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Impact of Roadside Dust on Growth, Development and Cellular Characteristics of Tomato Plants

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Abstract
Roadside dust is a common environmental pollutant that poses significant risks to plant health and productivity. This study investigates the effect of roadside dust on the growth and development of tomato plants, specifically focusing on plant height, leaf number, terminal leaf area, lateral leaf area, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, and cellular characteristics. The study examines seven treatments representing varying concentrations of roadside dust applied to the plants. The results reveal that the treatments had a significant effect on most of the parameters, except for root dry weight. The plant height, terminal leaf area, leaf number, and lateral leaf area showed a decreasing trend with increasing dust concentration, suggesting hindrance in vertical growth and leaf development. Root fresh weight, shoot fresh weight, and shoot dry weight also exhibited a decreasing trend as the concentration of dust increased, indicating a negative impact on root and shoot biomass. The cellular characteristics, such as guard cell, subsidiary cell, and epidermal cell measurements, demonstrated a decrease in values as dust concentrations increased, indicating adverse effects on cellular growth and development. Overall, the findings indicate that roadside dust has a detrimental effect on the growth and development of tomato plants, including biomass accumulation, leaf expansion, and cellular characteristics. Mitigation strategies, such as regular leaf cleaning, proper irrigation, and air pollution control, are recommended to minimize the negative impacts of roadside dust on plant growth and ensure optimal crop production and environmental sustainability.

Keywords: Biomass accumulation, Leaf expansion, Guard cells, Pollution control, Environmental sustainability

1. Introduction

The tomato (*Solanum lycopersicum*) is an edible berry of the nightshade family Solanaceae. The species initially arrived in Western South America, Mexico, and Central America. The Nahuatl word tomatl gave rise to the Spanish word tomate, which gave rise to the English term tomato. It's possible that Mexico's indigenous peoples are responsible for its domestication and usage as a cultivated food. Raw, cooked, or processed tomato products including tomato sauce, ketchup, and juice. In numerous cuisines all throughout the world, they are a well-liked ingredient (Parr et al. 2014).

Vitamins A and C, potassium, and lycopene are all present in tomatoes in good amounts. Lycopene is an antioxidant that has been linked to a number of health benefits, including a reduced risk of heart disease and cancer (Bjarnadottir, 2023).

Dust is a collective term for solid particles of natural or man-made origin that are often created by disintegration processes (Faith and Atkisson, 1972). According to Arslan and Boybay (1990), dust is one of the most pervasive air contaminants. According to estimates made by Jaarsveld (2008), around 30 million tons of dust are released into the sky each year. Agriculture-related activities, power plants, cement manufacturers, etc. are sources of dust pollution. Additionally, as a result of the growing reliance on road transportation, significant vehicle traffic on unpaved roads has led to a loosening of the soil structure and soil packing density. It causes a decrease in the mechanical stability and cohesiveness of the soil, which accelerates wind erosion and releases dust particles into the atmosphere (Weinan et al., 1998).

Dust can have both positive and negative effects on plants. It has been found that atmospheric deposition of dust particles enriched with essential nutrients such as phosphorus, potassium, calcium, magnesium, zinc, copper, iron, manganese, and molybdenum can act as a direct source of nutrients for plants, supporting their growth and enhancing primary biomass production (Lokshin et al., 2023). Furthermore, studies have indicated that high levels of dust may actually have a positive, light-scattering effect that improves plant performance, particularly in perennial grasses (Devan et al., 2021). Similarly, dust deposition on plant leaves can have negative impacts on plants, including altered gas exchange and reduced photosynthetic activity, which can affect yield and overall productivity (Devan et al., 2021). Dust pollution from quarry industries has been found to cause physiological changes in plants, such as stretched epidermal cells, deformed stomata, and reduced conductance indices and chlorophyll content (Ogbonna, et al., 2020). Dust particles deposited on leaves can interfere with normal photosynthetic processes, leading to stomatal closures and reduced photosynthetic parameters (Ramazan and Mevlut, 2019). If dust is mixture of organic manure like ash, cow dung or green manure, then the dust is making positive impact on plant. However, it is important to note that the positive effects of dust on plants are only seen when dust levels are low. When dust levels are high, the negative effects of dust can outweigh the positive effects. Dust particles are absorbed by different parts of the plant, affecting plant growth by reducing chemical processing rates and causing cell death and chlorophyll depletion, reducing photosynthesis, thereby.

