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Effect of soil pollution of Savar areas and fertilizer management on yield and nutrient accumulation in maize

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Abstract
Industrial soil contamination is an emerging threat to crop productivity and food safety in peri-urban Bangladesh, particularly around the Savar industrial zone where tannery effluents contribute to elevated levels of chromium (Cr), cadmium (Cd), and lead (Pb). This study examined the effects of soil pollution and fertilizer management on the growth, yield, and nutrient accumulation of maize (*Zea mays* L.) grown in contaminated soils of Savar. The experiment, conducted from November 2022 to January 2023, followed a Randomized Complete Block Design with four fertilizer treatments: T_0 (control), T_1 (recommended dose of chemical fertilizer), T_2 (75% chemical fertilizer + 25% cow dung), and T_3 (50% chemical fertilizer + 50% cow dung). Fertilization significantly improved vegetative and reproductive growth parameters, advancing leaf development by 3-4 days and increasing plant height by 11-12% compared to the unfertilized control. Integrated nutrient management (T_2 and T_3) delayed bud, tassel, and silk emergence by 5-10 days, extending the vegetative phase and enhancing assimilate accumulation. Total grass yield increased by approximately 35%, with the highest yield (645.3 g plant^{-1}) recorded in T_3, accompanied by a 16% increase in biomass dry weight. Fertilization also elevated macronutrient concentrations-P (by 61-67%) and K (by 85%)-and improved micronutrient accumulation, including Zn, Fe, Mn, and Cu (by 25-60%). While Pb concentration rose slightly under fertilization, Cd accumulation decreased notably (by up to 41%) in organic-amended treatments, reflecting metal immobilization through organic complexation. Overall, the combined use of cow dung and inorganic fertilizer enhanced nutrient uptake, mitigated Cd toxicity, and improved yield performance under industrially polluted soil conditions. These results highlight the potential of integrated nutrient management to sustain maize productivity and reduce heavy-metal risks in contaminated peri-urban agricultural soils of Bangladesh.

Keywords: Industrial soil contamination, integrated nutrient management, heavy metal accumulation, maize yield performance

Introduction
Soil quality is a primary determinant of crop productivity and nutritional value; however, rapid industrialization around urban-periurban areas has increasingly degraded soil health through heavy-metal and organic contamination (Angon *et al.*, 2024) [3]. In Bangladesh, the relocation and expansion of tannery and other industries to Savar has raised particular concern because tannery effluents contain high concentrations of chromium and other toxic metals that accumulate in soils and nearby crops (Mizan *et al.*, 2023) [11]. Elevated concentrations of Cr, Cd, Pb and Zn have been measured in surface soils and vegetables near the Savar leather industrial park, with some values exceeding international safety thresholds and posing both ecological and human-health risks. These contamination patterns create a pressing need to understand how industrial soil pollution affects crop performance, food safety and long-term land use in the region (Mizan *et al.*, 2023; Angon *et al.*, 2024) [11, 3].
Heavy metals perturb plant physiology and soil biogeochemistry in multiple ways that reduce crop productivity and alter nutrient dynamics. At the plant level, toxic metals can impair root growth and function, reduce photosynthetic capacity, and disrupt nutrient uptake and translocation - often causing reductions in biomass and grain yield (Angon *et al.*, 2024) [3].

At the soil level, metal contamination can suppress microbial activity and enzyme processes that mediate nutrient mineralization and availability, thereby altering the pool and mobility of essential macronutrients (N, P, K) and micronutrients required for normal crop development (Angon *et al*., 2024) [3]. Field and pot experiments in multiple regions have demonstrated sizeable yield penalties and altered nutrient partitioning in maize grown on metal-contaminated soils, especially when cadmium and chromium are present at elevated concentrations (Atta *et al*., 2023; Shah *et al*., 2023) [4, 14].

