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Mitigation of Cigarette Filter Residue Toxicity in Maize Through Organic Amendments Under Controlled Soil Conditions

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Abstract

Cigarette filter residues are emerging soil pollutants that may adversely affect crop growth and soil health due to the release of toxic compounds and non-biodegradable materials. The objective of this study was to evaluate the effects of cigarette filter residues and organic amendments on the growth, yield, and toxicity mitigation potential in maize (Zea mays L.) grown under contaminated soil conditions. A pot experiment was carried out at PMAS-Arid Agriculture University using a Completely Randomized Design (CRD) consisting of six treatments with three replications each. The treatments included control (T1), cigarette filters alone (T2), farmyard manure (T3), poultry manure (T4), farmyard manure + cigarette filters (T5), and poultry manure + cigarette filters (T6). Data regarding plant height, stem diameter, number of leaves, shoot and root biomass, total leaf area, leaf area index, and yield parameters were recorded and analyzed statistically value through analysis of variance (ANOVA), and treatment means were compared using the Least Significant Difference (LSD) test at a 5% probability level. The results revealed that organic amendments significantly improved maize growth and yield attributes compared with control and cigarette filter treatment alone. The combined application of poultry manure and cigarette filters (T6) produced the highest plant height (194 cm), total leaf area (5903 cm^2), grain yield per plant (141 g), biological yield per plant (267 g), and harvest index (52.8%), representing substantial improvements over the control treatment. Poultry manure performed better than farmyard manure due to its higher nutrient availability and rapid mineralization. The combined application of poultry manure and cigarette filters effectively minimized the negative effects of cigarette filter residues by improving soil fertility, nutrient uptake, and biomass accumulation. These findings demonstrate that organic amendments can serve as an environmentally sustainable strategy for mitigating cigarette filter residue toxicity in agricultural soils. In particular, poultry manure showed strong potential for improving soil quality and enhancing maize productivity, offering a practical waste-management and soil-remediation approach for contaminated environments. These findings were obtained under controlled pot conditions and should be validated through field-based investigations before broader agricultural recommendations are made.

Keywords: Maize (Zea mays L.), Cigarette filter residues, Organic amendments, Poultry manure, Farmyard manure, Soil pollution, Soil fertility, Crop productivity, Environmental stress remediation.

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Introduction

Maize (Zea mays L.) is a major cereal crop in Pakistan, widely used for food, livestock feed, and industrial applications such as starch and ethanol production. Its high-yielding potential and diverse uses make it essential for food security and agricultural sustainability. However, maize productivity strongly depends on soil health, which is increasingly threatened by soil degradation and environmental pollution. In Pakistan, soils already suffer from low organic matter, salinization, and improper fertilizer use, and emerging pollutants such as cigarette filter residues further worsen these conditions (Alloway et al., 2013).

Globally, maize remains a staple crop, with production reaching about 1.209–1.219 billion metric tons in 2024, showing a slight decline due to climatic and agronomic variations (Ajibade et al., 2024). In Pakistan, maize is among the leading cereal crops, with 2024–25 data reporting about 1.437 million hectares under cultivation and a total production of 8.239 million tonnes, with an average yield of 5.733 tonnes per hectare (Ayeni et al., 2011). Despite its importance, maize is highly sensitive to environmental stress, making it a suitable bioindicator for assessing soil contamination and evaluating remediation strategies. Improving its productivity is therefore directly linked to food security and sustainable agriculture.

A growing concern in agricultural soils is contamination from cigarette filter residues. Cigarette butts contain toxic compounds such as nicotine, polycyclic aromatic hydrocarbons (PAHs), and heavy metals, including cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), and zinc (Zn), which negatively affect soil health and plant growth. They are also composed of cellulose acetate, a non-biodegradable plastic that gradually breaks down into microplastics, further contributing to soil pollution and altering soil structure, water retention, and root development (Aziz et al., 2021). Globally, about 4.5 trillion cigarette butts are discarded annually, many entering agricultural fields and increasing soil contamination risks (Aziz et al., 2021).

Once in soil, these pollutants disrupt nutrient cycling, microbial activity, and plant physiological processes. Soil contamination theory explains that such pollutants alter biological, chemical, and physical soil functions depending on their persistence and interactions with soil components. Cigarette butt leachates have been reported to reduce seed germination, root growth, microbial biomass, and enzyme activity, thereby lowering soil fertility and crop productivity (Boateng et al., 2006; Calamai et al., 2020). Phytotoxic effects occur due to the release of toxic compounds that interfere with nutrient uptake, photosynthesis, and enzymatic functions, while also inducing oxidative stress through reactive oxygen species (ROS), leading to cellular damage and reduced growth. Additionally, cigarette residues alter soil microbial communities by reducing bacterial diversity essential for nutrient cycling and soil health (Calamai et al., 2020).

Recent research highlights cigarette filters as a source of microplastic pollution in soils. These particles persist for long periods, affecting soil aeration, moisture retention, and root penetration. Heavy metals released from cigarette residues can accumulate in plants, disrupt metabolism, reduce photosynthesis, and decrease biomass production. They also alter microbial diversity, enzyme activity, and nutrient cycling. Soil microorganisms and plant–microbe interactions play a key role in pollutant degradation and determining contaminant availability in the rhizosphere.

Ecotoxicological studies show that.

Cigarette butt leachates negatively affect soil fauna such as earthworms by reducing survival, growth, and causing behavioral avoidance (Egobueze et al., 2019). Due to the slow degradation of cellulose acetate, cigarette filters persist in soil and continuously release toxic compounds, posing long-term risks to agricultural ecosystems (Grant et al., 2001).

To address soil pollution, organic amendments such as compost, farmyard manure, poultry manure, and biochar are widely used. These materials improve soil structure, organic carbon, microbial activity, and nutrient availability while reducing contaminant bioavailability through adsorption and enhanced microbial degradation (Kafle et al., 2015). Organic matter-based remediation improves soil quality and reduces pollutant mobility, thereby restoring fertility and supporting plant growth.