Plant responses to dust accumulation can vary among different species, as dust deposition varies by plant species due to leaf orientation, leaf surface shape, leaf puberty, and roadside height and canopy. From a physiological and morphological point of view, plants of the contaminated areas showed significant changes, especially in leaf color, shape, length, width, surface, and length of petioles. The accumulation of dust particles on leaf surface in dusty environments has been shown to alter leaf properties, especially surface reflectivity in the visible and short-wave infrared radiation spectra, limiting the quality and quantity of light reaching the chloroplast for plant photosynthesis.

In addition, the stomata are blocked and gas exchange is disturbed due to the dusty carbon coating covering the plant tissues. As a result, photosynthesis and net transpiration are reduced, leading to a decrease in growth rate and biomass. (Leghari et al., 2014).

Dust decreases the rates of photosynthetic activity, transpiration, and stomatal conductance. However, due to the dust-loaded leaf substrate, increasing near-infrared light spectrum irradiance absorption might raise leaf temperature and photorespiration while decreasing net photosynthesis (Nawaz, et al., 2022).

Therefore, the present work is mainly designed to analyze the effects of dust pollution, dominantly presented by automobile, industrial pollution and microclimate on physiology and morphology of *Solanum lycopersicum* (tomato), because tomato is one of the most widely grown vegetable crops in the investigated area (Chapainawabganj to Godagari, Rajshahi road). They have a wide distribution, which indicates a high economic, ecological plasticity in study area. Our goal in the present study is to evaluate the relationships among dust deposition, physiological and growth parameters of *Solanum lycopersicum* (tomato).

2. Materials and Methods

2.1 Experimental site

The proposed experiment was conducted on the rooftop shade house of EXIM Bank Agricultural University Bangladesh in Chapainawabganj city. It is situated at 24035’49’’ N latitude and 88016’12’’ E longitude at an altitude ranging from 20 to 25 meter above the mean sea level (Reza et al., 2010). However, the elevation of the rooftop was recorded about 38 meter above the mean sea level using an altimeter. Chapainawabganj is in Bangladesh's northwestern region. It is part of the Rajshahi Division and was previously a sub-district of the Malda district. Chapainawabganj is flanked to the north and west by the Indian districts of Malda and Murshidabad, to the east by the Naogaon District, and to the south-east by the Rajshahi District.

In Nawabganj, the dry season is pleasant and mainly clear while the wet season is oppressively hot and overcast. The average annual temperature ranges between 51°F and 97°F, with lows of 46°F and highs of

103°F being extremely rare. With an average daily high temperature above 91°F, the hot season lasts for 3.0 months, from March 22 to June 21. May is the hottest month of the year in Chapainawabganj, with an average high temperature of 96°F and low temperature of 79°F. From December 7 to February 6, which is the length of the cool season, the daily maximum temperature is often below 76°F. With an average low of 51°F and high of 72°F, January is the coldest month of the year in Chapainawabganj.

2.2 Climate and Soil

The proposed experiment will be performed during the month of February to March (late rabi season). Generally, no rainfall occurs during the season. Production depends on irrigation. The experimental site is medium high to high land in Agro-Ecological Zones of Ganges River Floodplain (AEZ no. 10 and 11).

2.3 Rainfall

The rainfall accumulation over a sliding 31-day period centred on each day of the year in order to highlight variance within the months as well as overall monthly totals. The monthly rainfall in Chapainawabganj varies greatly throughout the year. With a typical 31-day rainfall of at least 0.5 inches, the rainy season lasts for 8.0 months, from March 13 to November 12. Chapainawabganj experiences an average rainfall of 6.5 inches each month, with July being the wettest month. From November 12 to March 13, the year's rainless period lasts for four full months. December has 0.2 inches of rain on average, making it the driest month in Nawabganj. There are around 1,448 millimeters (57.0 inches) of rain in the district each year.

2.4 Studied plant

Tomato (*Solanum lycopersicum*) a (summer) variety was used as the experimental plant. Same irrigation, fertilizer and manure doses, etc. were applied to every plot and growth and development performance was observed of tomato.

2.5 Methodology

The experiment will be conducted in Randomized Complete Block Design with three replications. Total 21 tobs each measured 200 cm2 will be prepared for the experiment with 7 treatments.

2.6 Experimental Materials

The experimental setup included a diverse range of materials essential for the study. Tomato seeds were the primary biological specimen, while Safranin and Tobs served as staining agents for cellular analysis. Glycerin was used for sample preservation. The growth medium consisted of a mixture of soil and compost, supplemented with manure and fertilizers to promote optimal plant development. A leaf area meter was employed to measure leaf surface area, and roadside dust was collected to simulate environmental pollution. Key tools included blades for sample preparation, beakers for measurements, a microscope for detailed cellular examination, and slides for mounting specimens. Additional instruments, such as a microscale for precise weight measurements, forceps and brushes for handling samples, a drying oven for moisture control, and a measuring scale for plant growth measurements, were utilized to ensure comprehensive data collection throughout the experiment.

