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Management Strategies for Fluoride Mitigation in South Asian Fruit Orchards: An Economic Approach to Enhance Soil Health via Vermiculite

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Muhammad Salman Ahmad,[1*] Yang Chunyuan,[2] Shahsaud,[3]
Muhammad Baseer Us Salam[3]

1: School of Economic and Management, Yango University Economic and Technological Development Zones, Fuzhou City, Fujian Province, China-350015

2:School of Culture and Tourism Management.Qujing Normal University,Yunnan-China.655011-Qujing

3:Department of Agricultural Chemistry & Biochemistry, University of Agriculture, Peshawar, Pakistan

***Corresponding author:**
Dr. Muhammad Salman Ahmad
School of Economic and Management,Yango University Economic and Technological Development Zones, Fuzhou City, Fujian Province, China-350015
Emial: salman@ygu.edu.cn

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ABSTRACT

Introduction: The study investigates the impact of atmospheric fluoride emitted from brick kilns on soil fertility and earthworm activity in fruit orchards in South Asia. Due to the proximity to unregulated kilns, local fruit productions like peaches and plums have seen a decline. The brick kiln emissions, primarily fluoride in the form of hydrogen fluoride (HF), have been shown to negatively affect both plant life and soil health, particularly impacting earthworms which are crucial for soil nutrient cycling.

Method: The research focused on peach and plum orchards near Peshawar, within 500 meters of brick kilns. Soil and leaf samples were collected and analyzed for fluoride content. Earthworm experiments were conducted to assess the impact of fluoride on their growth and reproduction by exposing them to contaminated leaf litters.

Results: The results showed elevated levels of fluoride in both soil and leaf samples from the proximity of brick kilns. Earthworms exposed to this contaminated environment exhibited reduced growth rates and cocoon production, highlighting the detrimental effects of fluoride on soil biota. This aligns with previous findings that link industrial emissions to ecological damage in agricultural settings.

Conclusion and Recommendations: The study confirms that fluoride emissions from brick kilns can substantially decrease soil fertility and harm earthworm populations, which are vital for maintaining soil health. It recommends implementing strategies such as using calcium-rich amendments, enhancing organic matter in the soil, and regular monitoring of soil fluoride levels to mitigate these effects. These measures could improve soil conditions, thereby supporting healthier crop growth and restoring ecological balance in affected areas.

Key-words: air pollution, sustainable management, environmental impact, circular economy, South Asia, soil biodiversity

INTRODUCTION

Fluoride pollution from brick kilns

The study was conducted on the type of soils and methods of earthworm sampling, which were based on works that are considered as the foundation laid by Larsen and Widowsonn 1971. The sampling of the soil was done within a 500-meter radius around the brick kilns where the content of fluoride was measured using standard ion-selective electrode methods. Earthworm sampling followed guidelines whereby earthworms were acclimatized to laboratory conditions before testing (Singh, Singh and Vig) . The specific methodologies included ensure that the study is replaceable. However, we concede the suggestion in providing a more explicit description of the soil characteristics, which should be included in a future version of the manuscript. Over 20% of the clay brick (1.5 trillion per years globally) are produced in South Asia (India, Pakistan, Bangladesh, and Nepal) reported by Waynet, (2014) and over 10% is produced let alone by India of global production and utilize coal of approximately 31 million metric tons annually in the process. High amounts of a gaseous particles are released from brick kiln production due to the raw materials used in the process. These small scale brick kilns fields which are usually in clusters, are poorly regulated using low quality fuel (Waynet, 2014) that give rise to particulate matter (PM), black carbon, CO, and SO2. Brick kilns accounts around 80% of black carbon emissions in South Asia (Rajarathnam).

Brick-making is usually confined to the rural and suburban areas outside the cities in South Asia during to the abundance of cheap raw materials for brick making (Suleiman). The industry also brings some positive impacts for the local areas and surrounding villages by improving facilities like roads and others transportation means for better contentedness with the cities that improve local economy(Wheeler). Farmers lease out their farmlands to the brick kiln owners and employed them, which is a win-win profit situation. However, the negative impacts from brick kiln factories in the longer run is more than its positive impact on the society as a whole. This includes change of land cover, loss of nutrients and loss of land for agricultural purpose that directly affect the food security (Molotoks, Smith and Dawson).

