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Humic Silica for Optimising Soil Phosphorus Availability and Phosphorus Uptake by Maize Plants on Industrial Contaminated Lands

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ABSTRACT

This study aimed to evaluate the effect of humic-silica application on P availability and P uptake by corn in land contaminated with heavy metals. The experiment was arranged in a Completely Randomized Design (CRD) with two treatment factors. The first factor consisted of three industrial locations: the pharmaceutical industry, the animal feed industry, and the paper industry. The second factor consisted of four levels of humic-silica application (in kg/ha): 0, 10, 20, and 30. Observations were made at the age of 14 and 70 days after planting (DAP). The parameters included soil organic carbon, Cation Exchange Capacity (CEC), soil P-available, and total P uptake by corn plants. Results showed that the humic-silica application at 20 kg/ha had a significant effect on P-available and P uptake by corn plants. This positive effect was consistent in the three industrial locations, both in 14 DAP and 70 DAP observations. These findings indicate that the use of humic-silica at 20 kg/ha has potential to reduce the negative impacts of heavy metal pollution on the availability of plant nutrients in industrial lands. This study provides insight into strategies for managing industrially contaminated lands to increase agricultural productivity, especially in terms of increasing the availability and absorption of phosphorus by corn plants.

1. INTRODUCTION

Corn productivity in urban areas forces farmers to grow corn on lands adjacent to industrial areas, which is often hampered by limited nutrient availability, especially phosphorus (P). Phosphorus is an essential macronutrient that plays an important role in various plant physiological processes, including photosynthesis, root formation, and seed development. However, P availability in soil is often limited because phosphorus tends to be bound by soil minerals such as iron and aluminum, or leached by water, especially in soils with low pH. The presence of heavy metals in lands around industrial areas can significantly affect the availability of phosphorus (P) in soil, an essential nutrient for plant growth. The interaction between heavy metals and available phosphorus is complex, involving various chemical and biological mechanisms. Heavy metal contamination can alter soil pH, which is a key factor in controlling phosphorus solubility and availability. Soils that become more acidic due to heavy metal pollution tend to increase phosphorus fixation by aluminum and iron, further reducing available P (Bolan *et al*., 2014). Heavy metals can also disrupt the activity of soil microorganisms that play important roles in the mineralization of organic phosphorus, such as phosphate-solubilizing bacteria, thus inhibiting the natural P cycle in the soil (Panjaitan *et al*., 2020).

Humic acid as a soil amendment has a high capacity to form complexes with heavy metals, a process known as chelation. According to Tan *et al*. (2023), the formation of humate-metal complexes can reduce the mobility and bioavailability of heavy metals, thereby reducing their toxicity to plants and soil microorganisms. This can indirectly help increase the activity of phosphate-solubilizing microbes that were previously inhibited by the presence of heavy metals. Additionally, humates can also improve soil water retention, which helps maintain soil moisture and nutrient availability. Humic acid functions as a ligand capable of binding nutrients in complex forms, temporarily storing them in the soil, and releasing them according to plant needs (Holatko *et al*., 2022). This ability is supported by the presence of active functional groups in humic acids, such as carboxyl groups (-COOH), phenolic hydroxyl groups (-OH phenolic), alcoholic hydroxyl groups (-OH alcoholic), and carbonyl groups (-C=O). These groups play important roles in the process of nutrient release and metal binding (Ali & Mindari, 2016). Silica in soil amendments can increase soil pH, especially in acidic soils. Li *et al*. (2023) reported that the increase in pH by silica can reduce phosphorus fixation by aluminum and iron, thereby increasing P availability. In addition, silica can compete with phosphate for adsorption sites on soil mineral surfaces, which can effectively increase the concentration of phosphorus in soil solution.