2.7 Treatments of the Experiment

The experiment involved the application of seven distinct treatment levels of roadside dust to assess its impact on tomato plant growth. The treatments ranged from a dust-free control group to increasing concentrations of dust. The treatment levels were as follows:

T_1: Control (No Dust)
T_2: 1 g/tob
T_3: 2 g/tob
T_4: 3 g/tob
T_5: 4 g/tob
T_6: 5 g/tob
T_7: 6 g/tob

Each treatment was carefully applied by distributing the corresponding amount of roadside dust uniformly over the tomato plants at regular intervals to simulate real-world exposure.

2.8 Data Collection Parameters
Data collection focused on a comprehensive set of parameters to capture both physiological and cellular responses of the plants to the dust treatments. The following measurements will be recorded:

1. Plant Height
2. Leaf Number
3. Terminal Leaf Area
4. Lateral Leaf Area
5. Root Fresh Weight
6. Root Dry Weight
7. Shoot Fresh Weight
8. Shoot Dry Weight
9. Guard Cell Count
10. 1Subsidiary Cell Count
11. Epidermal Cell Count

These parameters were selected to provide a holistic understanding of how dust exposure affects plant growth, biomass accumulation, and cellular structure.

2.9 Pot Preparation
The experiment was conducted using a Randomized Complete Block Design (RCBD), with 21 pots in total, each measuring 200 cm², and divided into seven different treatments. Soil was carefully mixed with compost to create a nutrient-rich growing medium, which was then placed into the pots. The filled pots were exposed to sunlight for 2-3 days to ensure proper soil conditioning before planting. The pots were arranged into three replications for accuracy and consistency in data collection. The first replication consisted of R1T1 to R_1T_7, the second of R_2T_1 to R_2T_7, and the third of R_3T_1 to R_3T_7. Each treatment pot was randomly arranged in rows to minimize bias, and after sowing, light irrigation was provided. The pots were then carefully placed under a shade house to protect the seedlings from excessive sunlight while maintaining optimal growing conditions.

2.9.1 Seed Sowing
Tomato seeds were sown using the dipping method, with a seed rate of 3 to 5 seeds per pot. This method ensured even distribution of seeds and optimal germination conditions.

2.9.2 Irrigation
Irrigation was administered twice before seed germination to ensure adequate moisture levels. During the seedling stage, light irrigation was applied regularly for 20-25 days to support early growth. Following this period, the pots were irrigated twice per week to maintain adequate soil moisture throughout the experiment.

2.9.3 Fertilizer Application
Fertilizers were applied in accordance with the recommended dosage, tailored to the specific soil type, moisture content, and growth stage of the plants. This ensured that the plants received the necessary nutrients for healthy development at each phase of their growth.

2.10 Intercultural operations
Different intercultural operations were conducted for better growth and development of the tomato. The intercultural operations wedding, thinning, gap filling & drainage. Weeding was done three times at 25 DAS & 40 DAS.
Seedlings were raised from randomly grown seeds in small pots filled with loam soil (2:1; loam soil: natural manure). In every pot we plant 3 seedling and collect data randomly from those plants.
2.11 Collection of the road dust
The road dust used in the experiment was collected from the surfaces of some busy streets. We collect from different street of the city of Chapainawabgonj. The road dust and loam were sieved by using a fine nylon screen to separate coarse particle

Dust was applied by hand on the treated plants, twice a week for 5 weeks. After every week, position of the pots was changed for obtaining random results and then in these weeks. Three replicates were maintained for each treatment and irrigation was provided by tap water. At the end of the experiment, the plants were uprooted carefully from the pots and were washed under tap water.

2.12 Statistical Analysis

The data collected from various parameters undergone statistical analysis to determine the level of significance. This analysis was performed using STATISTIX 10 and Python software, ensuring a robust evaluation of the experimental results. The mean separation was carried out using the Least Significant Difference (LSD) test at a 5% level of significance, with the coefficient of variation (CV) also calculated to assess the reliability and variability of the data.

Tools for Data Analysis:

1. Microsoft Office Excel 2016
2. Statistix 10
3. Python

   These tools were employed to efficiently manage, analyze, and interpret the data, ensuring that the findings are both accurate and meaningful.

2.13 Plant growth analysis

Data on growth parameters viz., plant height, leaf number, terminal leaf area, lateral leaf area, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, and cellular characteristics were recorded at four to five stages. Twenty-one pots in plants of uniform size were selected from each of the control and treatment pots for growth analysis. Plant samples were separated into stem, root and leaves and their leaf area was measured by plotting the plucked leaves on scale and area was calculated. Dry weight of the plant parts was obtained by placing the plant material in an electric hot air oven at 70^{o}C for three days. (Gardner et al.1985).

