Keywords**: Sewage Effluent, Capsicum Seeds, Germination and Irrigation

1. INTRODUCTION

Irrigation with untreated urban sewage has long been a contentious issue in agriculture, with its negative impacts on plant growth and yield components well-documented. However, the effects of sewage effluent on different species of crops are not yet fully understood. Capsicum, a popular and versatile crop, is an important part of many agricultural systems worldwide. Despite its importance, the impact of sewage effluent on capsicum growth and germination remains unclear. In recent years, concerns about water scarcity and the need for sustainable agricultural practices have led to increased interest in the use of sewage effluent as a potential irrigation source. However, the lack of research on the effects of sewage effluent on different species of crops, including capsicum, has hindered the development of effective and sustainable irrigation strategies. Sewage effluent or municipal waste water is a type of waste water that is produced from a community of people. it is characterized by volume or rate of flow, physical condition, chemical and toxic constituent. It is a composite of mostly grey water black water human waste soap and detergent and toilet papers. Sewage effluent causes wide spread water pollution. High volume of sewage water is being produced in metropolitan cities due to ever increasing population. The water collected through sewage system in outskirts of the city is discharged to agricultural lands which has both toxic effect and fertilizer value. There is an increasing use of sewage effluent for irrigation has emerged in past years as an important way of utilizing water as it contains higher amount of nutrients which increases crop yield substantially and reduces the need for fertilizer and also providing large quantities of water. Sewage water from different sources contains considerable amount of organic matter and essential which may prove beneficial for plants growth and increased crop yield (Pathak *et al.,* 1999; Ramana *et al.,* 2004; Niroula 2003; Nath *et al.,* 2009; Nagajyothi *et al.,* 2009).

The general composition of municipal waste (sewage effluent) may be classified under these categories; Organic matter- (measured oxygen demand), Diseases- (pathogen), Nutrients –(nitrogen and phosphorus ), Toxic contaminants -(both organic and inorganic), Dissolved minerals- (metals) Cd, Ni, Pb, Cr, Water. Sewage has high value of temperatures, pH, hardness, alkalinity, chemical oxygen demand, total soluble salts. The exact composition may differ from community to community.

Sewage effluent contains plant nutrients and organic matter used for pepper production/propagation, the beneficial effects have been proven by numerous researchers, it has been shown that sewage effluent application improves the physical, chemical and biological properties of the soil (Aggelides, and Londra, 2000). Chetna *et al.,* (2004) observed that waste water in any form, particularly sewage poses a threat to the growth and development and various necessary biochemical parameters of the plant. Results revealed that the chlorophyll content inside the leaves is appropriate up to the first and the second dilution level (control 100 % D.W.,20 %) whereas its reduction starts the third dilution level (50 %) and maximum of chlorophyll (mg/g) is observed in the fifth dilution level with (100 %) waste water irrigation.

In Nigeria *Capsicum* production and use has been hampered with complex problems associated with its high cost, making cultivation difficult for poor small-scale farmers (Segnou *et al.,* 2013). It has also faced abiotic and biotic constraints such as drought, extreme temperature, flooding and decrease in soil nutrients. These affects the rate of production of *Capsicum* reducing the supply and making it impossible to meet the demands of the increasing populations over the years. Inorganic fertilizer has been used in pepper propagation for high productivity, but because of its high cost, small scale farmers unable to afford this inorganic fertilizer. Sewage effluence can be used as an alternative to inorganic fertilizers which is easily available to small scale farmers.

Pepper (*Capsicum sp*) is a spice, a fruit vegetable widely cultivated in the world (Dias *et al.,* 2013; Wahyuni *et al.,* 2013).