The combination of humic and silica can provide synergistic effects in increasing P availability in the soil. Humic can help release P bound by soil minerals, while silica increases the efficiency of P uptake by plants. Humic and silica can increase the cation exchange capacity (CEC) of soil. This increase in CEC, as explained by Olk *et al*. (2021), can help retain nutrients including phosphorus, while providing more binding sites for heavy metals, reducing the possibility of these metals interacting with and immobilizing phosphorus. Research results show that the application of this combination not only increases P availability in the soil but also increases P uptake by corn plants, which ultimately can increase crop yields. Therefore, this research aims to evaluate the effectiveness of humic and silica soil amendments on soil P availability and P uptake by corn plants in several industrial lands. The results of this research are expected to provide practical solutions for increasing corn productivity in industrial lands through more efficient nutrient management.

2. MATERIALS AND METHODS

2.1. Research Location and Time

This research was conducted from July 2023 to January 2024. Soil samples were taken from rice fields near the industry in Sidoarjo. The AH-Si application test was conducted at the Balongpanggang District Experimental Garden, Gresik Regency, with coordinate's 7°19'27.5"S 112°23'31.1"E. Analysis of soil and plant samples was carried out at the Land Resources Laboratory of the Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Jawa Timur.

2.2. Tools and Materials

The tools used during the research included hoes, arco, sacks, rope, needles, sieves, analytical scales, writing instruments, cameras, and GPS. The materials required were soil samples, humic-silica soil amendment, leonardite, rice husk ash, polybags, zip-lock plastic bags, and chemical analysis materials.

2.3. Research Design

This research was arranged according to a factorial Completely Randomized Design (CRD) to evaluate the effects of two main factors: humic-silica dosage and industrial land sample location. The layout of the experimental plot using 20cm × 20cm black polybags with a distance between polybags of 40 cm after randomization using Excel 2019 software was depicted in Figure 1. The first factor, humic-silica dosage, consisted of four levels: control (0 kg/ha), 10 kg/ha, 20 kg/ha, and 30 kg/ha. The second factor included three different types of industrial lands: pharmaceutical industry, animal feed industry, and paper industry. The combination of these two factors resulted a total of 12 different

P0 L1 (2)	P1 L3 (3)	P2 L1 (3)	P3 L1 (3)	P0 L1 (1)	P3 L2 (1)
P2 L2 (2)	P1 L2 (2)	P2 L3 (3)	P0 L2 (1)	P2 L2 (3)	P1 L3 (2)
P3 L3 (2)	P1 L1 (2)	P0 L2 (3)	P3 L3 (1)	P3 L3 (3)	P2 L1 (2)
P0 L3 (2)	P2 L2 (1)	P0 L3 (1)	P3 L1 (2)	P3 L2 (2)	P2 L3 (1)
P1 L1 (1)	P1 L3 (1)	P1 L1 (3)	P0 L2 (2)	P0 L3 (3)	P3 L2 (3)
P1 L2 (1)	P2 L1 (1)	P1 L2 (3)	P2 L3 (2)	P3 L1 (1)	P0 L1 (3)

Figure 1. Completely randomized design combination

treatments. Each treatment was replicated three times to increase the accuracy of results and reduce the influence of uncontrolled variables. The factorial CRD was used to evaluate not only the individual effects of each factor but also the potential interactions between humic-silica dosage and industrial land type on the parameters being studied.

2.4. Research Implementation

2.4.1. Soil Sampling

Soil samples for the research were taken near industrial lands that were indicated to be affected by industrial waste due to industrial activities in the local area. The research began with a survey of locations adjacent to industries, road access, and irrigation sources. Sampling points included: (1) 550 m from a pharmaceutical industry in Ponokawan Village, Krian; (2) 950 m from an animal feed industry in Balong Village, Sukodono; and (3) 990 m from a paper industry in Kanigoro Village, Tarik. Samples were taken at a depth of 0-20 cm using hoes, sacks, rope, and needles.

2.4.2. Preparation of Growing Media

After sampling was completed, soil samples were air-dried. The soil was crushed and standardized to a size of ±2 mm using a sieve. The growing media was then placed into polybags with a weight of 8 kg per polybag. Before application, samples were saturated with water to field capacity.