2.14 Stomata Observation in Tomato Plants via Image Method

To observe stomata in tomato plants, the following materials were carefully prepared:

1. A digital camera
2. A microscope
3. A slide
4. A coverslip
5. A drop of water
6. Safranin
7. Glycerin
8. A piece of tomato leaf
9. Microscale

The process began by collecting a fresh tomato leaf and placing it in a beaker of distilled water to maintain its integrity. Thin, free-hand transverse sections were then delicately sliced from the leaf blade. These fine sections were prepared by hand and placed onto a slide. To enhance the visibility of cellular structures, the sections were stained with a few drops of Safranin. After a brief staining period, any excess Safranin was gently blotted away using tissue paper. A drop of glycerin was applied to the stained section, and a coverslip was carefully placed over the sample to ensure clarity.

Using a research microscope, the sections were examined under 40x magnification, ensuring uniformity in the focus. The image of the leaf surface was captured with a digital camera, providing a clear view of the stomata. The area of the leaf visible in the image was measured using a ruler, and the number of stomata within this area was meticulously counted. Stomatal density was then calculated by dividing the number of stomata by the measured area of the leaf surface. For reference, the scale of 100 micrometers^2 = 1 cm was used for measurements at 40x magnification under the microscope. This method allowed for precise stomatal observation and density calculations in the tomato plants.

3. Results And Discusion

3.1 Effect of Roadside Dust on Plant Height of Tomato at Different Days After Sowing (DAS)

The data presented in table 2 shows the effect of roadside dust on the plant height of tomatoes at various days after sowing (DAS). The treatments (T1-T7) represent different concentrations of dust applied to the plants, ranging from 0 gm to 6 gm.

Overall, the results indicate that the treatments had a significant effect on plant height, with variations observed across different DAS. It is important to note that the coefficient of variation (CV) values ranged from 11.25% to 21.39%, indicating relatively low variability within the data.

At 20 DAS, all treatments exhibited similar plant heights, with values ranging from 14.900 cm to 19.833 cm. However, as the plants continued to grow, differences among the treatments became more apparent. At 27 DAS, T1, T2, T3, and T4 had relatively higher plant heights compared to T5, T6, and T7. This trend continued at 34 DAS, with T1 having the highest plant height followed closely by T2, T3, and T4.

By 41 DAS, the differences in plant height among the treatments became more pronounced. T1 had the highest plant height of 47.733 cm, followed by T2, T3, T4, T5, T6, and T7. This pattern persisted until 48 DAS, with T1 maintaining the highest plant height and T7 having the lowest.

The observed trend suggests that increasing concentrations of roadside dust may have a negative impact on the plant height of tomatoes. As the dust concentration increased from T1 to T7, there was a gradual decrease in plant height. This indicates that higher concentrations of roadside dust may hinder the vertical growth of tomato plants over time.

The findings of this study are consistent with previous research that has reported adverse effects of environmental factors, such as dust and pollutants, on plant growth. Factors such as air pollution, physical barriers, nutrient imbalance, reduced light penetration, and water stress are likely contributing to the negative impact of roadside dust on plant height.

Table 1: Effect of Roadside Dust on Plant Height of Tomato at Different Days After Sowing (DAS)

Treatment	Plant Height (cm)				
	20 DAS	27 DAS	34 DAS	41 DAS	48 DAS
T1	19.833 a	36.733 a	42.467 a	47.733 a	52.333 a
T2	19.667 a	31.300 ab	39.500 ab	46.167 ab	48.067 ab
T3	19.433 a	27.733 ab	37.233 ab	39.833 abc	46.733 abc
T4	15.767 a	26.633 b	31.567 ab	39.567 abc	45.933 abc
T5	15.533 a	23.267 b	29.800 b	39.533 abc	42.600 bc
T6	15.267 a	23.267 b	29.500 b	38.100 bc	38.667 c
T7	14.900 a	22.233 b	29.067 b	36.000 c	38.667 c
CV	21.39	20.70	18.08	11.29	11.25
LSD (0.05)	6.5462(NS)	10.056	10.988	8.2365	8.9513

4.2 Effect of Roadside Dust on Leaf Number of Tomato at Different Days After Sowing (DAS)

The data in the table 3 represents the effect of roadside dust on the leaf number of tomatoes at various days after sowing (DAS). The treatments (T1-T7) correspond to different concentrations of dust applied to the plants, ranging from 0 gm to 6 gm.