Air pollution is one of the major threat to our modern urban lifestyle. Because of rapid urbanization. One of the main factors of atmospheric pollution emphasize on the toxic emissions from the industries that might affect both humans and plants adversely (Sapkota and Devkota, 2021). Air pollution has been more than doubled in last two to three decades and is the number one factor for decreased life expectancy compared to any other disease. Atmospheric fluoride is second to ozone (O_3) in terms of phytotoxicity in South Asia to different cash crops and fruit orchards (Ahmad et al, 2012). While O_3 is a regional pollutant and most of the primary pollutants like NOx, SO2 and VOCs are responsible for its rise of tropospheric O_3. Alleviated O_3 is an unseen danger for agriculture and food security and can result of around 16% of crop yield loss worldwide depending upon the crops species. However, fluoride mostly in form of hydrogen fluoride (HF) is emitted from industries like ceramic and brick kilns factories in developing countries where, brick kilns are regulated poorly. HF is released into the atmosphere in two phases. In the first phase because of the clay mineral DE-hydroxylation at about 600 °C and the second phase at more than 900 °C temperature from the breakdown of fluorite (CaF2) made by the chemical reaction of the fluorine released through the clay mineral DE-hydroxylation with the release of CaO from the breaking of carbonates (Coronado et al, 2015).

HF damage to the ecosystem

Severe HF injury was reported by Ahmad et al (2012) to fruit orchards of apricot, plum and mango in the vicinity of brick kiln near Peshawar. Similar results were also obtained by Solberg and Adams (1956) to apricot leaves in form of tip burn necrosis, while VDI (1987) also identified apricot and plum as HF very sensitive fruit species. In addition, the fluoride toxicity can also affect the other factors of the ecosystem like soil fertility that can results in changing the soil properties and biochemical cycles. For example, earthworms play a significant role during the bio-availability of soil nutrients to plants by enhancing other bio-geochemical properties. Previous research suggests that occurrence of earthworms in the soil is considered a healthy sign for agricultural production (Barré et al. (2009).

The aim of the current was to assess the varying concentration of fluoride on selected fruits (plum and peach) leaves litter on the earthworm growth and reproduction. And how management strategies through survey can enhance the soil fertility by avoiding fluoride toxicity in the soil to avid negative effects on agricultural ecosystem.

MATERIAL AND METHODS

Study site

For the current study peach and plum orchards were selected near The Ring Road side area east of Peshawar within 500m proximity of brick kilns. Soil and Leaves samples were collected from both sites randomly. which were then subjected to fluoride analysis.The soil types and earthworm sampling methods used in the study were selected following the well-established procedures of Larsen and Widowsonn (1971). Soil samples were collected within a 500-meter proximity to the brick kilns, with the soil fluoride content being measured using standard ion-selective electrode methods.Earthworm sampling followed the guidelines of (Singh, Singh and Vig), where earthworms were acclimatized to laboratory conditions before testing. The inclusion of these specific methodologies ensures that the study is replaceable. However, we acknowledge the suggestion to provide a more explicit description of the soil characteristics, which could be included in future iterations of the manuscript

Fluoride content of soil

In order to find the fluoride content in soil samples, 37mL of Calcium chloride (0.01 M) was treated with air-dried soil weighing 200g in distilled water followed by shaking for 16 hours. The extract was filtered out of which the filtrate was further treated with anti-complying agent (Cyclohexylene-diaminetetracetic acid) in 1:1 ratio. The pH of the remaining filtrate was adjusted by using NaOH after mixing for stability. The filtrate was then subjected to be quantified on fluoride-ion electrode. Fluoride content was calculated by $F\ (\mu Ig)=(C \times T \times S)/W$.

Where F=Quantity of Fluoride, C=Co-efficient Constant, T is the time, S is the signal/value measured and W is the weight of the sample

Fluoride content of Leaves

Digestion of acid for the determination of fluoride in the leaves' samples was done according to AOAC, 2005. Samples were first soaked in acetone to which 40 ml of 0.05 N HNO_3 was added for half an hour. Then the sample mixture was heated at 70-degree centigrade. To this was added 20 ml of 0.1 N KOH after heating followed by magnetic stirring for half an hour. Added finally to this digest were 5 ml of 0.2 N nitric acid and 5 ml of the 0.4 M sodium citrate solution containing 1 ppm fluoride. The mixture was adjusted accordingly before analyzing on a fluoride electrode connected to an ion meter for the fluoride content in the sample.