Organic amendments can also enhance pollutant sorption, reduce toxicity, and stimulate microbial transformation of contaminants (Kandil et al., 2020; Kareem et al., 2017). In maize, such amendments have been shown to reduce uptake of harmful substances, alleviate oxidative stress, and improve growth under contaminated conditions (Koroleva et al., 2021). This highlights their potential for mitigating emerging pollutants like cigarette filter residues.

In conclusion, cigarette filter residues pose a serious threat to soil health and maize productivity due to their toxic and persistent nature. However, organic amendments provide a sustainable remediation strategy. This study builds on these concepts to evaluate the effects of cigarette filter contamination and organic amendments on maize growth, suggesting that locally available organic resources can reduce stress, improve soil quality, and enhance crop productivity.

Material & Methods

Experimental Design & Treatments

The experiment consisted of six treatments arranged in a Completely Randomized Design (CRD) with three replications, giving a total of 18 experimental units (pots). Each pot was treated as an independent unit and randomly assigned a treatment to minimize bias. The study was conducted under natural conditions at PMAS-Arid Agriculture University, Rawalpindi, with average temperatures of 35–40°C and relative humidity of 41–50%. Uniform environmental conditions were maintained throughout the experiment.

Cigarette filters were commercially collected, air-dried, and used in either smoked or unsmoked form. A dose of 5.04 g per pot was thoroughly mixed into the soil before sowing to ensure even distribution. Farmyard manure and poultry manure were obtained from local farms, air-dried, homogenized, and applied at a rate of 53.066 g per pot before sowing.

Crop Management and Data Collection

Maize (*Zea mays L.*) variety Pak Afghoi was used as the test crop. Healthy, uniform seeds were sown in pots and maintained under standard agronomic practices with uniform irrigation. No additional fertilizers were applied to avoid confounding effects. Plant growth parameters were recorded at designated growth stages. Plant height (cm) was measured from ground level to the tip of the tallest leaf, stem diameter (mm) was measured using a digital Vernier caliper, and leaf number was counted manually. At harvest, roots and shoots were separated, washed, and weighed to determine fresh biomass (g). Dry biomass (g) was recorded after oven-drying samples at 65°C to constant weight. Leaf area (cm^2) was measured using standard methods, and Leaf Area Index (LAI) was calculated as the ratio of total leaf area to ground area occupied by the plant. Yield parameters included cob length (cm), cob diameter (mm), grains per cob, grain yield (g plant^{-1}), 1000-grain weight (g), biological yield (total dry biomass), and harvest index (%), which was calculated to assess the efficiency of biomass conversion into grain yield.

Statistical Analysis

The data collected was statistically analyzed by Statistic 8.1 software. Treatment means were compared using the Least Significant Difference (LSD) test at 5% probability level.

Result & Discussion

The performance of different treatments was checked on maize crop, and the following parameters were recorded (Plant Height, Stem diameter, Number of leaves per plant, Total Leaf Area, Leaf Area Index, Root Shoot Length, Fresh and Dry biomass, and yield parameters.

Plant Height (cm): Plant height differed significantly among treatments during the three weeks of observation (Figure 1). In all weeks, treatments containing organic amendments produced taller plants compared to the control and cigarette filter-only treatment. The maximum plant height was recorded in T6 (poultry manure + cigarette filters), followed by T5 (FYM + cigarette filters), while the control (T1) showed the lowest plant height. FYM (T3) and poultry manure (T4) alone also improved plant height compared to the control, indicating a positive effect of organic amendments on maize growth.

The increase in plant height with FYM and poultry manure is consistent with previous studies showing that organic manures improve soil structure and enhance the availability of essential nutrients such as N, P, and K, thereby promoting vegetative and stem growth (Kandil et al., 2020). The superior performance of combined treatments (T5 and T6) may be due to synergistic effects, including improved nutrient release and better soil moisture retention, as reported in integrated organic amendment studies (Dawar et al., 2022).

In contrast, the reduced plant height in the cigarette filter-only treatment (T2) is likely due to the toxic effects of soil contaminants, which can hinder nutrient uptake and suppress growth (Egobueze et al., 2019). However, the improvement in plant height when cigarette filters were combined with organic amendments suggests that organic matter can partially mitigate stress effects by improving soil fertility and reducing contaminant bioavailability (Calamai et al., 2020).

Annexure(A)

Stem Diameter (mm): Stem diameter increased significantly with treatment and growth duration (Figure 2), showing steady improvement from Week 1 to Week 3 across all treatments. The lowest stem diameters were consistently recorded in T1 (control) and T2 (cigarette filter-only), while all organic amendment treatments showed improved values. The highest stem diameter was observed in T6 (poultry manure + cigarette filters), followed by T5 (FYM + cigarette filters) at Week 3, both significantly higher than all other treatments. Intermediate values were recorded in T3 (FYM) and T4 (poultry manure).

The reduced stem diameter in T1 and T2 indicates nutrient deficiency and stress-induced suppression of cambial activity (Alloway et al., 2013). In contrast, the increase in stem girth under FYM and poultry manure treatments aligns with studies showing that organic amendments enhance soil fertility, microbial activity, and gradual nutrient release, thereby promoting maize growth (Aziz et al., 2021). Poultry manure showed slightly better performance than FYM, likely due to its higher nutrient content and faster mineralization rate (Kareem et al., 2017).

The superior performance of combined treatments (T5 and T6) suggests that organic amendments helped mitigate the negative effects of cigarette filter residues by improving soil conditions and buffering stress in the rhizosphere, consistent with findings in stressed maize systems (Rizwan et al., 2016).

Annexure(B)

No of Leaves per plant: Cigarette filter residues and organic amendments significantly affected the number of leaves per maize plant across all growth stages (Figure 3). Leaf number increased with plant age in all treatments, but the lowest values were consistently recorded in the control (T1) and cigarette filter-only treatment (T2). Organic amendment treatments showed higher leaf production, with T6 (poultry manure + cigarette filters) performing best, followed by T5 (FYM + cigarette filters), while T3 (FYM) and T4 (poultry manure) showed intermediate responses.