Overall, the results demonstrate that the treatments had a significant effect on leaf number, with variations observed across different DAS. The coefficient of variation (CV) values ranged from 8.36% to 13.58%, indicating relatively moderate variability within the data.

At 20 DAS, all treatments displayed similar leaf numbers, ranging from 4.0000 to 5.6667. However, as the plants progressed in their growth, differences in leaf number among the treatments became more apparent. At 27 DAS, T1 exhibited the highest leaf number of 8.0000, followed by T2, T3, T4, and T5. T6 and T7 had slightly lower leaf numbers compared to the other treatments.

By 34 DAS, the differences in leaf number among the treatments became more pronounced. T1 continued to have the highest leaf number of 8.6667, followed by T2, T3, T4, T5, T6, and T7. This trend persisted until 41 DAS and 48 DAS, with T1 consistently having the highest leaf number, and T7 exhibiting the lowest.
The data suggests that increasing concentrations of roadside dust may have a negative impact on the leaf number of tomatoes. As the dust concentration increased from T1 to T7, there was a gradual decrease in leaf number. This trend implies that higher concentrations of roadside dust may hinder leaf development and subsequent leaf production over time.
These findings align with previous studies that have reported detrimental effects of environmental factors, such as dust and pollutants, on plant growth. Factors like air pollution, physical barriers, nutrient imbalance, reduced light penetration, and water stress may contribute to the negative impact of roadside dust on leaf number.

Table 2: Effect of Roadside Dust on Leaf Number of Tomato at Different Days After Sowing (DAS)

Treatment	Leaf Number				
	20 DAS	27 DAS	34 DAS	41 DAS	48 DAS
T1	5.6667 a	8.0000 a	8.6667 a	9.6667 a	8.6667 a
T2	4.6667 b	7.0000 ab	8.6667 a	9.3333 a	8.6667 a
T3	4.6667 b	6.3333 bc	7.6667 ab	8.6667 ab	8.3333 a
T4	4.6667 b	5.6667 bcd	7.6667 ab	8.3333 ab	8.3333 a
T5	4.0000 b	5.3333 cd	7.0000 b	8.0000 ab	8.0000 a
T6	4.0000 b	5.3333 cd	7.0000 b	8.0000 ab	7.6667 ab
T7	4.0000 b	4.6667 d	6.6667 b	7.0000 b	6.6667 b
CV	8.36	13.58	8.90	11.19	9.13
LSD (0.05)	0.6724	1.4612	1.2070	1.6773	1.3069

4.3 Effect of Roadside Dust on Terminal Leaf Area of Tomato at Different Days After Sowing (DAS)

The results showed in the table 4 reveal significant variations in terminal leaf area among the treatments at different DAS. The coefficient of variation (CV) values, ranging from 0.62% to 21.39%, indicate relatively low to moderate variability within the data.
At 20 DAS, all treatments exhibited similar terminal leaf areas, with values ranging from 12.665 cm² to 16.858 cm². However, as the plants progressed in age, noticeable differences in terminal leaf area emerged. By 27 DAS, T1 had a slightly higher leaf area compared to T2, T3, T4, T5, T6, and T7.
At 34 DAS, the differences in terminal leaf area among the treatments became more distinct. T1 maintained the highest leaf area, followed by T2, T3, T4, T5, T6, and T7. This pattern continued at 41 DAS, with T1 still exhibiting the largest terminal leaf area, while T7 displayed the smallest.
The trend persisted at 48 DAS, with T1 having the highest terminal leaf area of 30.847 cm², and T7 exhibiting the lowest value. It is noteworthy that the difference in terminal leaf area between T1 and the other treatments increased as the plants matured.
The LSD (0.05) values provide insight into the minimum significant differences between treatment means. These values suggest that the differences observed among the treatments at each DAS are statistically significant.
The data indicates that increasing concentrations of roadside dust have an adverse effect on the terminal leaf area of tomato plants. As the dust concentration increased from T1 to T7, there was a gradual decrease in the

leaf area. This suggests that higher concentrations of roadside dust may hinder the leaf expansion and development of tomato plants over time.

The findings align with previous research that has documented the negative impacts of environmental factors, including dust and pollutants, on plant growth. Factors such as air pollution, physical barriers, nutrient imbalances, reduced light penetration, and water stress likely contribute to the detrimental effects of roadside dust on the terminal leaf area.

It is important to note that the terminal leaf area is a vital parameter for photosynthesis and overall plant growth. Reductions in leaf area can affect the plant's ability to capture sunlight and synthesize energy, potentially leading to compromised growth and productivity.