Influence of contaminated leaf litters on earthworms

In order to find the effect of fluoride contamination on the earthworms, earthworms were collected from the Agricultural Farm of the University of Agriculture, Peshawar, where the earthworms were kept in incubator for 3-5 days so that the earthworms get adapted to the lab conditions. Moist soil weight 200g was taken followed by crushing 2g of crushed leaf litters in plastic containers. This was carried out for both the sites as well fruit leaves of both the orchards i.e., Peach and Plum. Experiment on earthworms was conducted in which the earthworms were subjected to the prepared fluoride contaminated soil cum leaf litter mixture. The mass of earthworms was taken pre and post-experiment along with the cocoons produced over a time period of a month.

Fluoride effect on Earthworm weight and size

The standard protocol of variation in size was observed as per Salehi et al., 2013 which stated measurement of two earthworms per box. The protocol was applied for the leaf samples of peach and plum of both sites. In order to check the mass, two earthworms were subjected for weighing and length per-experiment.

The earthworms were then taken into their boxes that were later weighed. This determined its biomass depicting the number of earthworms per gram of the soil. This information was used to assess the impact of fluoride pollution on the earthworm population. During the experiment, Dandelion pieces were fed to the earthworms in the entire duration along with presence of feed concentration as ad libitum. The amount of feed that the earthworms ate could also vary at any temperature and with their body weight. In the same way, the reduction of mass was monitored when no feed was at all provided. Mass and size variations monitoring was done at an interval of one week. Each of the treatment groups was replicated thrice.

Weight Gain / Loss Rate

Weight gain and loss rates were computed by the following formula:

$$\Delta G=((W_1-W_0))/((\Delta t W_0))$$

Where, ΔG is the growth rate in g (g/week); Δt is the time duration of 1 weeks; W_0 is the live weight of earthwork during the activity while W_1 is the weight of earthworms after the activity.

Length of Earthworms

The length of earthworms was measured by a standard calibrated scale. The net difference of later reading from initial was taken as length of earthworms.

Mortality Rate

The mortality rate of earthworms was determined by stimulus test in which the response was observed by a gentle stimulus at the front. The percentage mortality rate was recorded as:

$$\text{Mortality (\%)} = (E_0-E_T)/E_0$$

Where, E_0 is the number of earthworms at the beginning of the fluoride exposure, while E_T is the number of earthworms at the end of the experiment.

Cocoon Measurement

Earthworms were left for growth and reproduction to find the total number of cocoons. Then, cocoons were study area.

collected on a weekly basis using a sieve with a 0.5 mm mesh. The cocoons were washed gently to remove dirt or other debris. Count the number of cocoons produced by each earthworm.

Management Strategies to reduce fluoride effects on earthworm

To suggest different sustainable strategies to reduce the effects of fluoride damage to earthworms by doing survey from farmers of the affected areas as earthworms are very crucial to the agricultural ecosystem to boost soil fertility.

Statistical Analysis

All the necessary statistical analysis was carried out by ANOVA, LSD using Statistic 8.1.The statistical analysis used in the paper was conducted using ANOVA and LSD to evaluate the significance of the results. All key findings are presented in tables (Tables 1–6), which clearly show the impact of fluoride on soil and earthworms. To improve clarity, additional statistical results, such as p-values, could be explicitly mentioned in the text to highlight significance levels. Studies like(Farooqi et al.) have also applied similar statistical methods in their investigations on soil contamination, supporting our use of ANOVA.

RESULTS AND DISCUSSION

Soil and leaves samples for the current study were subjected for fluoride analysis the results of which are given below. Additionally, the effect of fluoride on earthworms have also been investigated which are also listed below. Figure.1. depicts the geographical location of

