

# **Ex-Situ Spatial distribution of Iron in soil and its effect on uptake by maize (*Zea mays*)**

## **ABSTRACT**

This study investigated ex-situ spatial distribution of iron in soil and its effects on uptake of Fe by *Zea mays*. A greenhouse pot experiment which simulated three treatments control (0mg/kg Fe added, homogeneous (1000mg/kg Fe added) and heterogeneous (Simulated realistic heterogeneity). *Zea Mays* was transplanted into the three treatments for six weeks after germination and initial establishment for four weeks. At harvest, root and shoot samples were collected and analyzed for Fe using the atomic absorption spectrometer (AAS) Thermos Fisher Scientific model ICE 3000 after acid digestion with nitric acid. The mean root Fe concentration in the control, homogeneous and heterogeneous treatments were 5965mg/kg, 7111mg/kg and 5389mg/kg respectively while the much shoot Fe concentration in the control, homogeneous and heterogeneous treatments were 1121mg/kg, 1405mg/kg and 831mg/kg respectively. There was no significant difference ( $p>0.05$ ) in the shoot and root Fe concentration between treatments. This suggest that *Zea Mays* will acquire Fe from varying soil distribution effectively, However the root and shoot Fe concentration was 0.5 two percent higher than the control and heterogeneous treatments indicating an exaggerated uptake of Fe on a homogeneous distributed soil medium which unrealistic in nature shoot Fe concentration were two times as low as the root Fe concentration which implies that Fe is accumulated to a greater degree on the root and translocation to the shoot is greatly impaired in this plant. However, the shoot Fe concentration showed significant amount of Fe that may be potentially fund on the edible fruit consumed by humans and animals. The concentration factor (CF) were 0.3656, 0.4394 and 0.3209 for the control, homogeneous and heterogeneous treatments respectively. This similar trend in concentration factor showed that this plant has same ability for uptake of Fe in varying nutrient patch. This study demonstrated that spatial distribution of Fe metals plays a significant role in their uptake by plants it also showed that the metal uptake is also affected by the nature of the sort and *zea Mays* may be a rich source of Fe if grown in Fe rich soil. The plant iron concentration exceeded the WHO limits on food which may power a health risk to consumers. This study has implications for improving the nutritional quality of maize especially in Fe deficient Soils.

**Keywords:** concentration factor, *Zea mays*, *nutritional quality*, *micronutrient*

## INTRODUCTION

“Iron(Fe) is an essential micronutrient for plant growth and development, playing a vital role in various physiological processes, including photosynthesis, respiration, and enzyme activation” (Keller et al., 2006). Iron deficiency in plants can lead to chlorosis, stunted growth, reduced yield, and lower nutritional quality (Fageria, 2001). “While iron is abundant in the Earth's crust, its availability to plants is often limited due to its low solubility and the presence of various soil factors that influence its distribution and uptake” (Fimmen, 2009).

The distribution of iron in the soil is rarely uniform, exhibiting spatial heterogeneity at various scales (Kabata-Pendias and Mukherjee, 2007). Factors such as soil parent material, weathering processes, land use history, and soil management practices contribute to the non-uniform distribution of iron (Kabata-Pendias and Mukherjee, 2007). The spatial variability of iron in the soil can range from macro-scale patterns, such as variations across landscapes or field sections, to micro-scale patterns, such as variations within a single soil aggregate (Viscarra et al., 2016). Understanding the heterogeneous distribution of iron in the soil and its relation to iron uptake by maize is of great importance for agricultural productivity and sustainable plant nutrition (Setimela et al., 2017).

“Maize is a globally important crop mainly utilized as feed, food and raw material for diverse industrial applications. Among cereals, it occupies the third place after wheat and rice and is a staple food for a large segment of population worldwide”

UNDER PEER REVIEW

“Maize (*Zea mays*) is one of the most widely cultivated cereal crops globally, serving as a staple food for millions of people. Its growth and productivity are directly influenced by the availability and uptake of essential nutrients, including iron” (Setimela *et al.*, 2017; Ogunlade-Anibasa *et al.* 2024).

The spatial variability of iron in the soil can significantly impact the iron uptake efficiency of maize plants. Regions with high iron concentrations in the soil may provide favorable conditions for iron uptake, leading to improved plant growth and yield. Conversely, areas with low iron concentrations may pose challenges for maize plants in acquiring sufficient iron, potentially resulting in nutrient deficiencies and reduced crop productivity (Marschner, 2012).

“The relationship between iron distribution in the soil and its uptake by maize is influenced by various factors. Soil properties, such as pH, organic matter content, and redox conditions, can affect iron solubility and availability” (Johnson, 2017).