Table 3: Effect of Roadside Dust on Terminal Leaf Area of Tomato at Different Days After Sowing (DAS)

Treatment	Terminal Leaf Area (cm^2)				
	20 DAS	27 DAS	34 DAS	41 DAS	48 DAS
T1	16.858 a	16.912 a	16.521 a	20.508 a	30.847 a
T2	16.717 a	16.666 b	15.756 a	17.856 b	18.748 b
T3	16.518 a	13.606 c	12.257 b	17.261 c	17.057 bc
T4	13.402 a	11.481 d	11.934 b	16.343 d	16.666 bcd
T5	13.203 a	10.478 e	10.622 b	14.694 e	15.306 cd
T6	12.977 a	8.234 f	10.016 b	13.776 f	14.796 cd
T7	12.665 a	7.324 g	7.225 c	8.217 g	14.150 d
CV	21.39	0.79	11.30	0.62	8.19
LSD (0.05)	5.5643(NS)	0.1703	2.4215	0.1726	2.6543

4.4 Effect of Roadside Dust on Lateral Leaf Area of Tomato at Different Days After Sowing (DAS)

The results showed in the table 5 reveal significant variations in lateral leaf area among the treatments at different DAS. The coefficient of variation (CV) values, ranging from 0.36% to 8.36%, indicate relatively low to moderate variability within the data.

At 20 DAS, all treatments exhibited similar lateral leaf areas, with values ranging from 3.4000 cm^2 to 4.8167 cm^2. However, as the plants continued to grow, differences in lateral leaf area became more evident. By 27 DAS, T1 had a higher leaf area compared to T2, T3, T4, T5, T6, and T7.

At 34 DAS, the differences in lateral leaf area among the treatments became more pronounced. T1 maintained the highest leaf area, followed by T2, T3, T4, T5, T6, and T7. This pattern persisted at 41 DAS, with T1 still exhibiting the largest lateral leaf area, while T7 displayed the smallest.

By 48 DAS, T1 had the highest lateral leaf area of 17.686 cm^2, while T7 had the lowest value. It is important to note that the difference in lateral leaf area between T1 and the other treatments increased as the plants matured.

The LSD (0.05) values indicate that the differences observed among the treatments at each DAS are statistically significant.

The data suggests that increasing concentrations of roadside dust have an adverse effect on the lateral leaf area of tomato plants. As the dust concentration increased from T1 to T7, there was a gradual decrease in the leaf area. This implies that higher concentrations of roadside dust may hinder the expansion and development of lateral leaves in tomato plants over time.

These findings are consistent with previous research that has highlighted the negative impacts of environmental factors, including dust and pollutants, on plant growth. Factors such as air pollution, physical barriers, nutrient imbalances, reduced light penetration, and water stress likely contribute to the detrimental effects of roadside dust on the lateral leaf area.

In conclusion, the data presented in this study demonstrates that increasing concentrations of roadside dust have a negative impact on the lateral leaf area of tomatoes. The findings underscore the need for measures to mitigate the effects of roadside dust on leaf development to ensure optimal plant growth and productivity. Strategies such as regular cleaning of leaves, minimizing dust accumulation, proper irrigation, and air pollution control in the vicinity may help alleviate the negative effects of roadside dust. Further research is warranted to deepen our understanding of the underlying mechanisms and to develop effective mitigation strategies.

Table 4: Effect of Roadside Dust on Lateral Leaf Area of Tomato at Different Days After Sowing (DAS)

Treatment	**Lateral Leaf Area (cm^2)**				
	20 DAS	**27 DAS**	**34 DAS**	**41 DAS**	**48 DAS**
T1	4.8167 a	13.776 a	17.346 a	17.116 a	17.686 a
T2	3.9667 b	11.906 b	16.836 b	15.510 b	16.870 b
T3	3.9667 b	10.393 c	12.144 c	13.096 c	16.530 c
T4	3.9667 b	9.951 d	9.288 d	12.858 d	15.552 d
T5	3.4000 b	9.568 e	7.486 e	12.382 e	14.966 e
T6	3.4000 b	8.574 f	6.806 f	12.382 e	12.824 f
T7	3.4000 b	6.967 g	6.806 f	6.976 f	12.144 g
CV	8.36	0.65	1.15	0.68	0.36
LSD (0.05)	0.5715	0.1180	0.2249	0.1561	0.0987

4.5 Effect of Roadside Dust on Root Fresh Weight, Root Dry Weight, Shoot Fresh Weight, and Shoot Dry Weight

The results presented in the table 6 indicate that the treatments had a significant effect on the measured parameters except root dry weight. Root fresh weight varied among the treatments, with T1 having the highest value of 15.533, followed by T2 (14.000), T3 (12.467), T4 (9.100), T5 (7.533), T6 (7.400), and T7 (7.300). The trend suggests a decreasing root fresh weight with increasing dust concentration, indicating that higher concentrations of roadside dust may negatively impact root growth.