2.4.3. Preparation of Humic-Silica Soil Amendment

Preparation was carried out in several stages: preparation, soil amendment application, planting, plant maintenance, and harvesting. The preparation stage included extraction of humic acid and silica, which were then mixed. Humic acid extraction used a modified from Stevenson (1994) method. Silica extraction from rice husks involved manually burning the husks to produce ash, following (Njoku *et al*., 2015). Silica was adjusted to pH 8-9 using KOH solution with a stirrer at 85°C. Silica was added to the humic acid and adjusted to pH 4-5 using a stirrer. At low pH, competition between H^+ ions and metal cations for binding increases, which can cause the release of metals from soil particles (Shahid *et al*., 2020).

2.4.4. Application of Humic-Silica

The prepared growing media were then treated with humic-silica soil amendment. The soil amendment was applied 7 days before 7-day-old corn seedlings were transplanted into the polybags. Humic-silica was applied at doses of 0 kg/ha (0 g), 10 kg/ha (0.052 g), 20 kg/ha (0.104 g), and 30 kg/ha (0.156 g).

2.4.5. Plant Corn to Harvest

The corn plants used are local Madura corn varieties of Elos. The seeds are sown on trays filled with moist soil to optimize corn seedling growth. Two corn seedlings aged 7 days after sowing are planted in each polybag filled with soil with the addition of AH-Si.

Fertilization was done once, using doses of Urea 200 kg/ha (1.04 g) (Shaila *et al*., 2019), SP-36 175 kg/ha (0.91 g) (Afriani *et al*., 2023), and KCl 125 kg/ha (0.65 g) (Amirrullah *et al*., 2020). Corn plant maintenance included regular watering and weed cleaning. Harvesting is done when the corn is 70 HST, according to the age of the Elos variety of corn. Corn plants are removed from polybags, by separating the plant parts into 3 parts: stems, leaves, and roots.

2.4.6. Laboratory Analysis

Soil samples were taken from polybags on days 14 and 70, using the destruction method, with 3 sampling points per polybag. Sampling was done at 0 days after planting (DAP), 14 DAP, and 70 DAP, then dried, crushed, and sieved (sizes 2 mm and 0.5 mm). Analysis was performed on the initial soil before humic-silica soil amendment treatment, as well as at 14 DAP and 70 DAP. Soil analysis included measurements of organic carbon, soil CEC, available P, and total P in plant tissue. This process allowed for a comprehensive evaluation of soil conditions and nutrient uptake by plants after treatment (BSIP, 2023).

2.4.7. Data Analysis

For research data processing, a two-way Analysis of Variance (ANOVA) method was used. This method was chosen to assess the effects of two main factors: location and humic-silica dose, as well as possible interactions between them. When ANOVA results showed significant differences, the analysis continued with Tukey's test (Honestly Significant Difference) at a 5% confidence level. This further test aimed to specifically identify where significant differences occurred between factors.

3. RESULTS AND DISCUSSION

3.1. Characteristics of Humic-Silica Soil Amendment

The humic-silica soil amendment will be applied to three industrial locations. With a pH of 5.3, this amendment is slightly acidic, which can influence nutrient availability and heavy metal behavior in the soil after application (Tan *et al*., 2023). The organic carbon content of 0.27%, although relatively low, indicates the presence of organic components that can contribute to increased water retention capacity and soil nutrients (Stevenson, 1994). The very low total nitrogen (N-total) content (0.01%) indicates that this amendment is not a primary source of nitrogen, but rather focuses on improving soil structure and adsorption capacity (Brady & Crockett, 2024). The equally low total phosphorus (P-total) content (0.01%) shows that this amendment is not intended as a phosphorus source, but rather plays a role in enhancing the availability of phosphorus already present in the soil through interactions with soil minerals (Bueis *et al*., 2019). The total potassium (K-total) content of 0.13% indicates potential potassium supply, albeit in limited quantities, which can support plant nutrition (Liu *et al*., 2024).