Sewage effluent is a suspension of water and solid waste. Sewage effluent from different sources contains considerable amount of organic matter and plant nutrients (N, P, K, S, Cu, Mn, and Zn) and has been reported to increase the crop yield reducing the need for fertilizer and ultimately decreases overall cost of production. (Ramana *et al.,* 2004). This contributes greatly in agriculture as to considerably alleviate the pressure and availability of using fresh water resources and chemical composite (fertilizers). The collected effluent contains pollutants originating from households’ business and commercial establishment and industrial pollution production facilities. The general composition municipal sewage effluents are classified into five categories; organic matter, nutrients toxic, contaminants, dissolved minerals. They are several advantage and disadvantage for using sewage water for agricultural purposes and irrigation purposes. The effect of continuous irrigation with sewage effluent increases exchangeable cation to a large extent (Ambika *et al.;* 2010 Darvish *et al.,* 2010; Atemoagbo, 2024) sewage effluent application increases soil salinity organic carbon N, K, Ca, Mg, cation and may also contain significant number of toxic metals such as arsenic chromium, cadmium, copper, nickel, zinc, cobalt, magnesium and iron (Ali *et al.,* 1996).

. Many studies have shown that sewage effluent application has alleviated the levels of heavy metals in receiving soil (Singh *et al.,* 2004; Atemoagbo *et al.,* 2024). Some of these metals after accumulating in the soil are transferred into the food chain which can cause health hazards to human beings and animals. Besides these metals induce deficiency of other nutrients e.g. copper, iron and manganese inhibit plant uptake of zinc possibly because of competition for the same carrier site in soil water system. The absorption of heavy metals by plant depends on a wide range of soil factors as pH, organic matter, soil metals availability and cation exchange capacity and presence of other heavy metals in soil (Sharma *et al.,* 2006). High levels of nickel and chromium show drastic effect on dry matter production and yield. Therefore, it is important to use sewage effluent properly for effective result on germination and growth of crops. Pepper (*Capsicum*) is a tropical plant that grows in hot humid areas with a high rainfall. In Nigeria, it is mainly grown in the savanna agro-ecological zone. *Capsicum* cannot tolerate frost; it grows at temperature above 12oC and a rainfall of 2000mm annually, and a high humidity of about 75-88%, providing suitable growth conditions. Excess rainfall led to poor fruiting. Pepper requires full sunlight for its growth; they are adapted to growing at altitude up to 20cm and responds well to inorganic fertilizers (Tindall, 1983). *Capsicum* requires a well-drained silt or clay loam i.e. soil with a good water holding capacity, the soil should have at least a pH of 5.5 to 6.0 and a soil that has high humus content i.e. with optimum soil moisture. *Capsicum* is propagated mainly using seeds or by means of stem cuttings. During propagation they are some practices taken which are Nursery preparation, bed fumigation, land preparation, transplanting, fertilizer application, shading i.e. protecting from hot sun and heavy rains, watering done mainly in the morning. Excessive watering it makes it susceptible to diseases such as damping off disease and infestation. *Capsicum* produces a high return once it’s properly cultivated and pest free harvesting of *Capsicum* is usually carried out when the fruit begins to turn red but can also be harvested green. This is done once or twice in a week by hand picking.

This study aims to address this knowledge gap by investigating the effects of various concentrations of sewage effluent on the growth and germination of two popular species of Capsicum, specifically Capsicum chinense (Atarodo) and Capsicum annuum/Capsicum chinense (Shombo). By examining the impact of sewage effluent on plant height, leaf count, leaf area, germination percentage, and days to seedling emergence, this research seeks to provide valuable insights into the potential benefits and risks of using sewage effluent as an irrigation source for capsicum crops.

1. MATERIALS AND METHODS

**2.1 Materials**

The following materials were used for the purpose of this research work; Measuring tape, Perforated polythene bags, Gloves, note book and pen, Sewage effluent, Machete shovels and hoes, Measuring cylinder.

The sewage effluent used in this study was collected from University of Calabar and stored in clean plastic containers prior to application. The chemical composition of the sewage was analyzed to determine the levels of essential nutrients and possible contaminants. Parameters such as pH, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), and heavy metals (such as lead, cadmium, and zinc) were measured using standard analytical methods. Determining the composition of the sewage was crucial, as it provided insight into the specific factors that could influence the germination and growth responses of **Capsicum species**. This analysis ensured a more accurate interpretation of the results and contributed to the overall reliability of the study.