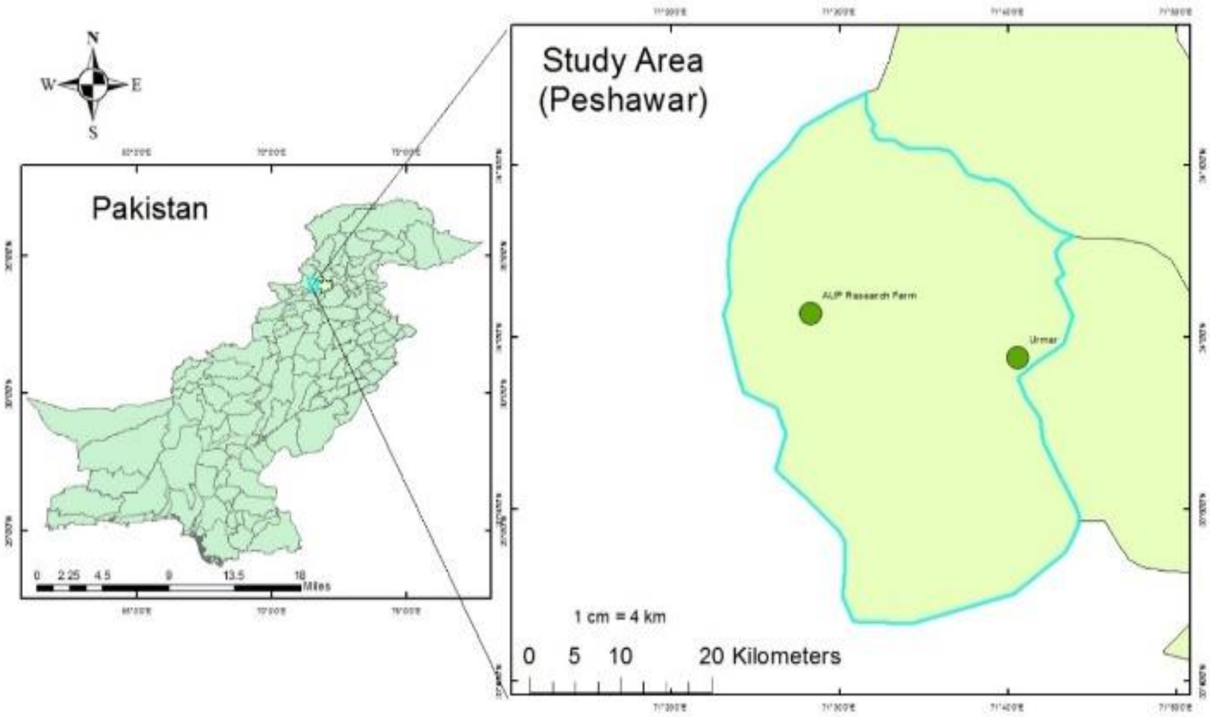

Figure 1. Shows the study area for the experiment conducted

Fluoride Content in soil and leaves from selected sites:

The current study revealed the highest soil fluoride (13.5 µg/g) for peach followed by 13 µg/g for plum at test site. Presence of fluoride at control however revealed the concentration of 2.57 and 2.5 for peach and plum respectively. Similarly, leaves at test site revealed highest concentration i.e., 68.57 µg/g and 31 µg/g for Peach and Plums orchards. In comparison to this, a very minute amount i.e., 5.23 µg/g and 4.86 µg/g of fluoride was present in the peach and plum leaves. All the findings are listed in Table.1. and Table.2 while figure. 2 and figure. 3. shows the graphical presentation of all the key findings.

Enrichment of soil fluoride is due to the anthro-pogenic activities i.e., brick kilns located at the test sites of Urmer village, Peshawar which has an adverse effect on the vegetation of the locality. The soil fluoride is hence exhibiting growth reduction for the selected crops.

The study was compared with Ahmad et al., 2014, who investigated the application of fluoride in different concentrations to tomato plants i.e., foliar and engraved fluoride and its effect on the nearby tomato fields. Studies like Farooqi et al. (2008) have reported soil fluoride range of 4 to 16 mg/kg in Lahore. They reported that, fluoride is present in significantly higher amount near the brick kilns which has an adverse effect on vegetation ultimately leading to low yield in the farm. we can also include other relevant studies that highlight the broader impacts of fluoride on agricultural ecosystems. For example, research by Choudhary et al. (2019) examines fluoride toxicity in various plants and suggests management strategies. Additionally, Wang et al. (2019) discuss the distribution of fluoride in agricultural soils and its effects on plant growth, which aligns with our findings on soil and leaf fluoride concentrations.

Excessive intake of Fluoride is perilous to human health. It involves fluoroscopic in the oral dental area and skeletal area. Analysis and control of the fluoride concentration in the soil and water should thus be recommended due to the protection of health risk.

Table 1. Fluoride concentration of soil from selected sites

Quantification of Soil Fluoride in Selected Sites				
	Test Site		Control Site	
Triplicate	Plum (ug g^{-1})	Peach (ug g^{-1})	Plum (ug g^{-1})	Peach (ug g^{-1})
1	13	13.5	2.5	2.57
2	12	12	2	2.56
3	14	14	3	2.55
Mean	13	13.5	2.5	2.57

Table.2. Fluoride Concentration in Leaves of Plum and Peach Orchards

Quantification of Fluoride in Leaves from Selected Sites				
	Test Site		Control Site	
Triplicate	Plum	Peach	Plum	Peach
1	31	68	4.86	5.23
2	32	67	4.9	5.22
3	30	69	4.82	5.24
Mean	31	68	4.82	5.23