A similar pattern is observed for root dry weight, where T1 exhibited the highest value of 3.1300, followed by T2 (3.1000), T3 (2.6000), T4 (1.8667), T5 (1.7333), T6 (1.5000), and T7 (1.4000). The decrease in root dry weight with increasing dust concentration further supports the notion that roadside dust may hinder root development and biomass accumulation.

In terms of shoot fresh weight, T1 recorded the highest value of 140.00, followed by T2 (117.00), T3 (112.67), T4 (111.27), T5 (84.00), T6 (70.67), and T7 (59.00). The trend in shoot fresh weight indicates a decreasing trend similar to that observed for root fresh weight and root dry weight. This suggests that roadside dust may have a detrimental effect on the overall shoot growth and biomass production of tomato plants.

The trend in shoot dry weight is consistent with the previous parameters, with T1 having the highest value of 21.500, followed by T2 (20.000), T3 (19.327), T4 (17.100), T5 (14.300), T6 (11.000), and T7 (9.567). The decreasing shoot dry weight with increasing treatment number suggests that the presence of roadside dust can lead to reduced shoot biomass and, consequently, lower yield potential in tomato plants.

In conclusion, the results of the experiment suggest that the presence of roadside dust has a negative impact on the growth and development of tomato plants. Higher concentrations of roadside dust corresponded to decreased root and shoot biomass, indicating a reduction in plant growth and potential yield. These findings are consistent with the study of Siddique et al., (2013) that have reported adverse effects of environmental factors, such as dust and pollutants, on plant growth and productivity. Further research and measures to mitigate the effects of roadside dust on plant growth may be warranted to ensure optimal crop production and environmental sustainability.

The negative impact of roadside dust on the growth and development of tomato plants, probably, happens due to the factors such as air pollution, physical barriers, nutrient imbalance, reduced light penetration, and water stress. Roadside dust contains pollutants that can be absorbed by the plant, hindering its physiological processes and reducing growth. Dust accumulation on leaves can impede photosynthesis, disrupt nutrient balance, block light penetration, and increase water stress. These factors collectively lead to decreased root and shoot biomass, indicating reduced plant growth and potential yield. Mitigation strategies include regular leaf cleaning, proper irrigation, and air pollution control in the vicinity.

Table 5: Effect of road-side dust on root fresh weight, root dry weight, shoot fresh weight, and shoot dry weight

Treatment	Root Fresh Weight (g)	Root Dry Weight (g)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)
T1	15.533 a	3.1300	140.00 a	21.500 a
T2	14.000 ab	3.1000	117.00 b	20.000 a
T3	12.467 b	2.6000	112.67 b	19.327 a
T4	9.100 c	1.8667	111.27 b	17.100 a
T5	7.533 c	1.7333	84.00 c	14.300 a
T6	7.400 c	1.5000	70.67 d	11.000 ab
T7	7.300 c	1.4000	59.00 e	9.567 b
CV	11.49	55.57	4.86	37.46
LSD (0.05)	2.1416	2.1652 (NS)	8.5820	10.738

4.6 Effect of Roadside Dust on Guard Cell, Subsidiary Cell, and Epidermal Cell of Tomato at Different Days After Sowing (DAS)