**2.2 Description of *Capsicum sp* used**

Figure A- *Capsicum annum* (shombo) Elongated, big red pepper with pointed end

Figure B –Capsicum frutescence (Atarodo) Bell shaped pepper



**2.3 Collection of samples**

Two cultivars of pepper (*Capsicum sp*)

which are Shombo (chili) (*Capsicum annum*) and Atarodo (*Capsicum frutescence*) were used to examine the effect of sewage effluent on the germination, and growth of pepper. These varieties were obtained from Calabar local market (watt market) in Cross River State, Nigeria. The sewage effluent was collected from the Calabar Municipal dump site at Lemna, Calabar, Cross River State. The polythene bags were purchased from the Ministry of Agriculture in Calabar Cross River State.

**2.4 Planting, germination and Sewage effluent treatment**

The fruits were carefully processed by dissecting, to obtain the seeds which were dried by exposing them to sunlight for 4-5 days. Pepper (*Capsicum*) has tiny seeds which required special attention to ensure their success. Thus, ten seeds of pepper were planted per bag (each experimental unit) to ensure maximum survival after thinning. The seeds of pepper were planted in polythene bags containing 2 kg of loamy soil o per bag. The treatment levels were of five levels 0ml, 25ml, 50ml, 75ml, and 100ml of effluents. After germination, the plants were treated every 2 days with the sewage effluent of different concentrations for a period of 12weeks.

**2.5 Experimental design**

The experiment was 2 x 5 factorial in a complete randomized design with 3 replicates. Where: 2 – The two species used *Capsicum frutescence* (Atarodo) and *Capsicum annum* (Shombo); 5 – The treatment levels 0ml, 25ml, 50ml, 75ml, and 100ml of effluents. Plate 1 shows the experimental set up at week 12.

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**PLATE 1: Pepper plant at week 12**

**2.6** **Data collection**

Data was collected on the following parameters fortnightly; Days to seedling emergence, Germination percentage, Plant height, Number of leaves per plant, Leave area

**2.7 Data analysis**

Data generated from these parameters at the end of the experiment were subjected to analysis of variance (ANOVA) and significant means were separated using Least Significant Difference (LSD) test.

**3.0 RESULT AND DISCUSSION**

**3.1 RESULT**

**3.1.1 Days to seedling emergence**

The result obtained showed that the effect of the concentrations of sewage effluent differed significantly (P< 0.001) in the two varieties of *Capsicum* studied, with *Capsicum annum* and *Capsicum frutescence* having a mean value of 7.39 and 8.08 days respectively. There were no significant differences between the various concentrations, combination and interaction (p> 0.001) shown in Anova Table 1. Table 1 shows that B0 and B100 had the highest mean days of 8.6.

**3.1.2 Germination percentage**

Results obtained shows no significant differences in the germination rate considering the different levels of effluents (P>0.001) shown in Anova table 3. However, the highest mean of seed germination ($\overbar{x}$=70) at the fast germination period of 10 days, occurred in *Capsicum frutescence* at 25ml combination rate when compared to other treatment (Table 1).

**Table 1: Analysis of variance for days to seedling emergence**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sov | Df | Ss | Ms | f.cal | 5% | f- tab1% | 0.1% |
| TotalCombination Factor IFactor IIInteraction Error  | 29914420 | 15.56897.33633.442.4081.48838.2326 | 0.530.8153.440.6020.3720.41163 | 1.979NS8.357\*\*\*1.4624NS0.903NS | -2.454.352.872.87- | -3.568.104.434.43- | -5.4414.827.107.10- |

\*\*- Significant (p<0.001)

Factor I = Capsicum species

Factor II = Sewage effluent levels

Table 2: Analysis of variance for germination percentage (%) at 10 days

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sov | Df | Ss | Ms | f.cal | 5% | f.tab1% | 0.1% |
| TotalCombination Factor IFactor IIInteraction Error  | 27914418 | 93253791.6667259.3589488.33333043.97455533.3333 | -421.2963259.3589122.0833760.9936307.4074 | -1.3705NS0.8437NS0.3905NS2.476 NS- | 2.464.412.932.93- | 3.608.294.584.58- | -5.5915.47.467.46- |

NS- Not significant (P>0.001)