Acidic soils with low pH often limit iron availability, while alkaline soils can lead to iron precipitation and reduced uptake (Gupta and Lipsett, 1981).

Organic matter can influence iron retention and release, affecting its accessibility to plant roots (Gupta and Lipsett, 1981). The redox potential of the soil environment can influence iron speciation and its availability for uptake (Gupta and Lipsett, 1981).

Efficient management of iron in the soil is crucial to enhance iron uptake by maize and improve crop productivity (Verte *et al.*, 2002). Targeted

dfertilization approaches, based on the specific distribution patterns of iron, can optimize nutrient application, ensuring that maize plants receive adequate iron in regions with low concentrations (Vert *et al.*, 2002). Soil amendments and organic fertilizers can also be employed to modify soil properties and improve iron availability (Vert *et al.*, 2002). Iron (Fe) uptake by *Zea mays*, commonly known as maize, is a nuanced process influenced by spatial heterogeneity within the soil environment (Thompson *et al.*, 2012).

The spatial distribution of iron in the rhizosphere, which is the soil region influenced by root activity, plays a pivotal role in determining the availability and subsequent uptake of iron by maize plants. Understanding the spatial heterogeneity in iron uptake is crucial for optimizing agricultural practices and enhancing the efficiency of iron acquisition by this essential cereal crop (Kronzucker *et al.*, 2016).

The rhizosphere is a dynamic and complex interface where soil, plant roots, and microorganisms interact. In this microenvironment, the availability of iron is subject to spatial variations influenced by factors such as soil texture, pH, and the presence of organic matter. Maize roots release various compounds into the rhizosphere, including organic acids and root exudates, which can influence the solubility and mobility of iron in the soil (Kronzucker *et al.*, 2016).

Maize exhibits a distinctive root architecture, with primary, seminal, and lateral roots exploring the soil in search of nutrients. Each type of root contributes

to the spatial heterogeneity of iron uptake. Lateral roots, for instance, are responsible for exploring the outer regions of the rhizosphere, encountering different iron availability zones. The spatial distribution of iron uptake zones is not uniform across the root system, and specific root segments may exhibit higher or lower iron uptake capacities (Kronzucker *et al.*, 2016).

Microorganisms in the rhizosphere further contribute to spatial heterogeneity in iron availability. Some microbes can enhance iron solubility through the production of siderophores, organic molecules that chelate iron, making it more accessible to plant roots. The spatial distribution of these microbial populations and their activities in the rhizosphere can create hotspots of increased iron availability, influencing the areas where maize roots are more likely to absorb iron (Kronzucker *et al.*, 2016). One of the critical processes in iron uptake by maize is the reduction of ferric iron ( $\text{Fe}^{3+}$ ) to ferrous iron ( $\text{Fe}^{2+}$ ) at the root-soil interface. This reduction occurs primarily in the rhizosphere and is influenced by spatial variations in oxygen levels. Microsites with different redox potentials within the rhizosphere contribute to spatial heterogeneity in the availability of Fe, impacting the efficiency of iron uptake by maize roots.

The relationship between the heterogeneous distribution of iron in soil and the efficiency of iron uptake by plants remains poorly understood.

The impact of soil heterogeneity on the dynamics of iron uptake by plants needs to be understood.

The identification of factors that may influence the heterogeneous distribution of iron is crucial in optimizing iron availability to plants.

The lack of comprehensive studies on the effect of soil heterogeneity on iron uptake limits our understanding of plant nutrient acquisition strategies.

The complex interaction between soil properties, such as pH, organic matter content, and iron mobility may contribute to the heterogeneous distribution of iron and consequently affect iron uptake by plant.

However, several knowledge gaps and challenges exist in understanding the heterogeneous distribution of iron in the soil and its relation to maize iron uptake. The spatial variability of iron needs to be accurately characterized at different scales, and the underlying factors contributing to this variability should be identified. (White *et al.*, 2010). The genetic and physiological variations in maize plants that influence iron uptake efficiency require further investigation. Additionally, the interactions between iron and other nutrients, as well as the impact of environmental factors, need to be considered to develop comprehensive strategies for optimizing iron uptake in maize (Vert *et al.*, 2002).

Investigating the heterogeneous distribution of iron in soil provides valuable insight into understanding the availability of this essential nutrient to maize plants. This knowledge helps farmers and agriculturists make informed decisions regarding soil management practice including iron supplementation strategies to optimize plants growth and yield. A comprehensive understanding of the relationship between iron spatial heterogeneity in the soil and its uptake by maize can aid in optimizing fertilizer application.

Maize is a staple crop worldwide, an iron deficiency can severely affect its productivity. By studying the heterogeneous distribution of iron and its impact on iron uptake by maize, researchers can develop strategies to enhance crop productivity and mitigate iron deficiency-related issues. This knowledge can be used to improve breeding programmes, develop iron-efficient maize varieties, or implement precision agriculture techniques to ensure optimal iron availability to the crop.