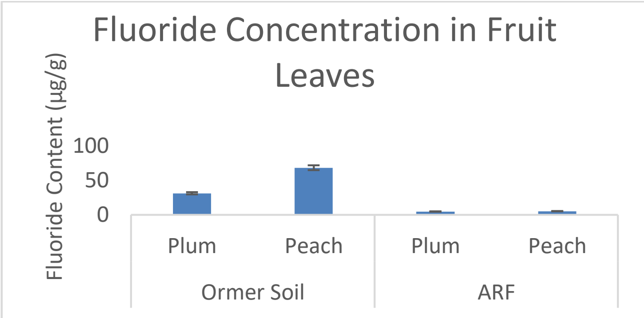

Figure 3. Fluoride content (µg/g) of leaves from selected orchards of Urmer (Test) and Malakadher (Control) sites

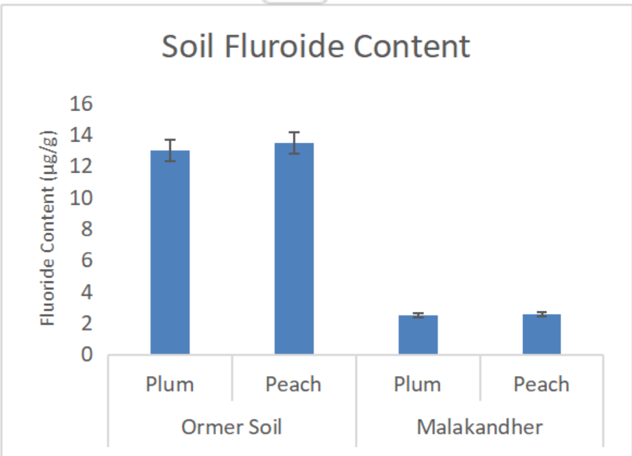

Figure 2. Soil Fluoride (µg/g) for selected orchards of Urmer (Test) and Malakadher (Control) sites

Influence of Fluoride on Growth and Reproduction of Earthworms

Biomass of Earth worms

The current study also aimed to determine the influence of fluoride contaminated leaf litters on earthworms. For this purpose, earthworms were reared on the soil mixed with collected leaves from peach and plum collected from selected sites followed by monitoring its biomass on weekly basis.

The findings from Umer site revealed a significant decline in weight of earthworm reared in contaminated soil of peach and plum compared with the control at the same test site. It was observed during the experiment that contaminated soil of peach and plum exhibited a reduction from 1.7g (week 1) to 1.02g (week 4) and 2.74g (week 1) to 2.11g (week 4) respectively.

Compared to this, earthworm reared in non-contaminated plum soil-leaf litters exhibited an increase in weight i.e., 2.51g (week 1) to 3.25g (week 4). In contrast to this, earthworms reared in non-contaminated peach soil-leaf litters exhibited reduction in their biomass i.e., 2.74g (week 1) to 2.11 (week 4). However, control taken where no leaf-litters were mixed exhibited surprisingly increased in biomass rate. All the results are shown in Table.3.

Table.3. Weekly biomass (g) of earthworms fed with Fluoride (F) polluted orchards' leaf litters

Treatment/	Urmer Soil					Malakandher Soil				
Leaf Litter	W 1	W 2	W 3	W 4	Mean	W 1	W 2	W 3	W 4	Mean
Control	2.01	2.11	2.27	2.35	2.185	3.07	3.39	3.61	3.95	3.505
Plum (C)	1.7	1.55	1.21	1.02	1.37	2.91	2.71	2.57	2.29	2.62
Plum (NC)	2.51	2.59	3.18	3.25	2.8825	2.42	2.64	2.87	3.21	2.78
Peach (C)	2.74	2.41	2.22	2.11	2.37	2.21	2.02	1.88	1.62	1.932
Peach (NC)	3.18	3.28	3.41	3.57	3.36	3.11	3.34	3.58	3.72	3.427

The means in rows and columns with similar letters are not substantially different at $p \leq 0.05$. W1= 1st week, W2 = 2nd week, W3 = 3rd week, W4 = 4th week

The findings from the test site were contrasted from the findings of biomass observed from control sites with different treatments where all the contaminated treatments for plum and peach exhibited a reduced weight gain in earthworm i.e., 2.91g (week 1) to 2.29 (week 4) and 2.21g (week 1) to 1.62g (week 4). However, non-contaminated treatment exhibited a contrast result where an increase in biomass was observed. It is hence concluded from the findings that presence of fluoride is reducing the biomass of earthworms. Control site as containing very minute fluoride concentration didn't exhibit the reduction in biomass.