The reduced leaf number in T1 and T2 reflects nutrient stress and restricted vegetative growth due to soil contamination, consistent with findings that pollutants can inhibit nutrient uptake and leaf development in maize (Alloway, 2013). In contrast, higher leaf production under FYM and poultry manure is linked to improved soil fertility, enhanced microbial activity, and better nitrogen availability, which is essential for leaf formation (Muhammad et al., 2016). Poultry manure performed slightly better than FYM due to its higher nutrient content and faster mineralization. Overall, combined treatments were more effective as organic amendments helped reduce the toxic effects of cigarette filter residues by improving soil conditions and alleviating rhizosphere stress, thereby supporting normal vegetative growth (Rizwan et al., 2016).

Annexure(C)

Shoot Fresh Matter Yield (kg/hac): Cigarette filter residues, organic amendments, and their combinations significantly influenced shoot fresh matter yield (SFMY) of maize (Figure 4). The lowest SFMY was recorded in the control (T1), while the cigarette filter-only treatment (T2) showed a slight but still significantly lower yield than all organic amendment treatments. FYM (T3) improved SFMY compared to T1 and T2, whereas poultry manure (T4) resulted in an even greater increase. The highest SFMY was observed in the combined treatment, with T6 (poultry manure + cigarette filters) showing the best performance, followed by T5 (FYM + cigarette filters).

The low SFMY in T1 reflects nutrient deficiency and poor soil conditions, while the slight improvement in T2 suggests limited enhancement of soil physical properties without adequate nutrient supply. Increased SFMY under FYM is attributed to improved soil structure, microbial activity, and gradual nutrient release (Kafle et al., 2015). Poultry manure further enhanced SFMY due to its higher nutrient content and faster mineralization, which promoted better water uptake and biomass accumulation (Boateng et al., 2006). Overall, integrated treatments were more effective as organic amendments reduced the negative effects of cigarette filter residues by improving soil buffering capacity and nutrient availability, thereby restoring vegetative growth under stress conditions.

Annexure(D)

Shoot Dry Matter Yield (kg/hac): The control (T1) exhibited a significant decrease in shoot dry matter yield (SDMY), which is a sign of low soil fertility and limited nutrient supply (Figure 5). The minor rise in the given case of the cigarette filter-only treatment (T2) can be taken as a sign of the insignificant enhancement of soil physical properties, but the SDMY is too low to ensure the nutritional advantage of cigarette filter residues and can cause slight phytotoxic stress. Conversely, FYM (T3) and poultry manure (T4) had a great positive impact on SDMY, increasing the soil structure, microbial activity, and nutrient supply, which have been reported in previous studies of increased maize dry biomass after the application of organic manure (Kafle et al., 2016).

The SDMY of poultry manure was larger than that of FYM, which is probably related to the fact that this type of manure contains more nutrients that can be rapidly mineralized and release nutrients faster, which stimulates photosynthesis and biomass partitioning. The highest SDMY of the combined treatment (T5 and T6) shows that organic amendments were able to alleviate the negative impacts of cigarette filter residues to buffer the stress of soils and to recover nutrient uptake. The efficacy of T6 in alleviating stress and biomass development also shows that nutrient density and mineralization rate are critical in the efficacy of organic amendment (Rizwan et al., 2016)

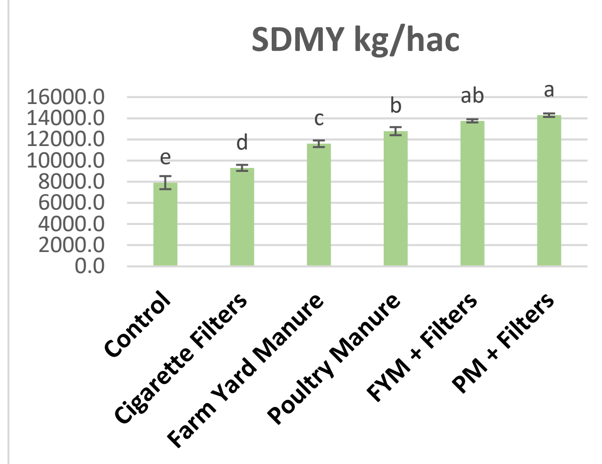

Figure 5: Shoot dry matter yield, SEM are the error bars, the letters that are received are the same, and it demonstrates that there is no notable difference.

Root Fresh Matter Yield (kg/hac): Maize fresh matter yield (RFMY) was significantly affected by cigarette filter residues, organic amendments, and their combinations (Figure 6). The lowest RFMY was recorded in the control (T1), followed by the cigarette filter-only treatment (T2), which showed a slight but still significantly lower value than all organically amended treatments. FYM (T3) significantly improved RFMY compared to T1 and T2, while poultry manure (T4) showed a further increase. The highest RFMY was observed in the combined treatments, with T6 (poultry manure + cigarette filters) performing best, followed by T5 (FYM + cigarette filters).

The low RFMY in T1 reflects poor soil physical conditions and nutrient deficiency, while the slight improvement in T2 may be due to minor changes in soil aeration, though phytotoxic effects likely restricted plant growth. Higher RFMY under FYM is attributed to improved soil aggregation, microbial activity, and water availability (Zheng et al., 2017), whereas poultry manure performed better due to its higher nutrient content and faster mineralization, which enhanced biomass production (Boateng et al., 2006). Overall, combined treatments were more effective as organic amendments helped reduce the toxicity of cigarette filter residues and improved rhizosphere conditions, with poultry manure showing superior performance compared to FYM (Rizwan et al., 2016).