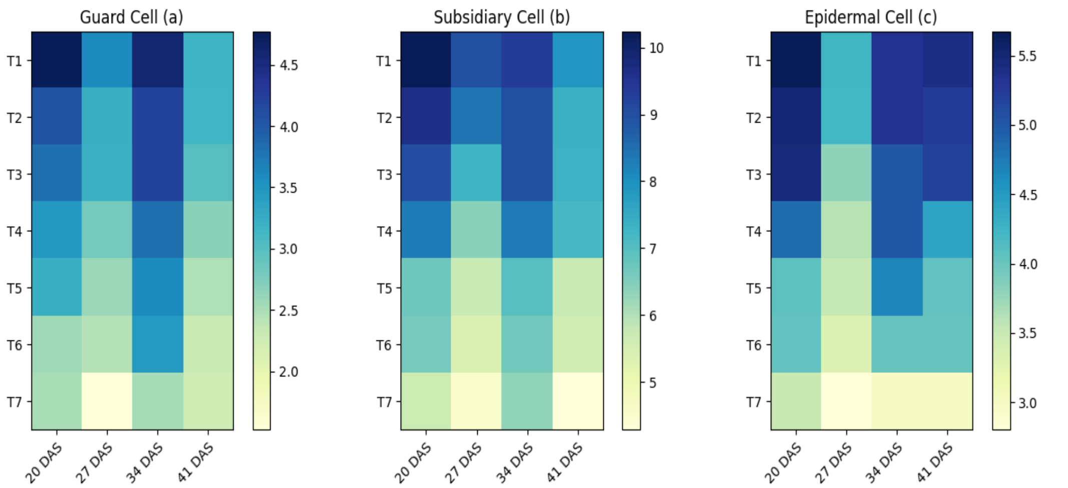

Figure 1: Effect of Roadside Dust on (a)Guard Cell, (b)Subsidiary Cell, and (c)Epidermal Cell of Tomato at Different Days After Sowing (DAS)

The Guard cell heatmap represents the variations in guard cell measurements across different treatments (T1 to T7) and time points (20 DAS, 27 DAS, 34 DAS, 41 DAS). The color intensity in the heatmap indicates the magnitude of the measurements, with darker shades representing higher values. By observing the heatmap, the following patterns can be identified:

Generally, as the amount of roadside dust (treatments T1 to T7) increases, there is a decreasing trend in guard cell measurements. This suggests that higher dust concentrations negatively impact guard cell growth and development.

Comparing different time points, it can be observed that guard cell measurements tend to decrease as the plants progress from 20 DAS to 41 DAS. This may indicate natural changes in guard cell characteristics as the plants mature.

The Subsidiary cell heatmap represents the variations in subsidiary cell measurements across treatments and time points. Similar to the Guard cell heatmap, the color intensity represents the magnitude of the measurements. From the Subsidiary cell heatmap, the following conclusions can be drawn:

Increasing amounts of roadside dust (treatments T1 to T7) generally result in a decrease in subsidiary cell measurements. This suggests that higher dust concentrations have a negative impact on the growth and development of subsidiary cells.

There is a gradual decline in subsidiary cell measurements as the plants progress from 20 DAS to 41 DAS. This indicates that subsidiary cell characteristics may change as the plants mature.

The Epidermal cell heatmap represents the variations in epidermal cell measurements across treatments and time points. By analyzing this heatmap, the following observations can be made:

Similar to the previous heatmaps, an increase in roadside dust concentrations (T1 to T7) generally leads to a decrease in epidermal cell measurements. This suggests that higher dust levels negatively affect the growth and development of epidermal cells.

Comparing different time points, we can observe variations in epidermal cell measurements. However, these variations do not follow a consistent pattern across treatments.

Overall, the heatmaps provide a visual representation of the impact of roadside dust on the growth and development of tomato plants. The patterns and trends observed can help researchers and stakeholders understand the effects of dust exposure on cellular characteristics, supporting further analysis and discussions regarding the potential risks and mitigation strategies for roadside dust pollution

Conclusion

Increasing dust concentration has a negative impact on plant growth and development. This is evident in the decreasing trend of plant height, terminal leaf area, leaf number, lateral leaf area, root fresh weight, shoot fresh weight, and shoot dry weight. Additionally, the cellular characteristics of guard cells, subsidiary cells, and epidermal cells also decreased in value as dust concentrations increased.

The study's findings suggest that dust can hinder vertical growth and leaf development and can also have a negative impact on root and shoot biomass. Additionally, dust can adversely affect cellular growth and development.

The study's findings have important implications for plant health and productivity. In areas with high dust concentrations, plants may be more susceptible to damage and may not be able to grow as well. Dust can block the stomata, which are small pores on the leaves that allow for gas exchange. This would prevent the plant from taking in carbon dioxide and releasing oxygen, which would ultimately lead to decreased growth.

Additionally, dust can coat the leaves and prevent them from absorbing sunlight, which is essential for photosynthesis.

Overall, the findings indicate that roadside dust has a detrimental effect on the growth and development of tomato plants, including biomass accumulation, leaf expansion, and cellular characteristics.

Recommendation

Based on the study's findings, several recommendations can be made to mitigate the negative effects of roadside dust on plant growth and development. Reducing dust emissions through measures such as water sprinkling, planting windbreaks, and applying dust suppression agents can help limit dust exposure. Protecting plants from dust by covering them with nets or shelters, or by cultivating dust-tolerant species, offers another line of defense. Regular monitoring of dust levels is crucial for identifying high-dust areas and tracking changes over time. Additionally, educating the public about the harmful effects of dust on plants can raise awareness and encourage actions to reduce emissions and safeguard plant health. To further minimize the impact of dust, regular cleaning of leaves, proper irrigation practices, and air pollution control are recommended, ensuring both sustainable crop production and environmental well-being.

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