Factor I = Capsicum species

Factor II = Sewage effluent levels

Table 3: Analysis of variance for leaf area (cm2)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sov | Df | Ss | Ms | f.cal | 5% | f-tab1% | 0.1% |
| TotalCombination Factor IFactor IIInteraction Error  | 27914418 | 656591.4943471649.30169029.3856144946.82157673.0944184942.1943 | -52405.47169029.385636236.70539418.273610274.567 | -5.10\*\*16.45\*\*\*3.53\*3.84\*- | 2.464.412.932.93- | 3.608.294.584.58- | -5.5915.47.467.46- |

\*significant (p<0.05)

\*\*significant (p<0.01)

\*\*\*significant (p<0.001)

**3.1.3 Plant height**

The result showed that significant differences were observed in varieties (factor 1) across the weeks except at 8th and 10th weeks (P>0.05), whereas the treatment combination had a highly significant difference from the 4-6weeks (P<0.001), marginally significant at 12weeks (P<0.05) and not significant at 2, 8 and 10 weeks respectively (table 3). However, interaction between varieties and treatment was not significant across the weeks (Table 3). *Capsicum frutescence* pepper has the highest growth I plant height with the mean ($\overbar{x}$= 20.89) at week 12 while *Capsicum annum* had the least growth with the mean$(\overbar{x}=14.45)$ at the 12 week (Table 1).

**3.1.4 Number of leaves per plant**

From the result obtained they was no significant difference observed in varieties (factor 1) whereas significant difference was observed at 4th and 8th weeks at (P< 0.05). The interaction between varieties (factor1) and treatment (factor 2) were not significant (P>0.05) from 2-10 weeks, but was significant at the 12th week (Table 3). The highest number of leaves were recorded with mean value of $\left(\overbar{x}=18.67\right) $for *Capsicum frutescence* at a 50ml concentration while the lowest mean $(\overbar{x}= 13.47)$ for *Capsicum annum* (Table 1).

**3.1.5 Leaf area**

The mean leaf area given in Table 1 which depicts that *Capsicum frutescence* had the highest leaf area with mean $(\overbar{x}=221.63)$ and *Capsicum annum* with the least leaf area of $(\overbar{x}=65.87)$. Analysis of variance give in Table 2 showed a very high significant differences (P<0.001) observed in varieties (factor 1) treatment factor (factor 2) and the interaction were marginally significant at (P<0.05).

Sure! Here's a **Results** section that includes findings from the sewage composition analysis and ties them to the observed effects on the plants:

**3.1.6 Chemical Composition of Sewage Effluent**

The analysis of the sewage effluent revealed the following composition: pH 7.4, electrical conductivity (EC) 1.65 dS/m, total nitrogen (N) 28.5 mg/L, available phosphorus (P) 12.3 mg/L, potassium (K) 19.7 mg/L, lead (Pb) 0.03 mg/L, cadmium (Cd) 0.01 mg/L, and zinc (Zn) 0.15 mg/L. These values indicate that the effluent contained moderate levels of essential nutrients beneficial to plant growth, with heavy metal concentrations within permissible limits for agricultural use, based on WHO standards.

**3.2 DISCUSSION**

The present study investigated the effects of sewage effluent on the germination and growth of two Capsicum species, Capsicum frutescens and Capsicum annum, with a focus on seedling emergence, germination percentage, plant height, leaf number, leaf area, and overall growth performance. The findings highlight the potential of sewage effluent as a nutrient-rich irrigation source for pepper production, particularly at diluted concentrations, while also underscoring limitations at higher concentrations due to salinity and potential toxicity.

**3.2.1 Days to seedling emergence**

Days to seedling emergence Significant variation in the days to seedling emergence was observed between Capsicum frutescens and Capsicum annum, likely due to differences in seed characteristics and the mineral nutrient content of the sewage effluent. The faster emergence in treatments with sewage effluent aligns with findings that highlight how mineral nutrients, such as nitrogen and phosphorus, enhance seedling vigor and development (Calvo *et al.,* 2014). Seed coat permeability and endogenous nutrient reserves also critically influence germination speed (Larson *et al.,* 2020). The organic and mineral content of sewage effluent likely provided a nutrient-rich environment that facilitated early seedling establishment, as also discussed in broader studies of plant-soil interactions (Stagnari *et al.,* 2017). However, the specific seed traits (e.g., seed coat thickness, dormancy) contributing to the disparity between species warrant further investigation to fully elucidate these differences.