Table 1. Characteristics of humic-silica soil amendment

Parameter	pH	Organic-C	Total N	Total P	Total K
Value	5.3	0.27%	0.01%	0.01%	0.13%

These characteristics indicate that the humic-silica soil amendment is directed more toward improving the physical and chemical properties of soil rather than serving as a direct nutrient source. The combination of humic and silica in this amendment has the potential to increase cation exchange capacity, improve soil structure, and enhance water retention (Olk *et al*., 2021; Li *et al*., 2023). In the context of heavy metal remediation of contaminated soil at industrial sites, these characteristics can assist in the immobilization of heavy metals through complex formation with humates and pH enhancement by silica (Park *et al*., 2011; Liang *et al*., 2019).

3.2. Initial Soil Characteristics

The analysis results of initial soil characteristics show that the soils from three locations associated with pharmaceutical, animal feed, and paper factories exhibit significant variations, reflecting the potential impact of factory activities on soil conditions. All three locations have relatively neutral pH (6.97-7.04), but differ in nutrient content and texture. The soil at the animal feed factory location shows the highest organic carbon content (2.94%) and total N (0.21%), while the paper factory location has the lowest (organic carbon 1.89%, total N 0.11%). The highest available P was found at the animal feed location (34.73 ppm), followed by the pharmaceutical location (27.21 ppm) and paper (18.02 ppm), all categorized as high (Havlin *et al*., 2022). The CEC of all three soils is also high, with the pharmaceutical location being the highest (44.34 cmol/kg). These types of industrial sites are associated with potential heavy metal contamination. Pharmaceutical factories can produce waste containing heavy metals such as cadmium, chromium, and lead (Okoro *et al*., 2023). The animal feed industry contributes to the accumulation of zinc and copper in soil (Zhang *et al*., 2014). Meanwhile, the paper industry has the potential to release heavy metals such as chromium, lead, and mercury into the environment (Tewari, *et al*., 2023).

Application of humic-silica soil amendment has the potential to change soil conditions, especially in the context of heavy metal contaminated soil remediation. Humic substances can form stable complexes with heavy metals, reducing their mobility and bioavailability in soil (Park *et al*., 2011). This can be highly beneficial in reducing the risk of heavy metal uptake by plants around the three industrial locations. Silica can increase soil pH and buffer capacity, which can

Table 2. Initial soil characteristics

Parameter	Unit	Pharmaceutical	Animal feeding	Paper	Criteria (*)
pH H_20	-	7.04	6.97	6.97	Neutral
C-organic	%	2.21	2.94	1.81	Medium- low
N-total	%	0.18	0.21	0.11	Low
P-available	ppm	27.21	34.73	18.02	high
CEC	cmol/kg	44.34	38.88	33.80	high
Texture		Silty Loam	Silty Loam	Loam	
Sand	%	7	3	29	
Silt	%	67	74	49	
Clay	%	26	23	22	

Note (*): Criteria sourced from BSIP Soil and Fertilizer (2023)

help in immobilizing certain types of heavy metals (Liang *et al*., 2019). This is particularly effective at the paper factory location which has higher sand content. The humic-silica combination potentially enhance soil microbial activity and improve soil structure, which can support natural phytoremediation processes (Li *et al*., 2023). Increased CEC by humic-silica help in retaining heavy metal cations, preventing leaching into groundwater (Olk *et al*., 2021).

3.3. Results of Humic-Silica Application

3.3.1. Effect of Humic-Silica at 14 DAP

Analysis data shows the effect of humic-silica application at three factory locations (Pharmaceutical, Animal Feed, and Paper) with various doses (0, 10, 20, and 30 kg ha^{-1}) after 14 days of application. Compared to initial conditions, significant changes were observed in several parameters. For the pharmaceutical factory location, organic carbon content slightly decreased from 2.21% to a range of 1.87-1.96% across various application doses. However, CEC showed an increase from 44.34 cmol kg^{-1} to 44.06 cmol kg^{-1} at the highest dose. Available P also increased from 27.21 ppm to a range of 35.07-38.57 ppm. These increases in CEC and available P align with the findings of Li *et al*. (2023) who reported that humic-silica can increase soil nutrient retention capacity.