Iron deficiency is a widespread form of micronutrient malnutrition, particularly in developing countries where maize is a dietary staple. Understanding the factors influencing iron uptake by maize can contribute to addressing this nutritional challenge (Pii *et al.*, 2015). In interventions such as iron fortification, biofortification, or soil amendment practices can be implemented to enhance soil iron content, thus improving the nutritional quality of the crop and reducing iron deficiency-related health issues.

Efficient nutrient management is a key aspect of sustainable agriculture. By investigating the spatial heterogeneity of iron and its relation to iron uptake by maize, researchers can contribute to more sustainable farming practices. This knowledge helps optimize resource allocation, reduce nutrient loss through leaching or runoff, and enhance overall nutrient use efficiency.

The aim of this study is to investigate the uptake of iron by *Zea mays* and its relationship with its spatial distribution in soil.



## 2. MATERIALS AND METHOD

Maize (*Zea mays*) was selected for pot trials based on the fact that it is commonly consumed. Maize (*Zea mays*) is one of the most widely cultivated cereal crops globally, serving as a staple food for millions of people. Knowledge of the in situ heterogeneity of lead in an earlier study on contaminant heterogeneity (Anibasa and Ramsey 2020) was applied to simulate similar scales of heterogeneity of the iron in this study based on known scale of heterogeneities. Maize (*Zea mays*) was used in a greenhouse pot trial modelling the simulated in situ heterogeneity. Herbage samples were processed and analyzed for the concentrations of iron in roots and shoots at the end of the growth period using appropriate analytical methods and equipment e.g. the Atomic Absorption Spectrometer (AAS). Data collected from this study was analyzed using appropriate statistical tools. Growth medium samples were also analyzed for the concentrations of iron. These data will provide information on the uptake potential of the maize and availability of these nutrients to potential consumers of these crops.

### 2.1 Experimental Design

This was done as described by (Solomon-

Wisdom *et al.*, 2015). Four heterogeneity models were simulated (using excel computer models with a combination of the Robust ANOVA- a visual basic programme developed based on a FORTRAN programme and previous work, which will generate the level of heterogeneity similar to those that had been found in field sites and previous field studies. The scale of heterogeneity used, the plant

species selected, and the mean Fe concentrations that was chosen, was based upon conclusions of pot trials in earlier studies (Ogunlade-Anibasa, 2023). The sample size was determined using power analysis to estimate the minimum number of replicates required to detect a statistically significant difference between means of different treatments based on the assumption that data will be normal in their distribution. Data from the seed germination was used for power analysis having confirmed they are normally distributed using the Kolmogorov Smirnov test. It is impossible to simulate the exact in situ heterogeneity (real life situation). The actual spatial heterogeneity of nutrients can only be estimated by sampling at the field site, and it is practically impossible to recreate the exact in situ heterogeneity in pot trials. In view of this potential complexity, the model of heterogeneity was designed to simulate as closely as practicable possible the in situ heterogeneity of trace elements measured at this scale in field sites in an earlier study (Anibasa, 2023) with a range of intermediate HF (HF ranged from 1 to 3.22 (3.22 at the 20 m scale)). The proposed simulation of heterogeneity factors (HF) was 1.00, 1.25, 2.00 and 3.19 while an overall mean concentration of approximately 1000 mg/kg in all treatments was maintained. The simulation was based on the log-normal distribution observed in those field sites, with increasing values of geometric standard deviation (GSD) and hence the values of HF. The central cell (C3) of all treatments was maintained at 1000 mg/kg Fe. This is to ensure that the heterogeneity treatment did not differentially affect the early establishment of these seedlings.

Cells	1	2	3	4	5
A	900	700	900	1100	900
B	1100	1100	1400	1400	1400
C	1100	700	1000	900	900
D	1100	900	1100	1800	900
E	900	1100	900	1100	700

**List1a:Modelsof*insitu*heterogeneity.**

Cells	1	2	3	4	5
A	1000	1000	1000	1000	1000
B	1000	1000	1000	1000	1000
C	1000	1000	1000	1000	1000
D	1000	1000	1000	1000	1000
E	1000	1000	1000	1000	1000