Annexure(E)

Root Dry Matter Yield (kg/ha): Cigarette filter residues, organic amendments, and their combinations significantly affected the root dry matter yield (RDMY) of maize (Figure 7). The lowest RDMY was recorded in the control (T1), while cigarette filter-only treatment (T2) showed a slight but significantly higher value, though still lower than all organic amendment treatments. FYM (T3) significantly improved RDMY, while poultry manure (T4) showed an even greater effect. The highest RDMY was observed in the combined treatments, with T6 (poultry manure + cigarette filters) performing best, followed by T5 (FYM + cigarette filters).

The poor root development in T1 reflects low soil fertility and nutrient deficiency, which restricts root growth and dry matter accumulation (Grant et al., 2014). The slight improvement in T2 may be due to minor changes in soil physical properties caused by cigarette filter fibers, although toxic compounds likely inhibited root metabolism (Slaughter et al., 2011). Improved RDMY under FYM is attributed to enhanced soil structure, microbial activity, and gradual nutrient release (Kafle et al., 2016), while poultry manure performed better due to higher nutrient content and faster mineralization, promoting stronger root growth and dry matter accumulation (Boateng et al., 2006). Overall, combined treatments enhanced root performance by reducing stress from cigarette filter residues and improving rhizosphere conditions through better nutrient availability and toxicity buffering (Rizwan et al., 2016).

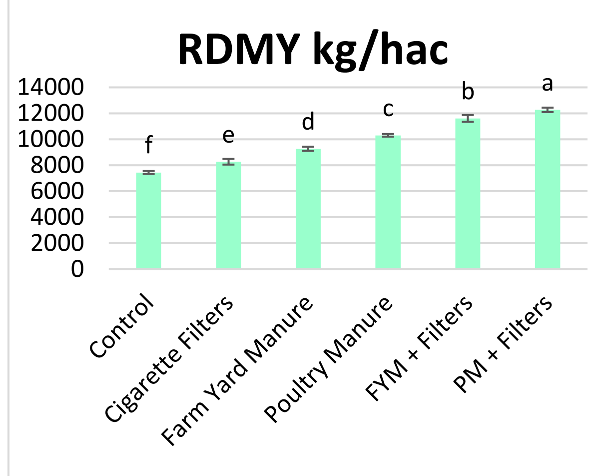

Figure 7: Root dry matter yield was lowered compared to the cigarettes that were not filtered at all. SEM is defined with error bars.

Total Leaf Area (cm²): Cigarette filter residues, organic amendments, and their combinations significantly affected the total leaf area (TLA) of maize (Figure 8). The lowest TLA was observed in the control (T1), while a slight but significant increase was recorded in the cigarette filter-only treatment (T2). Further improvements were seen with FYM (T3) and poultry manure (T4), with poultry manure showing a greater effect. The highest TLA was recorded in the combined treatments, where T6 (poultry manure + cigarette filters) performed best, followed by T5 (FYM + cigarette filters).

The low TLA in T1 reflects nutrient deficiency and poor soil fertility conditions (Pandey et al., 2000). The minor increase in T2 may be due to a slight improvement in soil physical conditions, although phytotoxic compounds in cigarette filters likely restricted leaf expansion (Novotny et al., 2009). Higher TLA under FYM is linked to improved soil structure and gradual nutrient release, particularly nitrogen (Kafle et al., 2016), while poultry manure performed better due to higher nutrient content and faster mineralization (Boateng et al., 2006; Ayeni et al., 2011). Overall, combined treatments enhanced leaf expansion by reducing toxicity and improving nutrient availability, with poultry manure proving more effective than FYM (Rizwan et al., 2016).

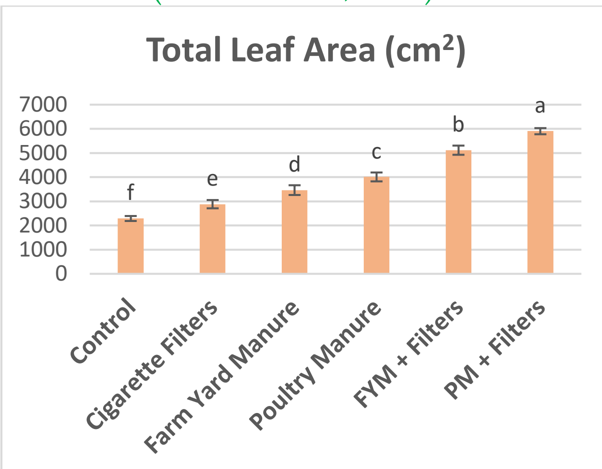

Figure 8: The total leaf area (cm²). Organic amendments were used to minimize the growth with the use of cigarette filters. SEM is given as error bars.

Leaf Area Index: Cigarette filter residues, organic amendments, and their combinations significantly affected the leaf area index (LAI) of maize (Figure 9). The lowest LAI was recorded in the control (T1), followed by the cigarette filter-only treatment (T2), which showed only a slight improvement but remained lower than all organically amended treatments. FYM (T3) and poultry manure (T4) significantly increased LAI, with poultry manure showing a stronger effect. The highest LAI was observed in T6 (poultry manure + cigarette filters), which was significantly better than all other treatments, followed by T5 (FYM + cigarette filters), indicating the superiority of combined applications.

The low LAI in T1 is attributed to nutrient deficiency and poor soil fertility (Muchow et al., 1988), while the slight improvement in T2 may be due to limited moisture retention, though phytotoxic effects likely restricted canopy development (Slaughter et al., 2011). Increased LAI under FYM is linked to improved soil structure and gradual nutrient release, especially nitrogen (Kafle et al., 2015), while poultry manure performed better due to higher nutrient content and faster mineralization (Boateng et al., 2006). Overall, combined treatments alleviated the stress caused by cigarette filter residues by improving nutrient availability and reducing toxicity, supporting better canopy development. These findings confirm that cigarette filter residues negatively affect plant growth through phytotoxic compounds and microplastic-related soil disturbances, while organic amendments enhance soil fertility, microbial activity, and nutrient availability cycling, resulting in improved maize performance.