At the animal feed factory location, organic carbon decreased from 2.94% to a range of 2.04-2.18%, but remained higher compared to other locations. CEC experienced a significant increase from 38.88 cmol kg^{-1} to 48.63 e cmol kg^{-1} at a dose of 10 kg ha^{-1}. Available P also increased from 34.73 ppm to a range of 38.20-47.74 ppm. This significant increase in CEC was caused by the positive interaction between humic silica and the already high organic matter at this location, as explained by Olk *et al*. (2021). For the paper factory location, organic carbon increased from 1.89% to a range of 1.44-1.73%. CEC decreased from 33.80 cmol kg^{-1} to 25.78-28.03 abc cmol kg^{-1}, available P increased from 18.02 ppm to a range of 24.55-31.04 ppm. The increase in organic carbon at this location was due to the direct contribution of humic in the soil amendment, as proposed by Stevenson (1994). Overall, the application of humic silica showed varying effects on initial soil characteristics and application doses. The increase in available P at all locations is consistent with the findings of Bueis *et al*. (2019) regarding the role of humic in increasing phosphorus availability. The variation in CEC response is related to differences in texture and initial soil organic content, as explained by Brady & Crockett (2024), with increases in CEC at some locations potentially having positive implications for heavy metal immobilization, in line with research by Park *et al*. (2011).

Table 3. ANOVA test on the effect of humic-silica on P-available, CEC, and C-organic at 14 DAP

		F- value			F-0.05	F-0.01
Sources	Df	Available- P	CEC	Org_-C		
Treatment	11	0.006	0.001	27.66	2.22	3.09
Location (L)	2	243.413 **	48.626 **	146.176 **	3.403	5.614
AH-Si (P)	3	1.656 ns	0.903 ns	1.047 ns	3.009	4.718
L × P	6	0.951 ns	3.476 *	1.241 ns	2.508	3.667
Error	24					
Total	35					

Table 4. Effect of humic-silica at 14 DAP

Industry	Dosies	C-organic (%)	CEC (Cmol kg-1)	P-avail (ppm)
Pharmaceutical	0 kg/ha	1.92	40.18 cde	35.07
	10 kg/ha	1.87	39.12 bcde	35.62
	20 kg/ha	1.96	44.06 de	35.57
	30 kg/ha	1.9	42.52 de	38.57
Animal feed	0 kg/ha	2.11	44.66 de	47.74
	10 kg/ha	2.14	48.63 e	44.05
	20 kg/ha	2.18	35.48 abcd	38.2
	30 kg/ha	2.04	34.14 abcd	38.91
Paper	0 kg/ha	1.44	25.78 a	24.55
	10 kg/ha	1.49	26.65 ab	24.63
	20 kg/ha	1.54	24.19 a	27.22
	30 kg/ha	1.73	28.03 abc	31.04
BNJ 5%		0.55	13.02	16.8

Note: Mean values followed by the same letter are not significantly different according to HSD test at 95% significance level.

3.3.2. Effect of Humic Silica at 70 DAP

The analysis data shows the effect of humic silica application at three industrial locations (Pharmaceutical, Animal Feed, and Paper) after 70 days of application with various doses (0, 10, 20, and 30 kg/ha). Compared to the initial conditions and results 14 days after application, significant changes are seen in several soil parameters. At the Pharmaceutical factory location, organic carbon content increased from the initial condition of 2.21% to 2.31% at a dose of 30 kg/ha, showing the long-term positive effect of humic silica on soil organic matter content.