**List1b:Modelsof*insitu*heterogeneity.**

## **2.2SeedGerminationExperiment**

This was done as described by (Anibasa, 2016). Prior to seed germination experiment, one seed tray was washed and sterilized with household bleach (one part to nine parts of water), thoroughly rinsed with tap water and finally with reverse osmosis water and air dried to ensure they are sterile for seed sowing. Tray was labelled with the name of plant to be sown and date sown on them. Seed trays with drain holes were used to prevent water-logged conditions after seeds had been sown. A light density fine grade, Sinclair vermiculite of (grain size 2.0-5.0 mm) with neutral pH 7 (which is lighter and easier for seeds to breakthrough it) was used for sowing seeds. It was watered with tap water until evenly moist

before sowing seeds and then placed in the seed trays about 1 cm below the rim. The seeds were sprinkled thinly on the vermiculite or according to supplier's instruction if present and covered thinly with vermiculite. After sowing, the large tray with drain holes was used to cover tray to let in light and air, prevent medium from drying out and becoming damp as well. They were left to germinate in a greenhouse under a photoperiod of 16 hours' natural light and maintained at a temperature of  $30\text{ }^{\circ}\text{C} \pm 5^{\circ}\text{C}$ . The Tray was removed once germination occurred. Watering was done carefully when the top of the seed trays appeared dry using a fine spray watering can, and water sprinkled gently to avoid resetting or disturbing the seeds. The surface was kept evenly moist and never dried out. *Zea mays* considered for initial transplanting into unspiked growth medium after 7 days of germination to ensure proper growth and establishment before the actual transplant into the trace metal spiked growth medium. After germination and the development of the first true leaves, plants of approximately equal size were selected and transplanted into the Centre of separate circular 1-litre pots (15 cm deep and 12 cm wide) pots for each species containing unspiked growth medium (washed silver sand, John Innes compost II, 7 parts sand to 3-part compost). Thirty seedlings of *zea mays* were transplanted into pots (making a total of 30 seedlings) of unspiked growth medium first for two weeks and were watered daily using a fine rose watering can. This was maintained under 16 hours of natural light at  $30 \pm 5^{\circ}\text{C}$  in the greenhouse.

At two weeks after the first transplanting, ten seedlings of each species were transplanted

into the 15 pots containing growth medium spiked with Fe at concentrations of 1000 mg/kg Fe added (homogenous) and 0 mg/kg Fe added treatment (control) and heterogeneous treatment which simulated realistic heterogeneity. A total of 30 pots was maintained (1000 mg/kg (homogenous) and 0 mg/kg added treatment (control and heterogeneous treatments) for 6 weeks under a photoperiod of 16 hours natural sunlight at  $30 \pm 5^{\circ}\text{C}$  in the greenhouse. These were maintained in 3.5-litre square pots (dimensions 17 cm x 24 cm) in a simple randomized block design both in 1000 mg/kg Fe added and 0 mg/kg added Fe as control and heterogeneous treatment were rotated clockwise by 90° weekly to reduce the effect of uneven environmental conditions within the greenhouse. Randomized blocks were between treatments, because of the number of the available space/m<sup>2</sup> of greenhouse benches.

### **2.3 GreenHouse Pot Experiments**

This was done as described by (Anibasa, 2016) and (Ogunlade and Ramsey 2023). Fifteen (15) rigid square pots (14 X 14 cm and 17 cm deep) were thoroughly washed with detergents and labeled with names of plant species three treatments e.g. Homogeneous, heterogeneous and control. A customized cell divider made from a 1 mm clear polyethylene terephthalate glycol (PETG) sheet was inserted into the pots to produce a 5 by 5, 2-dimensional grid with each cell measuring 25 mm square and 170 mm deep. This was used to create the designed heterogeneity models. The relatively thin PETG helped to maintain the heterogeneity design by reducing the collapse of each column after its removal. Labeled paper liners were inserted

dintoeachcellwhilefillingcellswithgrowthmedia.Itprovidedafillingtemplate,tohel  
ptomaintainthe structural integrity of the divider and minimize spillage from  
adjacent cells. The gap between the paper liners and the outer edge of the pot  
were packed with an inert Sinclair Perlite (grain size 2.0-5.0 mm) because of the  
non-vertical sides  
of pots. Cells were filled according to the particular designed model of heterogeneity.

Filling of the pots was done in two stages to ensure that equal volume of growth  
medium goes into the cells and that the growth medium is evenly distributed  
throughout the pot. The gently compacted growth medium was measured with a  
100 ml customized container into each cell according to the design. The growth  
medium will be tapped down before an additional 50 ml will  
be added and tapped down again. Completed pots were placed on drip trays and  
arranged on benches in the randomized block design with blocks of 3 rows and  
3 columns as shown in table 1

The growth medium was moistened from below by  
capillary action before transplanting seedlings already established in an unspiked  
growth media for two weeks. Tap water was applied using a fine rose watering  
can. This ensured that the heterogeneity is disturbed to a minimal extent. The  
percentage moisture content of the growth media was taken. The pH of the  
growth media was taken. The established seedlings of the selected plant species  
was transplanted into  
the Centre of each treatment after two weeks growing in the unspiked growth media. Ten

replicates of each treatment was maintained in the greenhouse for six weeks under simulated sunlight using light-emitting diodes (LED) lights (under a photoperiod of 12 hours) at  $30 \pm 5^\circ\text{C}$ .