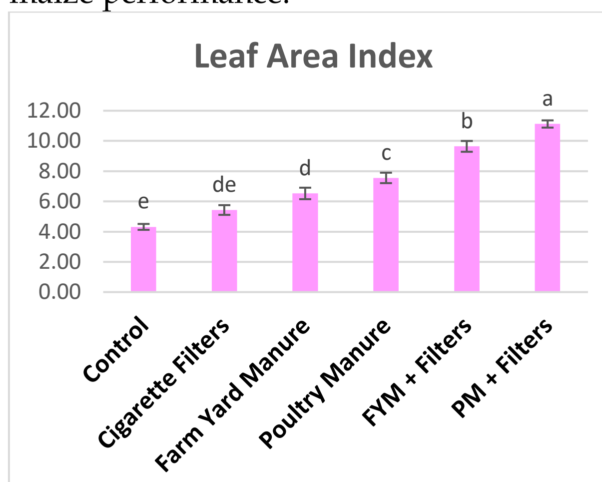

Figure 9: The various treatments' results were recorded for Leaf area index (LAI).

Yield Parameters

Yield and yield-related traits of maize were significantly influenced by cigarette filter residues and organic amendments (Figure 10). The highest values were recorded in T6 (poultry manure + cigarette filters), including cob length (19.7 cm), cob diameter (4.8 cm), grains per cob (472), 1000-grain weight (266 g), grain yield per plant (141 g), biological yield per plant (267 g), and harvest index (52.8%). In contrast, The control (T1) showed the lowest performance across all parameters.

Improved yield under organic amendments is attributed to better nutrient availability, enhanced microbial activity, and improved soil physical conditions, which support assimilate translocation toward reproductive parts. Poultry manure performed better than FYM due to its lower C: N ratio and faster nutrient release. Combined treatments (T5 and T6) showed superior performance, indicating a synergistic effect in improving soil fertility and reducing stress impacts of cigarette filter residues.

Higher 1000-grain weight and grain yield in T5 and T6 reflect improved photosynthesis, nutrient uptake, and dry matter accumulation during grain filling. These findings agree with Kandil et al. (2020) and Muhammad and Jan (2016), who reported that organic amendments enhance maize yield through improved soil fertility and nutrient use efficiency. The lower performance in the control and cigarette filter-only treatment (T2) is linked to nutrient deficiency and reduced soil biological activity. Overall, results indicate that poultry manure, especially in combination with cigarette filter residues, significantly improves maize yield and related traits under pot conditions.

Annexure(F)

Statistical Data of Measured Parameters: All values obtained were statistically significant ($p \leq 0.05$) when fertilized, and this was not the case anywhere. The Least Significant Difference (LSD) test was used to make mean comparisons, and coefficients of variation (CV%) were within acceptable ranges, showing the reliability of the experimental data.

Growth and Yield Parameters: All growth parameters of maize, including plant height, number of leaves per plant, stem diameter, shoot and root fresh and dry matter yield, total leaf area, and leaf area index, were significantly affected by the applied treatments (Table 1.1). A consistent increasing trend was observed from T1 to T6 over three weeks. Plant height at the third week increased from 119 cm in T1 to 128, 162, 175, 181, and 194 cm in T2 to T6, respectively, indicating improved vegetative growth under treatments with organic amendments. Similarly, the number of leaves increased from 8 in T1 to 11 in T6, while stem diameter also improved, reaching a maximum of 4 mm in T6 compared to 3 mm in most other treatments. Shoot and root fresh and dry matter yields showed a clear upward trend across treatments, with T6 consistently recording the highest values. Total leaf area increased markedly from 2289 cm² in T1 to 5903 cm² in T6, while leaf area index rose from 4 in T1 to 11 in T6, reflecting enhanced photosynthetic capacity and overall plant vigor under improved soil conditions.

Yield and yield-related traits were also significantly influenced by the treatments. T6 (poultry manure + cigarette filters) showed the highest performance for cob length (19.7 cm), cob diameter (4.8 cm), grains per cob (472), 1000-grain weight (266 g), grain yield per plant (141 g), biological yield per plant (267 g), and harvest index (52.8%), whereas T1 recorded the lowest values. The combined application of poultry manure and cigarette filters enhanced nutrient availability, soil fertility, and biomass accumulation, leading to improved reproductive performance. Poultry manure alone performed better than farmyard manure due to faster nutrient mineralization and greater nutrient uptake efficiency. The LSD values confirmed significant differences among treatments, while low CV (%) values (3.74–5.22%) indicated high precision and reliability of the experiment.

Table 1.1: Effects of various treatments on plant height, stem diameter, no of leaves, shoot fresh and dry matter yield, Root fresh and dry matter yield, Total leaf area, Leaf area index

Treatment	PH	NOL	SD	SFMY	SDMY	RFMY	RDMY	TLA	LAI
T1	119^{gh}	8^{ef}	3^{g}	31658^{e}	7914^{e}	24811^{f}	7443^{f}	2289^{f}	4^{e}
T2	128^{eg}	8^{f-h}	3^{g}	37249^{d}	9312^{d}	27575^{e}	8272^{e}	2882^{e}	5^{de}
T3	162^{c}	7^{h}	3^{e}	46357^{c}	11589^{c}	30904^{d}	9271^{d}	3464^{d}	7^{d}
T4	175^{b}	8^{f-h}	3^{de}	51131^{b}	12782^{b}	34359^{c}	10307^{c}	4009^{c}	8^{c}
T5	181^{b}	9^{c}	3^{b}	55025^{ab}	13756^{ab}	38693^{b}	11608^{b}	5116^{b}	10^{b}
T6	194^{a}	11^{a}	4^{a}	57161^{a}	14290^{a}	40892^{a}	12267^{a}	5903^{a}	11^{a}
LSD (0.05)	12.8	0.50	0.11	4379	1094	1858	557	512	1.02
CV (%)	5.94	3.78	3.34	5.30	5.30	3.18	3.18	7.31	7.76

PH = Plant Height; NOL = No of Leaves; SD = Stem Diameter; SFMY: Shoot fresh matter yield; SDMY: Shoot dry matter yield; RFMY: Root fresh matter yield; RDMY: Root dry matter yield; TLA: Total leaf area; LAI: Leaf area index. Treatment means were separated using the Least Significant Difference (LSD) test at 5% probability.