Table 5. ANOVA test of humic silica effect on P-available, CEC, and C-organic at 70 DAP

		F- value			F-0.05	F-0.01
Sources	Df	Available- P	CEC	Org_-C		
Treatment	11	0.001	0.002	71.48	2.22	3.09
Location (L)	2	32.922 **	71.068 **	381.354 **	3.403	5.614
AH-Si (P)	3	0.847 tn	0.333 tn	1.040 tn	3.009	4.718
L x P	6	0.558 tn	5.350 **	3.511 *	2.508	3.667
Error	24					
Total	35					

Table 6. Effect of humic-silica at 70 DAP

Industry	Doses	C-organic (%)	CEC (Cmol kg-1)	P-tavail (ppm)
Pharmaceutical	0 kg/ha	2.21 b	40.12 d	37.23
	10 kg/ha	2.20 b	36.78 cd	28.71
	20 kg/ha	2.31 bc	37.92 cd	32.12
	30 kg/ha	2.17 b	34.77 bcd	29.76
Animal feed	0 kg/ha	2.34 bc	32.47 abc	37.08
	10 kg/ha	2.37 bc	38.65 cd	36.97
	20 kg/ha	2.19 b	38.13 cd	39.54
	30 kg/ha	2.46 c	40.03 d	38.54
Paper	0 kg/ha	1.50 a	29.14 ab	15.74
	10 kg/ha	1.52 a	28.79 ab	15.12
	20 kg/ha	1.42 a	28.04 a	22.16
	30 kg/ha	1.48 a	27.72 a	14.92
LSD 5%		0.25	6.24	19.26

Note: Mean values followed by the same letter are not significantly different according to HSD test at 95% significance level.

This is in line with the findings of Liu *et al*. (2024), who reported an increase in soil organic carbon after the application of humic substances. However, CEC decreased from 44.34 cmol/kg to a range of 34.77 - 40.12 cmol/kg, due to changes in soil ion dynamics over time. Available P increased from 27.21 ppm to a range of 28.71 - 37.23 ppm, indicating the positive effect of humic-silica on phosphorus availability, as reported by Özmeir (2023).

At the Livestock Feed location, soil organic carbon slightly decreased from 2.94% to a range of 2.34 - 2.46%, but remained higher than other locations. CEC also slightly declined from 38.88 cmol/kg to a range of 38.13 - 40.03 cmol/kg. Available P increased from 34.73 ppm to a range of 36.97 - 39.54 ppm. The relative stability of these parameters suggests that the soil at the livestock feed location has a high organic matter content, as explained by Lehmann & Kleber (2015).

At the Paper Mill location, soil organic carbon decreased from 1.89% to a range of 1.48 to 1.52%, highlighting the challenge of maintaining organic matter in this area. CEC declined from 33.80 cmol/kg to a range of 27.72 to 29.14 cmol/kg. Available P dropped significantly from 18.02 ppm to a range of 14.92 to 15.44 ppm. This decline is associated with the sandier soil characteristics at this location, which tend to have lower nutrient retention capacity, as discussed by Brady & Crockett (2024).

Overall, the long-term effects of humic silica application vary depending on the initial soil characteristics and application rates. The increase in organic carbon in certain locations demonstrates the potential of humic silica to enhance soil quality, in line with the findings of Suciu *et al*. (2019). Variations in available P response are related to the complex interactions between humic silica and soil minerals, as explained by Guppy *et al*. (2005). The increase in organic carbon may enhance soil capacity for heavy metal immobilization, as reported by Park *et al*. (2011). For the Pharmaceutical Plant location, the optimal dose for P-available was 20 kg/ha, with the highest value of 32.12 ppm. At the Livestock Feed location, a dose of 20 kg/ha resulted in the highest P-available of 39.54 ppm. Increasing the dose from 0 to 20 kg/ha showed a positive trend in P-available. At the Paper Mill location, the 20 kg/ha dose also produced the highest P-available, at 22.16 ppm, with a significant increase from 0 kg/ha (15.74 ppm) to 20 kg/ha.