## **2.4 Harvesting**

Harvesting was done after 60 days of growth. Data such as Plant biomass root and shoot biomass (Fresh Weight and Dry Weight) in all pots in homogeneous, heterogeneous and control treatments were collected at harvest to assess

the impact of heterogeneity on the plant species. Shoots of all treatments were harvested.

Plant stems were cut 0.01 mm above the soil surface for shoot harvest and soil removed from the roots using a sieve. Soil was removed from harvested plant materials by repeated washing using tap water and dried at  $60^\circ\text{C}$  for 48 hours.

This was milled (using an herbage mill) for acid digestion using nitric and perchloric acids and analyzed for Fe using the AAS.

## **2.5 Chemical Analysis**

Shortened roots were carefully washed to remove soil particles that could introduce potential bias in measurements of Fe concentration. Harvested roots and shoots were dried at  $60^\circ\text{C}$  for 48 hours in a fan oven, weighed for Dry Weight, and analyzed for Fe concentration using an Atomic Absorption Spectrometer (AAS) after acid digestion using nitric acid (Thompson and Walsh, 1983).

Thompson and Walsh (1983) reported that a biomass of 1 gram (Dry Weight) was ideal for chemical analysis, but did not preclude the use of smaller masses,

with suitable checks on data quality. The growth media was analyzed for their actual Fe concentration. Regression analysis was used to show the relationship between the actual concentrations and the nominal concentrations.

## **2.6 Acid Digestion**

This was done as described by (AOAC, 1990) with little amendments

Samples of maize shoot and root were washed thoroughly after harvesting to remove any external contaminants. The maize shoot and root was dried to remove excess moisture. The maize root and shoot was ground into fine particles to increase the surface area available for digestion.

The respective prepared samples of maize were weighed 0.3g using a weigh balance and it was poured into a beaker 70% of concentrated nitric acid was added. The beaker containing the sample and nitric acid was placed in a microwave digesting system at a temperature of 100-200 degree Celsius for five to ten minutes in the process of the heating distilled water was added.

The digestion process was completed when the maize shoot and root of the respective samples were dissolved completely and no solid residue or undigested particles remain.

The digested samples were allowed to cool to room temperature and diluted with deionized water to reduce the acidity and concentrate the analytes in the solution for subsequent analysis. Filter paper was used to filter any undissolved particles or insoluble impurities to obtain a clear solution for further analysis.



## **2.7 Data Analysis**

Data were analyzed using statistical software Minitab 18 and SPSS 25 for Windows. Statistical tools such as analysis of variance (ANOVA), RANOVA (robust analysis of variance) was be used to test for significance of measured variables whilst Kolmogorov-Smirnov test was used to test for normal distribution of data. Other relevant statistical tools and software packages were used to analyze and model data from this study.

## **2.8 Quality Control**

Appropriate safety measures and procedure were followed to ensure the reliability of the test results. Chemicals and reagents used were of analytical grade, utensils were thoroughly and properly cleaned during the research. Samples were cautiously handled to minimize cross-contaminations and reagent blanks, duplicate samples, and certified Reference material (CRM) IAEA-V8 were incorporated into sample batch to check for contamination, analytical precision and estimation of bias respectively.