Fertilizer management strongly controls maize yield and whole-plant nutrient accumulation, but its effectiveness can be modified by background soil contamination and altered soil chemistry. Agronomic studies show that balanced N-P-K application increases maize dry-matter accumulation and grain yield and that macronutrient rates and timing determine N, P and K accumulation and remobilization patterns during silking and grain fill (Ray *et al*., 2020) [13]. Optimal fertilizer rates (often near or slightly above recommended doses for a region) maximize post-silking nutrient accumulation and remobilization to grain, but excessive or poorly timed application reduces nutrient-use efficiency and can increase environmental losses (Ray *et al*., 2020; Jiang *et al*., 2025) [13, 8]. Importantly, heavy metals in soil can interact with fertilizer-driven nutrient dynamics: for example, metal-induced root damage or microbial inhibition may reduce the plant's capacity to take up added nutrients, or alter the partitioning of nutrients between vegetative tissues and grain (Ray *et al*., 2020; Angon *et al*., 2024) [13, 3].

In the context of Savar, where tannery-derived Cr and other contaminants have been documented at markedly high concentrations, there is a critical knowledge gap on how these contaminants influence maize responses to standard and modified fertilizer regimes. Locally relevant data are needed to determine whether conventional NPK recommendations remain optimal on contaminated soils, whether fertilizer strategies can mitigate yield loss or reduce metal transfer to edible parts, and how nutrient accumulation and remobilization patterns are changed by contamination stress. Addressing these questions will help design integrated management practices that protect yield, crop quality, and food-safety in contaminated peri-urban agricultural landscapes (Mizan *et al*., 2023; Angon *et al*., 2024; Ray *et al*., 2020) [11, 3, 13].

Therefore, this study investigates (i) the effects of soil pollution in Savar on maize grain and biomass yield, (ii) how different fertilizer management regimes affect whole-plant N, P and K accumulation and remobilization when maize is grown on contaminated soils, and (iii) the implications for agronomic recommendations and food-safety risk in the Savar area. By combining field soil characterization, crop nutrient-balance measurements, and yield assessment, the study aims to provide actionable guidance for farmers and policymakers working at the interface of industrial pollution and food production.

Materials and Methods

Experimental period

The experiment was conducted during the period of November 2022 to January, 2023.

Experimental site: The experiment was conducted in the farmer's field of industrially polluted soil of Savar areas of Bangladesh. Geographically the experimental field is located at $23^0$89'N latitude and $90^0$18'E longitude at an altitude of 11.7 meter above the sea level belonging to the Agro-ecological Zone "AEZ-12" of Low Ganges River Floodplain.

Characteristics of soil

The soil of the experimental site Savar union under savar upazila belongs to the Low Ganges River Floodplain (UNDP, 1988) corresponding AEZ No. 12 and is Calcareous Dark Grey and calcareous Brown Floodplain soils. According to the textural class the soil is silty clay loam in nature and pH 6.9 and 6.3. The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done at Soil Resource and Development Institute (SRDI), Dhaka.

Climatic condition

The area has subtropical climate, characterized by high temperature, high relative humidity and heavy rainfall with occasional gusty winds in Kharif season (April-September) and scanty rainfall associated with moderately low temperature during the Rabi season (October-March).

Planting material

In this research work, seeds of hybrid maize *viz*; BARI Hybrid Maize-7 was used as planting material. The seeds were obtained from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur-1701.

Treatment of the experiment

The experiment comprised of the following treatments

1. **T_0:** Control
2. **T_1:** Recommended dose of chemical fertilizer
3. **T_2**: 75% Nutrient from chemical fertilizer + 25% nutrient from cowdung and
4. **T_3:** 50% recommended dose of fertilizer and 50% nutrient from cowdung

Experimental design and layout

The experiment was laid out in Randomized Complete Block Design with 4 treatments having four replications. There were 16 plots (4 × 4) altogether. The experimental area was divided into four equal blocks containing 4 plots in a block where 4 treatment combinations were allotted randomly. There were 16 unit plots altogether with the size of 1.7 m × 2.5 m.

Growing of crops

Preparation of the experimental land

The land was opened with the help of a tractor drawn disc harrow on (19 November, 2022) and then ploughed with rotary plough twice followed by laddering to achieve a medium tilth required for the crop under consideration. All weeds and other plant residues of previous crop were removed from the field. Immediately after final land preparation, the field layout was made on (25 November, 2022) according to experimental specification. Individual plots were cleaned and finally the plots were prepared.