Table 2. Effect Of Cigarette Filter Residues And Organic Amendments On Yield And Yield-Related Attributes Of Maize Crop

Treatment	**Cob Length (cm)**	**Cob Diameter (cm)**	**Number of Grains Cob^{-1}**	**1000-Grain Weight (g)**	**Grain Yield Plant^{-1} (g)**	**Biological Yield Plant^{-1} (g)**	**Harvest Index (%)**
T1	12.4f	3.2e	278f	182e	68f	165f	41.2d
T2	13.7e	3.5d	315e	198d	79e	182e	43.4cd
T3	15.8d	3.9c	362d	221c	96d	205d	46.8bc
T4	17.1c	4.2bc	398c	238b	112c	228c	49.1b
T5	18.5b	4.5ab	436b	252ab	128b	249b	51.4ab
T6	19.7a	4.8a	472a	266a	141a	267a	52.8a
LSD (0.05)	1.12	0.31	24.5	14.2	8.6	12.8	3.1
CV (%)	4.85	5.22	4.91	3.74	5.16	4.37	3.92

Environmental and Agronomic Implications of Cigarette Filter Residues

The findings of the present study indicate that cigarette filter residues may pose both environmental and agronomic risks when accumulated in agricultural soils. Cigarette filters are primarily composed of cellulose acetate, a non-biodegradable plastic material that can persist in soil for extended periods and gradually fragment into microplastic particles. In addition, cigarette filter residues may release nicotine, heavy metals, and other toxic compounds that adversely affect soil microorganisms, nutrient cycling, and plant growth. The reduction in maize growth and yield observed under the cigarette filter treatment suggests that such contaminants can negatively influence crop productivity by interfering with root development, nutrient uptake, and physiological processes.

From an agronomic perspective, the increasing accumulation of cigarette litter in agricultural and peri-urban environments may contribute to soil degradation and reduced crop performance over time. However, the results demonstrated that the application of organic amendments, particularly poultry manure, substantially alleviated the adverse effects of cigarette filter residues.

Organic amendments improved soil fertility, enhanced nutrient availability, and promoted biomass production, thereby supporting healthier plant growth under contaminated conditions. These findings highlight the potential of locally available organic resources as sustainable and cost-effective tools for mitigating emerging soil pollutants and improving agricultural productivity.

Conclusion: The present study demonstrated that cigarette filter residues adversely affected maize growth, biomass production, and yield performance by introducing phytotoxic stress within the soil environment. Organic amendments significantly improved soil fertility and mitigated the negative effects associated with cigarette filter contamination. Among the tested amendments, poultry manure consistently outperformed farmyard manure due to its higher nutrient concentration, lower C: N ratio, and rapid nutrient mineralization. The combined application of poultry manure and cigarette filter residues produced the highest values for growth and yield parameters, indicating that organic amendments can effectively reduce contaminant stress while enhancing crop productivity. Although these findings highlight the potential role of poultry manure as a sustainable remediation strategy, further field-based and long-term investigations are required to evaluate the persistence of cigarette filter residues, associated microplastics, heavy metals, and their ecological impacts under diverse agroecological conditions.

Recommendation: Based on the findings of the present study, the application of organic amendments is recommended as a practical approach for reducing the adverse effects of cigarette filter residues in agricultural soils. Poultry manure is particularly recommended due to its superior nutrient content and greater capacity to alleviate phytotoxic stress. Farmers should avoid the disposal of cigarette filter waste in cultivated fields and surrounding agricultural environments. In areas where contamination already exists, the incorporation of organic amendments may help restore soil fertility and improve crop productivity. Future studies should focus on long-term field evaluations to assess the persistence of cigarette filter-derived contaminants, their effects on soil microbial communities, and the sustainability of organic amendment-based remediation strategies under varying environmental conditions.

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Annexure(A)

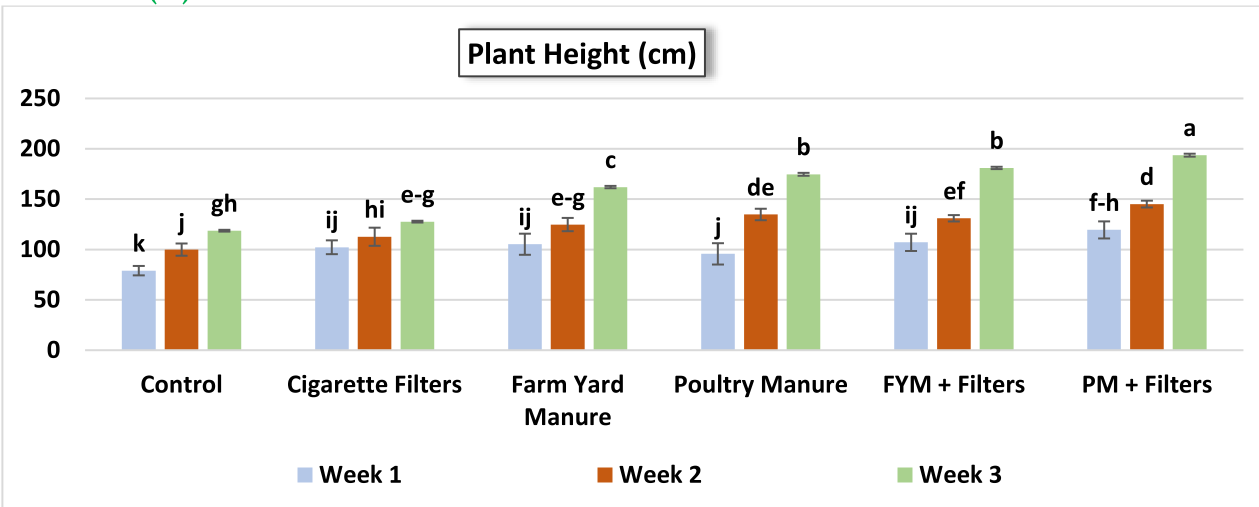

Figure 1: Plant Height, standard error of the mean (SEM) of the means are the error bars; the two bars with similar letters are not significantly different at p = 0.05.