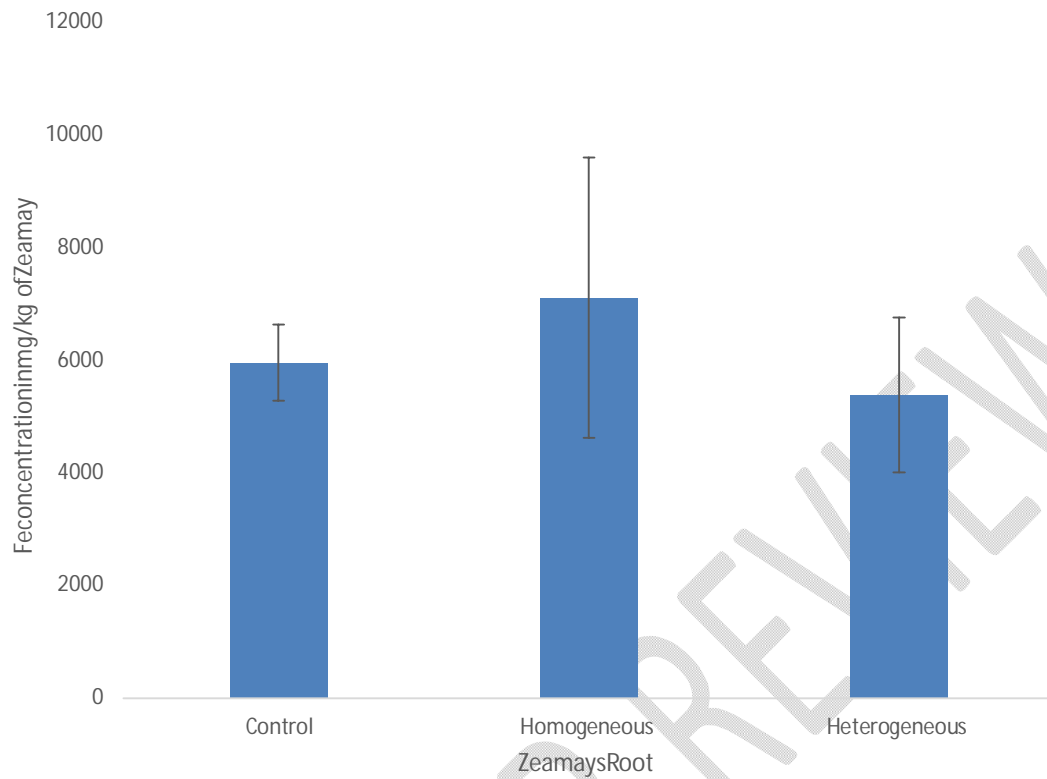
### 3. RESULTS

The mean shoot Fe concentration for the control, homogeneous and heterogeneous treatments were 1121 mg/kg, 1405 mg/kg and 831 mg/kg respectively (Figure 1) while the mean root Fe concentration for the control, homogeneous and heterogeneous were 5965 mg/kg, 7111 mg/kg and 5389 mg/kg respectively as shown in (Figure 2). There was no significant difference ( $P > 0.05$ ) in the root and shoot Fe concentration between treatments. The control has the highest shoot Fe concentration of 1121 mg/kg followed by the homogeneous treatments 1405 mg/kg and the heterogeneous treatments with the lowest mean shoot concentration of 831 mg/kg (as shown in Figure 3). This indicates that the normal soil is rich in Fe. The highest mean root Fe concentration of 7111 mg/kg was recorded in the homogeneous treatments followed by the control 5965 mg/kg and the heterogeneous treatment had the lowest mean root Fe concentration of 5389 mg/kg (as shown in figure 3). This showed that *Zea Mays* will accumulate Fe easily in a homogeneous distributed Fe medium. The root and shoot concentration were over 100 times higher than the WHO recommended value of 45 mg/kg in plants (Table 1). The concentration factors for control, homogeneous and heterogeneous were 0.3656, 0.4394 and 0.3209 respectively. The concentration factor (C.F) was highest in the homogenous treatment with about 0.1% higher than the control and heterogeneous. This showed that *Zea mays* accumulate Fe from the soil and

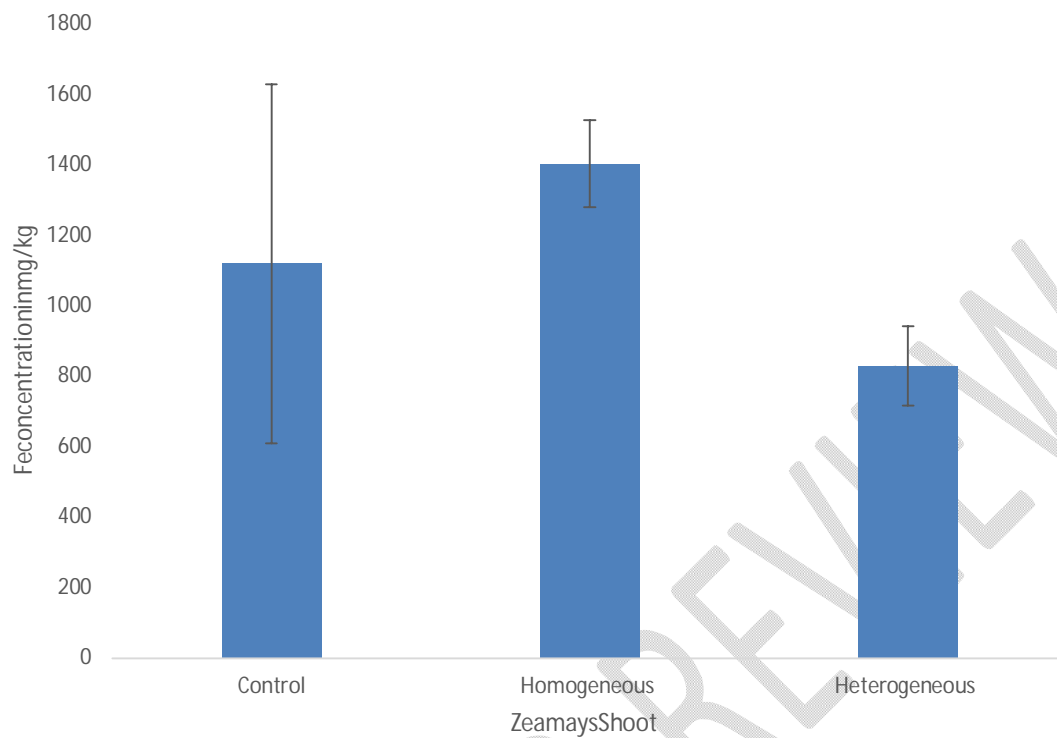
translocated about 10% of the accumulated Fe to the shoot in respect of the spatial distribution.