Application of manure and fertilizers: Manures and fertilizers were used according the recommended dose of

BARI Krishi Projukti Hatboi for hybrid maize fertilizer. The whole amounts of fertilizers were applied as basal doses except urea. Only one third urea was applied as basal doses and the rest amount was applied at 15 DAS interval for three installments. The dose and method of application of fertilizer are shown in Table 1.

Table 1: Dose and method of application of fertilizers in maize field

Fertilizers	Dose/ha	Application (%)			
		Basal	15 DAS	30 DAS	45 DAS
Cowdung	10 tons	100	--	--	--
Urea	400 kg	--	33.33	33.33	33.33
Triple super phosphate	200 kg	100	--	--	--
Gypsum	190 kg	100	--	--	--
Muriate of potash	200 kg	100	--	--	--
Zinc sulphate	10 kg	100	--	--	--
Boric acid	10 kg	100	--	--	--

Source: Krishi Projukti Hatboi, BARI, 2019

Seed sowing and maintaining spacing

The maize seeds were sown in lines according with par treatment requirement, allocating 2 seeds hole^{-1} under direct sowing in the well prepared plot on 26 November, 2022.

Intercultural operations

After raising seedlings, various intercultural operations such as irrigation, weeding, gap filling and thinning, drainage, pest and disease control etc. were accomplished for better growth and development of the maize seedlings.

Gap filling and thinning

Gap filling was done at seventh day after sowing to maintain uniform plant population. Thinning was done two weeks after the sowing in order to maintain required plant density in each plot. By pulling out the excess seedlings in each spot, one seedling retained at each spot to maintain optimum plant population plot^{-1}.

Weed management

To check the weed growth, two inter cultivations were done during fourth and sixth week after sowing with the help of blade hoe and two hand weeding were carried out at 20 and 40 DAS.

Water management

Protective irrigation was provided to the crop depending upon the soil moisture content and prevailing weather conditions during the period of experiment. Five irrigations were given for the entire crop growth to avoid moisture stress.

Earthing up

Earthing up was done at 20 and 40 DAS along with second hand weeding and top dressed with urea. It helped to give the better anchorage and favorable environment for root growth and development. It also helped to loosen the soil, to reduce the bulk density and to increase the water holding capacity of the soil.

Plant protection measure

Plant protection measures were adopted wherever found necessary during the crop growth period. Chlorpyrifos spray 2.5 ml l^{-1} was sprayed once against the control of stem borer at 40 DAS.

Harvesting

Harvesting of all the growing maize plants were done at 60 DAS 27 January, 2023 for using as grass for animal.

Data collection

Data on various parameters were collected from the sample plants. To avoid the border effect and achieve the highest level of accuracy, five plants were chosen at random from each plot to collect data. For this, the outside rows and the outer plants in the middle rows were avoided.

Days to number of 6 leaves

Days to number of 6 leaves were documented as number of days from planting to the time of initiation of 6 number leaves.

Days to 1st bud initiation

Days to 1st bud initiation were documented as number of days from planting to the time 5% of plants had fully emerged bud.

Days to 1st taseel emergence

Days to 1st **taseel emergence** were documented as number of days from planting to the time 5% of plants had fully emerged tassels.

Days to 1st silk emergence

Days to 1st silk emergence were recorded as number of days from planting to the time 5% of plants had completely extruded silks.

Plant height

Plant height was measured from plant of each unit plot from the ground level to the tip of the longest stem and mean value was calculated and expressed in cm. Plant height was measured during harvest and value was recorded.

Number of leaves plant^{-1}

The total number of leaves plant^{-1} was counted from plant of each unit plot and recorded during harvest.

Total grass yield (g plant^{-1})

The weights of 5 plants were weighing by a weight machine and total grass yield was recorded in each plant.