Annexure(B)

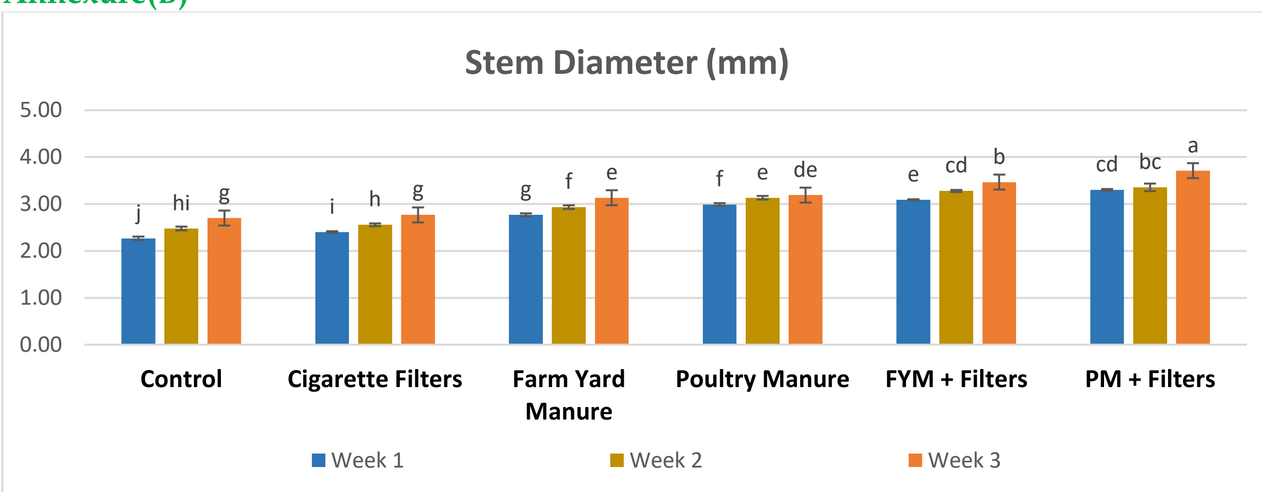

Figure 2: Stem Diameter, Error bars represent the standard error of the mean (SEM); and there is no difference between the treatments of letters and fonts identical in nature.

Annexure(C)

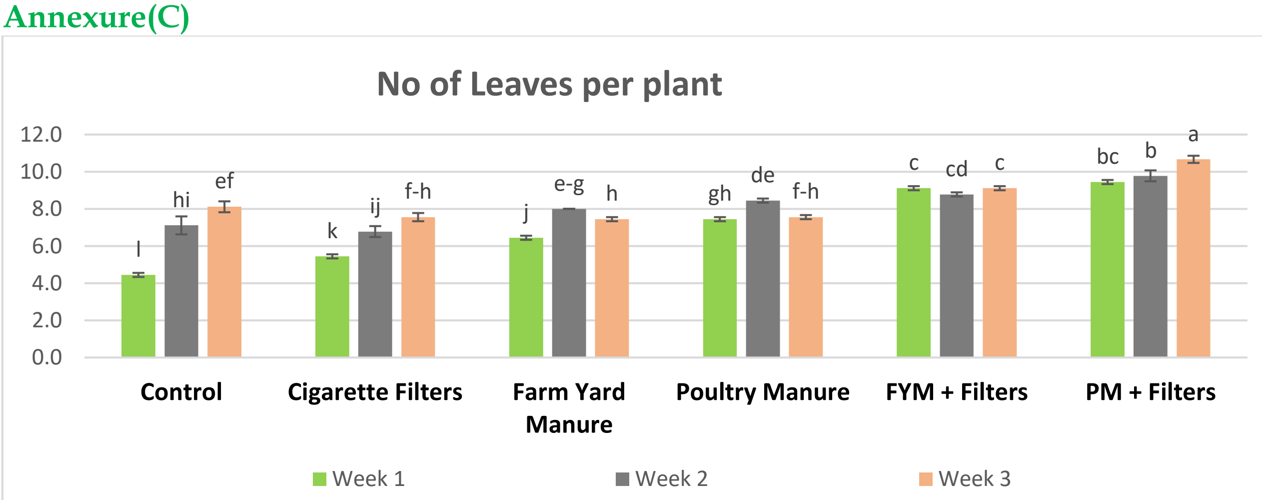

Figure 3:.No of leaves, SEM is taken as error bars, mid which the bars with the same letters do not show a significant difference.