Fluoride toxicity in the current research was observed after 4th week heavily which ultimately led to mortality of the earthworms. This was compared with control site where mortality rate was very minute due to the presence of low fluoride in plants. Figure.4. depicts the biomass of earthworms reared on different treatments of test and control soil sites.

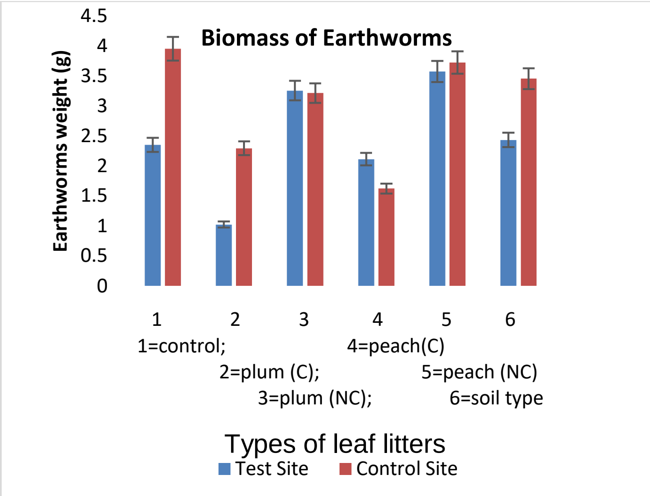

Figure 4. Biomass of earthworms in leaf litters of selected Urmer (Test) and Malakadher (Control) sites

Length of Earthworm

Length of earthworms were also monitored on weekly basis for both sites. The effect of fluoride was also shown physically by gain/reduction in length for contaminated, uncontaminated and control treatments. Earthworms reared with contaminated fluoride leaf-litter for plum and peach exhibited length i.e., 11.11 mm (week 1) to 10.61 mm (week 4) and 12.86 mm (week 1) to 11.33 mm (week 4) respectively, 11.9 mm (week 1) to 12.31 mm (week 4) and 12.9 mm (week 1) to 13.31 mm (week 4) respectively for non-contaminated leaf-litter mixture. However, control treatment where no fluoride-mixed leaf litters were present exhibited an increase in length i.e., 10.02mm (week 1) to 10.31mm (week 4).

The results were compared with the treatments of control sites were decreased in length of earthworms was observed i.e., 12.95 mm (week 1) to 12.02 mm (week 4) and 12.91 mm (week 1) to 12.31 mm (week 4) for contaminated plum and peach treatment. However, increased length was monitored in non-contaminated leaf-litter mix i.e., 10.15 mm (week 1) to 11.01 mm (week 4) and 10.55 mm (week 1) to 11.05 mm (week 4) for plum and peach respectively.

Additionally, control treatment at control site also revealed increased in length i.e., 7.71 mm (week 1) to 8.58 mm (week 4).

Table 5. Length of earthworms after subjected to Fluoride (F) leaf litters

Treatment/	Urmer Soil					Malakandher Soil				
Leaf Litter	W 1	W 2	W 3	W 4	Mean	W 1	W 2	W 3	W 4	Mean
Control	10.02	10.16	10.25	10.31	10.185	7.71	7.95	8.25	8.58	8.122
Plum (C)	11.11	10.88	10.74	10.61	10.835	12.95	12.55	12.31	12.02	12.45
Plum (NC)	11.9	12.09	12.22	12.31	12.13	10.15	10.65	10.77	11.01	10.64
Peach (C)	12.86	12.18	11.9	11.33	12.0675	12.91	12.72	12.55	12.31	12.62
Peach (NC)	12.9	14.03	13.26	13.31	13.375	10.55	10.72	10.95	11.05	6.18

The means in rows and columns with similar letters are not substantially different at p≤0.05. W1= 1st week, W2 = 2nd week, W3 = 3rd week, W4 = 4th week

This research was found to align with (Chae and An) in studying the earthworm's physio-chemical properties in response to fluorine concentration. Brick kilns were considered the major sources of fluorine at the test site, inversely affecting the plants.