3.3.3. Effect of Humic-Silica on P-uptake in Maize Plants

Based on the phosphorus (total P) uptake data presented in the table, an increasing trend in P uptake is observed with higher humic-silica application rates. In the leaf section, the highest total P uptake was recorded at a dose of 20 kg/ha across all locations: 0.18% at the Pharmaceutical Plant, 0.17% at the Livestock Feed location, and 0.14% at the Paper Mill. This is consistent with the findings of Nugroho (2021), which showed that organic matter application can enhance nutrient uptake in the vegetative parts of plants.

For the root section, the highest total P uptake was also achieved at a dose of 20 kg/ha, with values of 0.10% at the Pharmaceutical Plant, 0.12% at the Livestock Feed location, and 0.10% at the Paper Mill. The increase in total P uptake in roots indicates the plant's ability to absorb nutrients optimally, in line with the statement by Sutanto *et al*. (2022) that organic matter can improve the physical, chemical, and biological properties of soil. A similar pattern was observed in the stems, where the highest total P uptake was achieved at a dose of 20 kg/ha, with values of 0.20% at the Pharmaceutical Plant, 0.16% at the Livestock Feed location, and 0.15% at the Paper Mill. This suggests that the application of -ilica at a dose of 20 kg/ha can enhance the translocation of P nutrients throughout the maize plant. Overall, the 20 kg/ha dose of humic silica can be considered the optimal dose for increasing total phosphorus uptake in maize plants across the three locations.

Table 7. ANOVA test of the effect of humic-silica on P-total in leaves, root, and steam at 14 DAP

		F- value Total P			F-0.05	F-0.01
Sources	df	in leaves	In Root	In Steam		
Treatment	11	0.443	1.664	0.947	2.22	3.09
Location (L)	2	0.106 tn	3.282 tn	0.553 tn	3.403	5.614
AH-Si (P)	3	0.456 tn	1.289 tn	0.760 tn	3.009	4.718
L x P	6	0.538 tn	1.610 tn	1.181 tn	2.508	3.667
Error	24					
Total	35					

Table 8. Effect of humic-silica on P-uptake in maize plants

Industrial	Doses	leaves	Roots	Steam
Pharmaceutical	0 kg/ha	0.17	0.12 b	0.16
	10 kg/ha	0.17	0.10 ab	0.16
	20 kg/ha	0.18	0.07 a	0.2
	30 kg/ha	0.12	0.10 ab	0.11
Animal feed	0 kg/ha	0.14	0.11 ab	0.1
	10 kg/ha	0.17	0.11 ab	0.24
	20 kg/ha	0.17	0.12 b	0.16
	30 kg/ha	0.14	0.09 ab	0.19
Paper	0 kg/ha	0.18	0.08 ab	0.15
	10 kg/ha	0.13	0.10 ab	0.15
	20 kg/ha	0.14	0.09 ab	0.14
	30 kg/ha	0.15	0.08 ab	0.15
LSD 5%		0.2427	0.0468	0.1992

Note: Mean values followed by the same letter are not significantly different according to HSD test at 95% significance level.

4. CONCLUSION

The results of the experiment on the application of humic acid and silica on the availability and absorption of corn P on land contaminated with industrial waste can be concluded as follows: At 14 DAP (Days After Planting): The application dose of AH-Si of 20 kg/ha, caused relatively high available P in all three locations (Pharmaceutical Plant, Livestock Feed, and Paper Mill), ranging from 35.57 ppm to 38.20 ppm. Additionally, organic carbon and CEC values were favorable at this dose, indicating improved soil fertility and good nutrient availability for maize plants. At 70 DAP (harvest stage): The optimal dose remained at 20 kg/ha. At this dose, available P parameters were still high across the three locations, ranging from 32.12 ppm to 39.54 ppm. Organic carbon and CEC values also remained favorable at this dose. The application of humic-silica at 20 kg/ha was the most optimal for enhancing soil fertility, nutrient availability, and ultimately, P uptake and maize yield at all three locations. This dose provided the best balance between soil and plant parameters, thereby supporting optimal maize growth and productivity.

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