**Table 1: Mean concentration in (mg/kg) of maize roots and shoots between different treatments.**

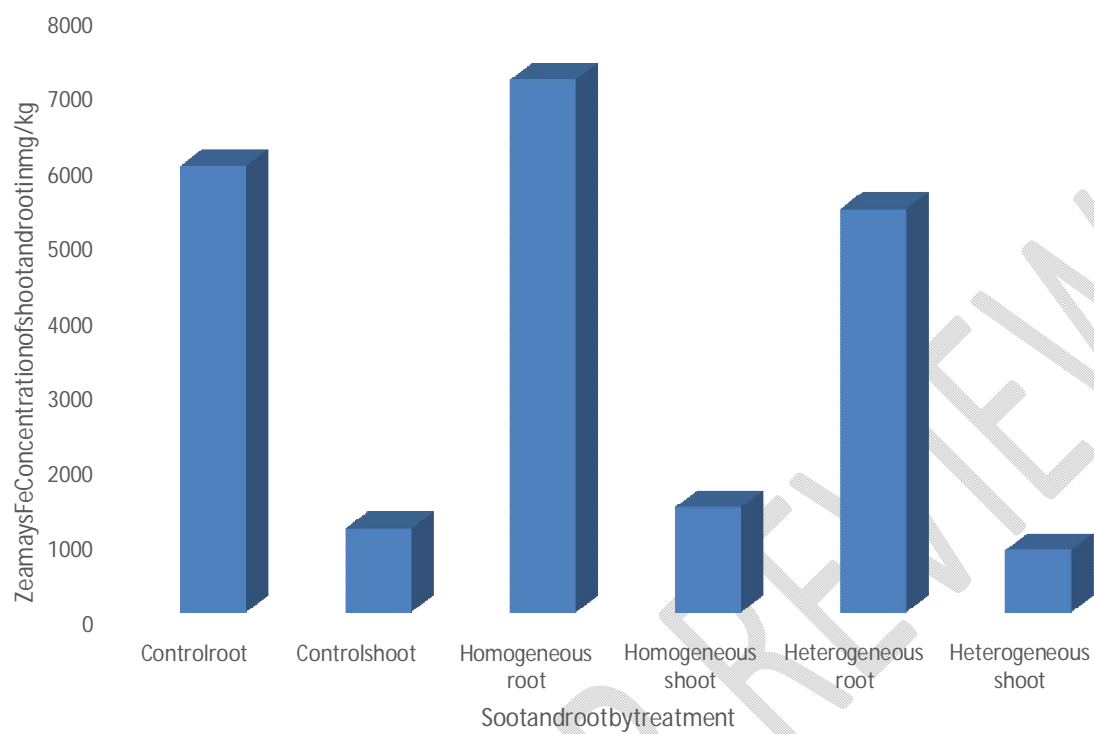
Soil Treatments	Mean concentration (mg/kg)
<b>Root</b>	
Control	5965±674
Homogeneous	7111±2492
Heterogeneous	5389±1374
<b>Shoot</b>	
Control	1121±511
Homogeneous	1405±123
Heterogeneous	831±114
Recommended value	45mg/kg (WHO 2002)



**Figure1:Ironconcentrationofmg/kgofZeamays rootbetweentreatments**



**Figure 2: Iron concentration in mg/kg of *Zea mays* shoot between treatments**



**Figure 3: Comparison of Shoot and Root concentration of between treatments**

#### 4. DISCUSSION

The results of this study indicate that the spatial distribution of Fe in the soil has significant impact on the Fe uptake by maize plants. Iron was found to have accumulated to a greater extent in the root in all treatments. This suggests that plant thrived well in normal Fe rich soil and on enhanced or Fe fortified soils. The higher shoot Fe concentration in the homogeneous treatment compared

to the heterogeneous treatment indicates that the plant has a tendency to accumulate higher Fe in a homogeneously distributed soil. Comparing the measured Fe concentration with the World Health Organization recommended value of 45 mg/kg of plants; it is evident that all three treatments exceeded the recommended Fe value. The mean root Fe concentration was 119.76 to 158.02 times higher than the WHO limit, while the mean shoot Fe concentration was 18.47 to 31.22 times higher. These findings indicate that the Fe concentration in the plants are relatively high, which may have implications for health impact for humans and animals.