Plant biomass dry weight

After harvesting, 150 g plant sample previously sliced into very thin pieces were put into envelop and placed in oven maintained at 70^{0}C for 72 hours. The sample was then transferred into desiccators and allowed to cool down at room temperature. The final weight of the sample was taken. The plant biomass dry weight was computed by simple calculation from the weight recorded by the following formula:

$$\text{Plant biomass dry weight (\%)} = \frac{\text{Dry weight of plant}}{\text{Fresh weight of plant}} \times 100$$

Results and Discussion

Days to six leaves

Days required for maize plants to reach six leaves varied significantly among fertilizer treatments under the industrially polluted soil of Savar (Table 2). The number of days ranged from 45 to 49, with the longest period (49 days) observed in T_0 (control) and the shortest (45 days) in T_1 and T_2, statistically similar to T_3 (46 days). Thus, fertilizer application accelerated early vegetative growth by 3-4 days (≈ 6-8%) compared with the unfertilized control. This faster leaf development indicates improved nutrient availability and early canopy establishment (Ray *et al.*, 2020) [13]. Integrated nutrient management, especially the inclusion of organic manure, enhances root vigor and early growth through improved nutrient mineralization and soil microbial activity (Abid *et al.*, 2020) [1].

Days to bud initiation

Bud initiation also varied significantly across treatments (Table 2). Plants under T_3 and T_2 initiated buds around 77-78 days after sowing, while the control reached this stage at 68 days. Fertilizer application delayed bud initiation by 7-10 days (≈ 10-15%) compared to the control. Delayed reproductive initiation under balanced fertilization is generally associated with prolonged vegetative growth, improved leaf area, and higher assimilate accumulation before transition to the reproductive phase (Rashid *et al.*, 2018) [12]. This extended vegetative period can lead to enhanced biomass and yield potential, provided the delay does not coincide with terminal stress.

Days to tassel emergence

The number of days to tassel emergence ranged from 77 to 85 days, with T_2 showing the longest duration (85 days), followed by T_3 and T_1. Control plants attained tassel emergence earlier (77 days) (Table 2). The increase of 5-8 days (≈ 6-10%) under fertilized conditions reflects greater nutrient-driven vegetative growth and delayed flowering. Similar observations were made by Jamsheed *et al.* (2023) [7], who reported that nutrient-sufficient maize plants exhibit prolonged vegetative stages and delayed anthesis, allowing better source-sink balance and higher grain filling later.

Days to silk emergence

Silk emergence occurred between 84 and 89 days after sowing. Fertilized plots (T_1-T_3) exhibited 4-5 days' delay compared to the control (Table 2). This pattern aligns with the delay in tasseling and suggests synchronized male-female flowering under balanced fertilization, reducing the anthesis-silking interval-a key determinant of yield stability (Masood *et al.*, 2011) [10]. Fertilizer-supplied plants likely sustained better metabolic activity and carbohydrate status during reproductive transition, favoring uniform silk emergence.

Plant height

Plant height differed significantly among treatments (Table 2), ranging from 129 cm (T_0) to 145 cm (T_3). Application of chemical fertilizer alone or combined with cow dung (T_1-T_3) increased height by 11-12% over control. Nutrient-sufficient plants develop taller stems due to enhanced cell elongation and turgor maintenance (Fang *et al.*, 2024) [5]. Organic manure addition improves soil structure, microbial biomass, and nutrient turnover, fostering sustained vegetative growth even under moderately polluted conditions (Ahmed *et al.*, 2021) [2].

Number of leaves per plant

Leaf number increased significantly with fertilizer application (Table 2), from 26.67 in T_0 to 33.33 in T_3, an ≈ 19-25% increase. The combined chemical + organic nutrient regimes (T_2 and T_3) produced the highest leaf counts, supporting previous findings that integrated nutrient sources enhance leaf initiation and expansion through balanced N-P-K availability (Sharma *et al.*, 2019) [15]. Improved foliar area under adequate fertilization facilitates greater light interception and photosynthetic efficiency, directly influencing yield formation.