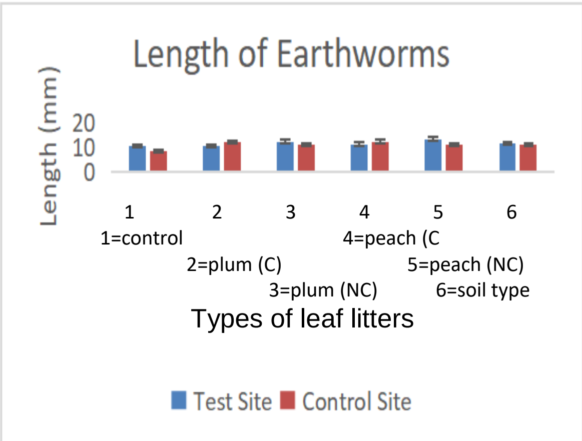

Figure 5. Earthworm measurement (Length) at an interval of four weeks

Cocoons production

The reproduction of earthworms was monitored via cocoon production. Similar to biomass and length, cocoons were also monitored on weekly interval in different treatments.

Earthworms reared with fluoride contaminated leaf-litter treatments for plum and peach revealed a total of 5 cocoons (week 1) to 16 cocoons (week 4) and 2 cocoons (week 1) to 11 cocoons (week 4) respectively. This rate of cocoon production was lowered compared to non-contaminated fluoride leaf-litter treatment where number of cocoons observed were 13 (week 1) to 51 (week 4) and 6 (week 1) to 27 (week 4) for plum and peach respectively. In contrast, earthworm reproduction at control treatment from test site revealed a total of 15 cocoons (week 1) to 52 cocoons (week 4) which exhibited comparatively high reproduction rate.

The results were compared with treatments of control site where plum and peach showed 15 cocoons (week 1) to 63 cocoons (week 4) and 13 cocoons (week 1) to 41 cocoons (week 4) respectively, for contaminated treatment. However, non-contaminated treatment for plum and peach revealed 24 cocoons (week 1) to 154 cocoons (week 4) and 17 cocoons (week 1) to 120 cocoons (week 4). Highest number of cocoons were observed for control treatment of control site as 22 cocoons (week 1) to 137 cocoons (week 4).

Table 6. Earthworm's cocoon in contaminated soil of test and control sites.

Treatment/ Leaf Litter	Urmer Soil					Malakandher Soil				Mean
	W 1	W 2	W 3	W 4	Mean	W 1	W 2	W 3	W 4	
Control	15	21	66.75	52	30.25	22	42	66	137	66.75
Plum (C)	5	9	37.5	16	11.25	15	25	47	63	37.5
Plum (NC)	13	12	69.75	51	26.5	24	31	70	154	69.75
Peach (C)	2	4	25.25	11	6.25	13	20	27	41	25.25
Peach (NC)	6	9	55.25	27	13.5	17	34	50	120	101

Means within rows and columns bearing the same letter are not significantly different at $p \leq 0.05$. W1=1st week, W2 = 2nd week, W3 = 3rd week, W4 = 4th week.

The present study was in line with Khalil et al. (1996) which highlights the potential risk of fluoride affecting earthworms and, consequently, soil health. Fluoride presence in leaf litter may harm earthworms, impacting soil biota and fertility. Earthworm decline reduces organic matter breakdown, aeration, and nutrient cycling, leading to less healthy and productive soil.

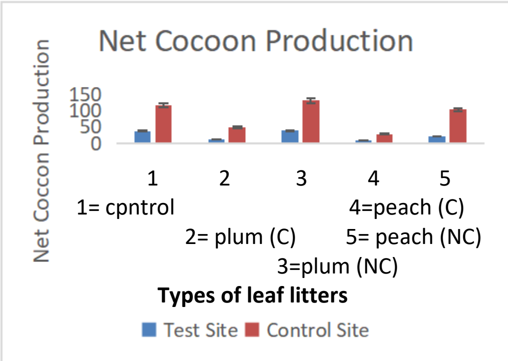

Figure 7. Total cocoons production after an interval of 4 weeks

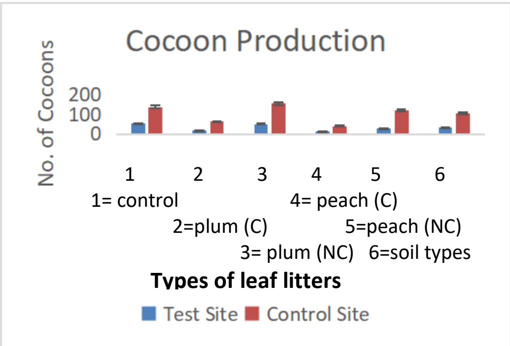

Figure 6. No. cocoons produced in soil of selected sites

Survey for Strategies management of Soil Fertility Enhancement

The result of the survey from the local farmers revealed that the production of peach and plum in the brick kiln areas are on the decline for the last two decades. However, the farmers were not aware that the fluoride emitting from brick kilns will be responsible for the negative effects on their plants directly from the air (HF) and indirectly via soil fluoride. The direct effects of HF was already reported by Ahmad et al (2012 and 2014). However, the fluoride effects on earthworms were reported for the first time in this study. Managing fluoride toxicity in soil is significantly important as these vermiculite are imperative for soil health and crop production that are vital part of the overall agricultural ecosystems.