Efficient iron uptake and translocation mechanism are crucial for adequate iron accumulation in the shoots which is essential for plant growth and development (Romheld and Marschner, 1986). Iron concentration to shoot was greatly reduced in this study complex interaction of edaphic factors and plant specific mechanism may have been responsible and this study shows that spatial distribution of Fe in the soil can be significantly influence uptake. This can be explored to improve Fe concentration of soils deficient in Fe to improve plant

growth and consequent availability to humans and animals. The high shoot Fe concentration observed in control treatment can be attributed to the fact the inherent soil was rich in Fe. The added Fe resulted in increased Fe uptake by the plants, leading to elevated Fe concentration in both the shoots and roots. However, it is important to note that these high Fe concentrations may not necessarily translate to improved plant health or nutrient availability. Excessive Fe concentration can disrupt the balance of other essential nutrients and potentially have adverse effects on plant growth and development.

## 5. CONCLUSION

In conclusion, spatial distribution of Fe impact uptake by maize plants. The control treatment, representing normal soil conditions without additional Fe supplementation, resulted in relatively high shoot and root Fe concentration, indicating that soil is originally rich in Fe. The homogeneous treatment, with a uniform distribution of Fe in the soil, led to higher mean root and shoot Fe concentration compared to the control and heterogeneous treatments. On the other hand, the heterogeneous treatment, with a non-uniform distribution of Fe, resulted in the lowest mean root Fe concentration.

All three treatments exceeded the recommended Fe concentrations set by the World Health Organization (WHO) for plants. The high Fe concentrations observed in the plants may be attributed to the inherent Fe-rich control soil and the fortified treatments which has implications for improving the nutritional quality of maize for human consumption.



## 6. RECOMMENDATIONS

Based on the results of this study, the following recommendation can be made:

**Soil Management:** Given the trends in the iron concentrations of *Zea Mays* in the control, homogeneous, and heterogeneous treatments, it is important to consider soil management practices to optimize iron availability for maize plants. This may include measures such as soil amendment with iron-rich fertilizers or organic matter to improve iron content and availability in the soil.

**Translocation Enhancement:** While the control treatment exhibited higher shoot iron concentrations, indicating efficient translocation from roots to shoots, the homogeneous group had higher root iron concentrations but comparatively lower shoot iron concentrations. Therefore, strategies to enhance the translocation of iron from roots to shoots could be explored, such as the use of foliar sprays containing chelated iron or bio fortification techniques.

**Site-Specific Approaches:** The lower iron concentrations observed in both shoots and roots of the heterogeneous treatment suggest limitations in iron availability and uptake. It is important to identify the factors contributing to this limitation, such as soil heterogeneity or environmental factors, and develop site-specific approaches to address them. This may involve targeted soil analysis, site-specific amendments, or adjustments in irrigation practices to optimize iron availability in heterogeneous soils.

**Nutritional Considerations:** The iron concentrations observed in all three groups exceeded the World Health Organization's recommended value of

45mg/kg. While this may be beneficial in terms of addressing iron deficiency in humans consuming maize, it is important to consider the overall nutritional balance and potential health implications of excessive iron intake. Further research is needed to assess the bioavailability and bio accessibility of iron in maize plants with high iron concentrations to ensure optimal nutritional benefits without potential adverse effects.

**Long-Term Monitoring:** To fully understand the effectiveness of recommended interventions and the stability of iron concentrations in maize plants, long-term monitoring studies should be conducted. This would help assess the sustainability of soil management practices, the persistence of enhanced iron uptake and translocation mechanisms, and any potential changes in plant health or productivity over time.

**Crop Diversification and Rotation:** Additionally, considering crop diversification and rotation strategies may be beneficial. Introducing leguminous crops or cover crops known for their ability to fix atmospheric nitrogen and improve soil health can contribute to better iron availability for plants.

**Collaboration and Knowledge Sharing:** Collaboration among researchers, agronomists, and farmers is crucial for sharing knowledge and best practices regarding iron uptake optimization in plants. This can facilitate the development and adoption of effective strategies tailored to specific regions and production systems.

By implementing these recommendations, it is possible to improve iron

uptake and accumulation in maize, thereby enhancing the nutritional quality of the crop and addressing iron deficiency concerns in populations relying on maize as a staple food.

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