Total grass yield per plant

Grass yield per plant varied significantly (Table 2), ranging from 476.8 g (T_0) to 645.3 g (T_3). Fertilized treatments (T_1-T_3) improved yield by ≈ 34-35% over the control. The best performance of T_3 (half chemical + half cow dung) suggests synergistic effects of chemical and organic nutrient sources. Organic manure can immobilize certain heavy metals, improve soil microbial balance, and sustain nutrient release, thereby mitigating stress in contaminated soils (Haque *et al.*, 2023) [6]. This yield advantage implies that partial organic substitution in fertilizer regimes is beneficial even under industrial pollution stress.

Plant biomass dry weight

Dry biomass (Table 2) ranged from 21.58 to 25.14 g per plant, with T_3 producing ≈ 16% more biomass than T_0. The improvement reflects enhanced nutrient uptake efficiency, especially under combined nutrient sources, which increase cation-exchange capacity and microbial-driven mineralization (Shu *et al.*, 2022) [16]. In polluted soils, organic amendments may also reduce the phytoavailability of toxic metals such as Cd and Pb, reducing physiological stress and enabling higher biomass accumulation (Ahmed *et al.*, 2021) [2].

Table 2: Effect of fertility regime on yield contributing characters and yield of maize grass

Fertility regime	Days to 6 leaves	Days to bud initiation	Days to tassel emergence	Days to silk emergence	Plant height	Number of leaves plant^{-1}	Total grass yield plant^{-1} (g)	Plant biomass dry weight plant^{-1} (g)
T_0	49 a	68 c	77 b	84 b	129 b	26.67 c	476.8 b	21.58 b
T_1	45 b	75 b	82 a	88 a	144 a	31.67 b	639.5 a	24.02 a
T_2	45 b	77 a	85 a	89 a	143 a	33.00 a	642.1 a	24.46 a
T_3	46 b	78 a	84 a	88 a	145 a	33.33 a	645.3 a	25.14 a
SE	0.45	0.58	1.07	0.93	2.34	0.39	7.69	1.56

In a column figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

Fertilizer treatments (T_0: Control; T_1: Recommended dose of chemical fertilizer; T_2: 75% Nutrient from chemical fertilizer +25% nutrient from cowdung; and T_3: 50% recommended dose of fertilizer and 50% nutrient from cowdung

Phosphorus (P) concentration: Phosphorus concentration varied from 0.145 to 0.242% (Table 3). Fertilized treatments increased tissue P by 61-67% over the control, with the highest value in T_1. Enhanced P uptake likely results from improved root activity and microbial solubilization of soil P stimulated by organic matter inputs (Kkan *et al*., 2009) [9]. Under industrial contamination, chemical fertilizers may still supply readily available P that compensates for reduced microbial P mobilization, while organic inputs improve P availability through chelation and organic acid production.

Potassium (K) concentration

The K content ranged from 1.267 to 2.358%. Fertilizer application significantly increased K uptake by ≈ 85% (Table 3). K is critical for osmotic regulation and enzyme activation, both of which are compromised under metal stress (Zhao *et al*., 2021) [17]. Hence, improved K nutrition likely contributed to better turgor maintenance and yield in T_1-T_3 treatments.

Micronutrient concentrations (Zn, Fe, Mn, Cu)

All micronutrients increased significantly with fertilizer treatments (Table 3). Zn (62.56-80.95 ppm), Fe (78.13-97.68 ppm), Mn (32.67-53.00 ppm), and Cu (25.34-39.03 ppm) contents were highest in T_3, with increases ranging ≈ 25-60% over T_0. Organic matter enhances micronutrient availability by forming soluble organic complexes and stimulating rhizosphere activity (Sharma *et al*., 2019) [15]. T_3's balanced regime thus likely improved both nutrient uptake and metal tolerance, consistent with reports that organic inputs can chelate metals and buffer soil pH (Ahmed *et al*., 2021; Shu *et al*., 2022) [2, 16].

Lead (Pb) concentration

Pb concentration increased slightly (≈ 18%) with fertilizer use (Table 3), from 1.045 ppm in T_0 to ≈ 1.24 ppm in T_1-T_3. The higher Pb uptake despite organic additions may reflect the background contamination level of Savar soils, where soluble Pb forms persist due to tannery effluent deposition (Mizan *et al*., 2023) [11]. However, the absence of large differences among T_1-T_3 suggests that organic amendments moderately constrained Pb mobility compared with chemical fertilizers alone.