Annexure(D)

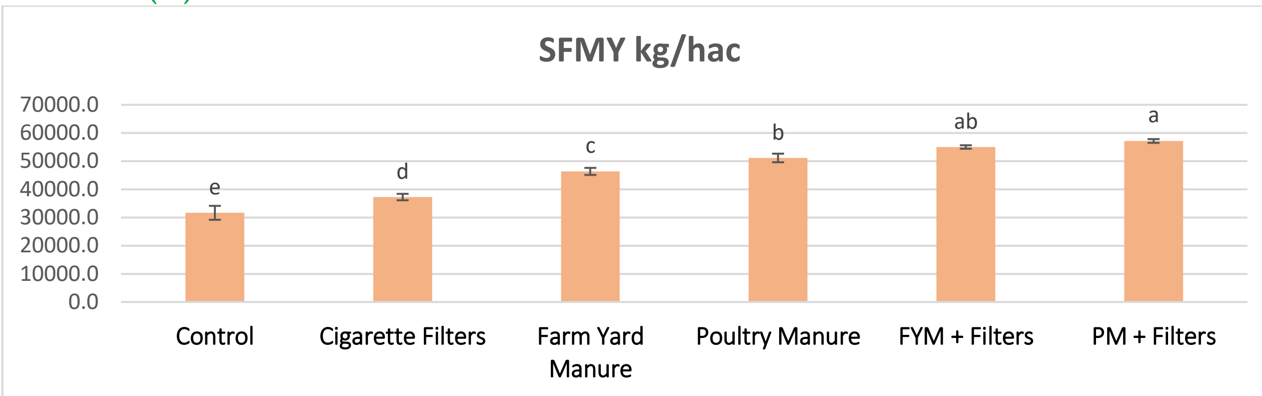

Figure 4: Shoot fresh matter yield, SEM is represented by error bars; letters of treatment that are regarded as being similar are not different.

Annexure(E)

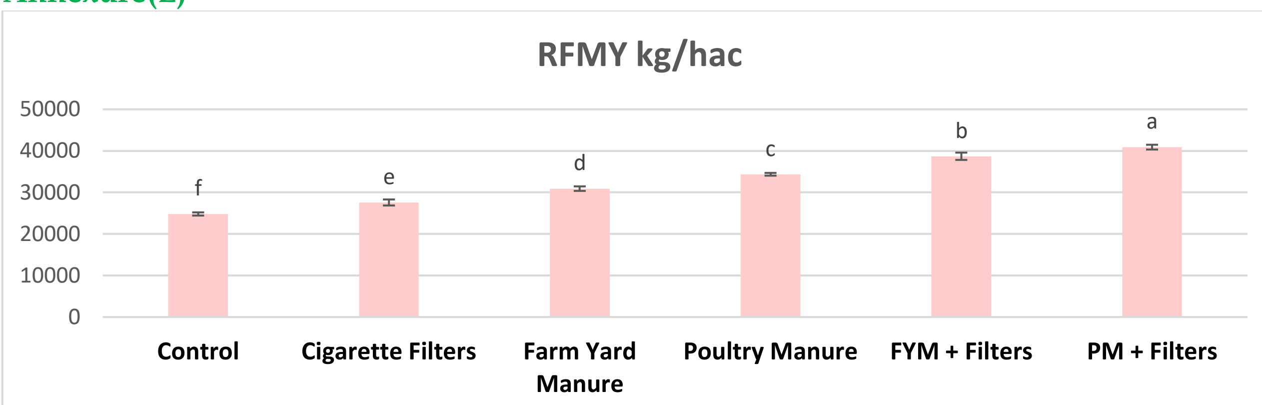

Figure 6: Root fresh matter, the adverse reaction of the filter residues of cigarettes, was overcome through organic additions. SEM is represented by the error bars.

Annexure(F)

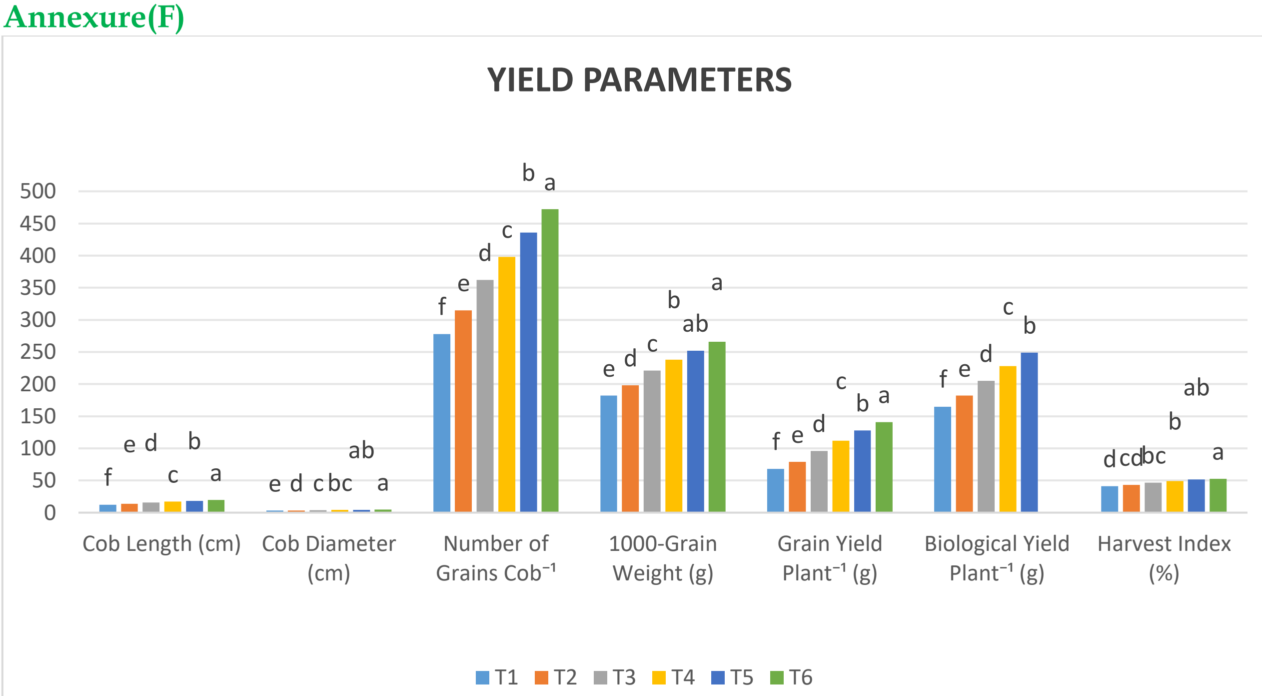

Figure 10: Effect Of Cigarette Filter Residues And Organic Amendments On Yield And Yield-Associated Parameters Of Maize