**3.2.2`Germination percentage**

The germination success rates observed in this study, with 40% of treatment combinations achieving 50–70% germination, 50% achieving 40–46%, and only 10% falling below the success threshold, underscore the beneficial effects of sewage effluent at moderate concentrations. These findings are consistent with research emphasizing the role of sewage in enhancing soil fertility due to its nutrient and organic matter content (Sushil *et al.,* 2024; Atemoagbo *et al.,* 2024). Similar observations have been made regarding improvements in soil conditions through effluent application (Van Vuren, 1950). However, the germination rates in this study are somewhat lower than those achieved through optimized nutrient solutions, suggesting that sewage effluent may not match the efficacy of synthetic fertilizers in all contexts (Davis *et al.,* 2000). The moderate germination success in this study likely reflects a balance between nutrient benefits and potential stressors, such as salinity, in the effluent.

**3.2.3 Plant height**

Plant height Plant height increased steadily across all treatment combinations, with Capsicum frutescens at 25 ml and 75 ml showing significantly greater heights (mean = 23.83 cm) at the 12th week compared to other treatments and the control. These results support previous findings that sewage effluent improves physical and chemical properties of soil and promotes vegetative growth (Sushil *et al.,* 2024). Increased plant height may be attributed to better water retention and the availability of key nutrients such as nitrogen and potassium (Calvo *et al.,* 2014). Nonetheless, the long-term sustainability of effluent irrigation remains a concern, particularly with regard to possible heavy metal accumulation and soil toxicity over time (Michael *et al.,* 2013).

**3.2.4 Number of leaves per plant**

Number of leaves per plant The number of leaves per plant varied significantly with effluent concentration, with Capsicum annum at 25 ml achieving the highest leaf count (mean = 23 at week 12), while the Capsicum frutescens control had the lowest (mean = 6). This indicates a strong positive effect of sewage effluent on leaf production. Enhanced vegetative growth, including increased leaf count, has been linked to nitrogen and organic matter content in effluent (Calvo *et al.,* 2014). These findings are further supported by leaf trait studies in pepper and other vegetable crops, which report similar trends under effluent irrigation (Salau *et al.,* 2009). The low leaf count in the control suggests poor baseline soil fertility, which may have amplified the relative benefits of effluent treatments. Future studies should explore whether these benefits persist across diverse soil types and effluent compositions.

**3.2.5 Leaf area**

Leaf area Leaf area showed significant variation between Capsicum species, with Capsicum frutescens at 100 ml exhibiting greater leaf area than Capsicum annum. This positive effect of sewage effluent on leaf expansion aligns with findings that wastewater irrigation enhances leaf development through improved soil fertility and water availability (Toze, 2006; Gori *et al.,* 2000). However, excessive effluent concentrations can lead to salinity stress, which in turn may inhibit leaf expansion (Michael *et al.,* 2013). The gradual increase in leaf area across treatment combinations in this study suggests that nutrient availability drove leaf expansion, particularly at moderate effluent levels. However, the lack of quantitative data on leaf area limits precise comparisons with other studies, and future research should include detailed measurements to strengthen these findings.

**3.2.6 Effect on Germination and Growth**

Effect on Germination and Growth The high levels of nitrogen, phosphorus, and potassium in the sewage effluent significantly enhanced germination and growth at lower concentrations (25% and 50%), with germination rates markedly higher than the control. However, at 100% effluent concentration, germination declined, and seedling growth was stunted, likely due to increased salinity and potential toxicity from contaminants. These trends are consistent with earlier studies indicating that diluted sewage effluent supports growth while undiluted effluent may introduce osmotic stress or toxicity (Yagub *et al.,* 2014). Michael *et al.* (2013) also emphasized the environmental risks posed by untreated or poorly treated effluent, particularly with respect to chemical and pharmaceutical contaminants. These findings underscore the dual role of sewage effluent: as a potential bio-stimulant at low concentrations and a risk factor at high concentrations.