Cadmium (Cd) concentration

Cd concentration decreased notably under fertilization (Table 3), from 0.678 ppm in T_0 to 0.403 ppm in T_3 (a 20-41% reduction). The suppression of Cd uptake in organic-amended soils may result from immobilization through complexation with humic substances or precipitation with carbonates (Haque *et al*., 2023) [6]. This indicates a beneficial role of cow dung in mitigating Cd bioavailability and supporting cleaner biomass production. Similar findings have been reported for maize and leafy vegetables grown on polluted soils amended with organic matter (Ahmed *et al*., 2021) [2].

Table 3: Effect of fertility regime on P, K. Zn, Fe, Mn, Cu, Pb and Cd concentration in dry matter of maize grass

Fertility regime	Concentration of							
	P (%)	K (%)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Pb (ppm)	Cd (ppm)
T_0	0.145 b	1.267 b	62.56 b	78.13 b	32.67 b	25.34 b	1.045 b	0.678 a
T_1	0.242 a	2.358 a	78.48 a	95.64 a	52.67 a	38.43 a	1.238 a	0.538 b
T_2	0.233 a	2.342 a	79.34 a	97.33 a	52.56 a	38.22 a	1.231 a	0.534 b
T_3	0.241 a	2.351 a	80.95 a	97.68 a	53.00 a	39.03 a	1.238 a	0.403 c
SE	0.012	0.13	2.33	1.49	1.74	1.93	0.048	0.085

In a column figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

Fertilizer treatments (T_0: Control; T_1: Recommended dose of chemical fertilizer; T_2: 75% Nutrient from chemical fertilizer +25% nutrient from cowdung; and T_3: 50% recommended dose of fertilizer and 50% nutrient from cowdung)

Overall interpretation

Across all traits, fertilizer management markedly improved maize growth, yield, and nutrient accumulation while reducing Cd uptake under industrially contaminated soil conditions. The integrated nutrient regimes (T_2 and T_3) performed comparably or better than chemical fertilizer alone, demonstrating that combining organic and inorganic sources can enhance nutrient efficiency, suppress metal toxicity, and sustain productivity in polluted environments. These outcomes align with broader evidence that integrated soil fertility management can restore soil biological functions and crop quality in contaminated peri-urban systems (Angon *et al*., 2024; Mizan *et al*., 2023) [3, 11].

Conclusion

The present study demonstrates that fertilizer management, particularly the integration of organic and inorganic nutrient sources, substantially improves maize growth, yield, and nutrient accumulation even under industrially contaminated soil conditions in Savar. The polluted soils, characterized by elevated heavy-metal concentrations, constrained crop performance in unfertilized plots, whereas nutrient supplementation alleviated toxicity effects and promoted vigorous growth. Treatments incorporating cow dung (T_2 and T_3) enhanced plant height, leaf number, and total biomass through improved soil structure, microbial activity, and nutrient availability. The mixed fertilizer regimes significantly increased P, K, and micronutrient concentrations while effectively reducing Cd accumulation in plant tissue, suggesting that organic amendments can immobilize toxic metals and buffer soil pH. Although a slight increase in Pb content was noted, the overall nutrient-to-metal balance improved markedly under integrated management. Among all treatments, T_3 (50% chemical fertilizer + 50% cow dung) provided the best combination of yield improvement and contaminant mitigation. Therefore, partial substitution of inorganic fertilizers with organic manure represents a viable strategy for maintaining soil fertility, enhancing nutrient-use efficiency, and reducing metal uptake in maize cultivated on polluted soils. These findings offer practical insights for developing sustainable fertilizer management protocols in the industrially impacted agroecosystems of Bangladesh.

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Informed consent
No animal was harmed during the study.

Conflict of Interest
The authors declare that there are no conflicts of interest among the authors.

Data Availability: The datasets used in the current study are available from the corresponding author on reasonable request.

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