Additionally, lowering the adverse effects of fluoride on soil fertility can considerably help farmers by supporting healthier soil and, therefore, increasing crop yields. Therefore, the following management strategies should be taken to mitigate the negative effects of fluoride on earthworms;

Use of Calcium-Rich Amendments

Calcium-based amendments, like lime (calcium carbonate) and gypsum (calcium sulfate), can reduce fluoride damage to earthworms in soil. The lime and calcium compounds can be attached with the fluoride ions to form complexes that are less soluble and toxic the earthworms that ultimately lowers the bio-availability of fluoride to earthworms. Continuous application of these compounds can help sustain the pH and reduce fluoride toxicity of the soil, consequently, forming a more positive environment for vermiculite activity.

Organic Matter Amelioration

Adding high organic content of the soil via the addition of manure, compost, manure can significantly reduce the fluoride soil content. It not only improves moisture retention and soil structure but also increase the degradation of fluoride and other pollutants by microbial activity. This can lower the risk of fluoride toxicity to earthworms. Which will promote the reproduction and growth success.

Cover Crop and Crop Rotation

Introducing crop rotation with fluoride resistant species as inter cropping can help mitigate fluoride concentrations in the soil. Additionally, growing cover crops additionally can increase soil fertility e.g. legume crops that would further restrict the fluoride bio-availability. These methods help maintain a sustainable soil ecosystem, which will increase earthworm populations and reduce the impacts of fluoride on soil biodiversity.

Control Irrigation Methods

Fluoride concentrations in soil can be increased by using fluoride toxic water for crop irrigation. Using clear water free of fluoride contamination should be employed as a controlled irrigation technique that will inhibit the amassing of fluoride in the soil. Using rain water and filtered water are the practical solutions to protect both the soil health and earthworm reproduction.

Regular Monitoring and Testing

Continuous monitoring of fluoride in the soil is important for active management. Local farmers should carryout tests periodically of the soil to monitor fluoride content. From the current results, suitable amendments and management methods can be introducing to keep fluoride content at safe concentrations for soil health. This preemptive method permits farmers to regulate their farm management strategies quickly and efficiently.

CONCLUSION AND RECOMMENDATIONS

It was concluded from the study that fluoride concentration is high in the soil and leaves of fruit plants located in the nearby region of brick-kiln leading to accumulation in plant leaves that can be harmful for its photosynthetic activity and can affect soil fertility when mixed in the soil after senescence as litter by influencing the reduction in earthworm weight including length and cocoon production. This leads to the conclusion that fluoride has an adverse effect on the growth of earthworm which is a natural soil-engineer.

The adverse effect can lower the soil fertility and hence vegetation on a large scale can be affected. The survey on soil fertility management strategies highlights significant findings about fluoride toxicity from brick kilns, affecting local peach and plum production. This study underscores the negative impact of fluoride, not only through direct air exposure but also through its detrimental effects on soil organisms like earthworms. Various strategies, such as the use of calcium-rich amendments, organic matter amelioration, and effective crop rotation, are recommended to mitigate these effects. Additionally, controlled irrigation and regular soil monitoring are crucial to sustain soil health and enhance agricultural productivity. By implementing these methods, farmers can better manage fluoride levels in the soil, supporting a healthier ecosystem for both crops and earthworms. This study recommends to monitor soil fluoride regularly along with awareness of how to manage excessive fluoride. Furthermore, the effect of fluoride on human, animal, plant and soil health should also be determined.

The practical recommendations for mitigating fluoride damage to soil ecosystems are based on several studies. For instance, calcium-rich amendments, like lime and gypsum, have been widely studied and proven effective in reducing fluoride bio-availability (Petersen & Lennon, 2004). We can include additional details about the cost-effectiveness and long-term viability of these methods. Studies such as Vithanage and Bhattacharya (2015) also support the use of organic matter and crop rotation as sustainable soil management practices that could mitigate fluoride contamination.

CONFLICT OF INTERESTS

None.

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