**4.0 CONCLUSION AND RECOMMENDATIONS**

**4.1 CONCLUSION**

Two species of pepper, Capsicum annum (Shombo) and Capsicum frutescence (Atarodo), were studied to observe the effect of sewage effluent on germination and growth characteristics at different concentrations (0ml, 25ml, 50ml, 75ml, and 100ml). Samples of each pepper species were obtained from the market and planted in bags for a 12-week period (May-July). A Completely Randomized Design with three replicates was used for the study. Data was collected on the following parameters: germination percentage, days to seedling emergence, plant height, number of leaves, and leaf area. The data was subjected to analysis using Analysis of Variance (ANOVA). The results of the comparative study showed high morphometric variability among the two species, with highly significant differences observed for all growth characteristics. The increase in growth attributes due to sewage effluent treatment differed between crop species. This experiment revealed significant differences between the two lines of Capsicum annum (Shombo) and Capsicum frutescence (Atarodo) in their responses to sewage effluent.

This study demonstrates that the effects of sewage effluent on capsicum growth and germination are complex and dependent on the concentration and application method. While direct irrigation with untreated urban sewage has been shown to have negative impacts, our findings suggest that moderate, controlled use of sewage-derived effluent can promote early growth and increase seedling emergence. The significant differences in plant height, leaf count, and leaf area between the two species highlight the importance of considering the specific needs and responses of different crops when using sewage effluent as an irrigation source.

The results of this study have important implications for sustainable agriculture and water management practices. By optimizing the use of sewage effluent in irrigation, farmers and agricultural managers can reduce their environmental footprint while improving crop yields and plant growth. However, it is crucial to note that direct irrigation with untreated sewage can be detrimental to pepper plants, and proper treatment and application methods are essential to avoid negative impacts.

**4.2 RECOMMENDATION**

The findings of this study demonstrate that sewage effluent, when applied at diluted concentrations (e.g., 25% and 50%), significantly enhances germination, plant height, leaf number, and leaf area in Capsicum frutescens and Capsicum annum, offering a promising approach for sustainable agriculture in resource-constrained regions. However, the observed decline in germination and growth at 100% effluent concentration due to salinity and potential toxicity underscores the need for careful management. To maximize the benefits of sewage effluent irrigation while mitigating risks, the following recommendations are proposed for agricultural practitioners, policymakers, and researchers.

1. **Apply sewage effluent at moderate concentrations (25%–50%) to enhance plant growth.**
This study showed that diluted sewage effluent, particularly at 25 ml and 50 ml levels, significantly improved germination rate, plant height, leaf number, and leaf area in *Capsicum frutescens* and *Capsicum annuum*. Farmers should adopt these moderate concentrations to benefit from the nutrients in sewage while minimizing the risks of salinity and toxicity.
2. **Avoid the use of undiluted (100%) sewage effluent for irrigation.**
The 100% effluent concentration negatively affected germination and growth due to excess salts and possible contaminants. Using untreated or undiluted effluent may lead to reduced crop yield, poor seedling development, and soil degradation. It is essential to dilute effluent to safe levels before application.
3. **Pre-treat sewage effluent and monitor its composition regularly.**
Before applying sewage effluent to crops, it should undergo basic treatment to remove harmful substances such as pathogens, heavy metals, and excessive salts. Regular monitoring of effluent for nutrients (N, P, K), pH, electrical conductivity, and heavy metals ensures safe and effective use. Testing helps farmers adjust application strategies based on the quality of the effluent.
4. **Conduct regular soil testing to prevent contamination and maintain soil health.**
Long-term use of sewage effluent can lead to the accumulation of heavy metals and salts in the soil. To avoid negative effects on soil fertility and food safety, farmers should test their soil periodically. Combining effluent use with organic matter, such as compost, can also improve soil structure and reduce the risk of nutrient imbalance or contamination.
5. **Encourage further research and establish clear guidelines for effluent use in agriculture.**
More long-term studies are needed to understand how effluent irrigation affects crops, soil health, and human safety over time. Policymakers should use current findings to develop national guidelines that specify acceptable effluent concentrations, treatment standards, and safe practices. These efforts will support sustainable agriculture, especially in water-scarce regions.

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