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 *viz*. control (0mg/kg Fe added, homogeneous (1000mg/kg Fe added) and heterogeneous (Simulated realistic heterogenity). *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 per cent 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~~ The similar trend in concentration factor showed that this plant have 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.

Comment [I1]: rewrite

INTRODUCTION

Comment [I2]: The Introduction needs to be brief avoiding the well established facts and long sentences.

Iron(Fe)isanessentialmicronutrientforplantgrowthanddevelopment,playing a vital role in various physiological processes, including photosynthesis,respiration, and enzyme activation (kelerpteris*et al*., 2006). Iron deficiency inplants can lead to chlorosis, stunted growth, reduced yield, and lower nutritionalquality(Fageria,2001).WhileironisabundantintheEarth'scrust,itsavailability to plants is often limited due to its low solubility and the presence ofvarioussoilfactorsthatinfluenceits distributionanduptake(Fimmen,2009).

Thedistributionofironinthesoilisrarelyuniform,exhibitingspatialheterogeneity at various scales (kabata-Pendias and Mukherjee, 2007). Factorssuch as soil parent material, weathering processes, land use history, and soilmanagementpracticescontributetothenon-uniformdistributionofiron((kabata-Pendias and Mukherjee, 2007). The spatial variability of iron in thesoilcanrangefrommacro-scalepatterns,suchasvariationsacrosslandscapesor field sections, to micro-scale patterns, such as variations within a single soilaggregate (Viscarra*et al.*, 2016).Understanding the heterogeneous distributionof iron in the soil and its relation to iron uptake by maize is of great importanceforagriculturalproductivityandsustainableplantnutrition(Setimela*etal.*,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

(Setimela*et* *al.*, 2017)

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 aredirectlyinfluencedbytheavailabilityanduptakeofessentialnutrients,includingiron(Setimela*etal.*,2017).

The spatial variability of iron in the soil can significantly impact the iron uptakeefficiency ofmaizeplants. Regions with high iron concentrations in the soilmay provide favorable conditions for iron uptake, leading to improved plantgrowth and yield. Conversely, areas with low iron concentrations may posechallenges for maize plants in acquiring sufficient iron, potentially resulting innutrientdeficienciesandreduced cropproductivity(Marschner,2012).

The relationship between iron distribution in the soil and its uptake by maize isinfluencedbyvariousfactors.Soilproperties,suchaspH,organicmattercontent,and redoxconditions,canaffectironsolubilityandavailability(Johnson,2017).

Acidic soils with low pH often limit iron availability, while alkaline soils canlead to iron precipitation and reduced uptake (Guptaand lipsett, 1981).Organicmattercaninfluenceironretentionandrelease,affectingitsaccessibility toplantroots(Guptaandlipsett,1981).Theredoxpotentialofthesoil environment can influence iron speciation and its availability for uptake (Guptaand lipsett, 1981). Efficient management of iron in the soil is crucial to enhanceironuptakebymaizeandimprovecropproductivity(Vert*etal.*,2002).Targete

dfertilization approaches, based on the specific distribution patterns of iron, canoptimizenutrientapplication,ensuringthatmaizeplantsreceiveadequateironin regions with low concentrations (Vert *et al.*, 2002). Soil amendments andorganic fertilizers can also be employed to modify soil properties and improveiron availability (Vert *et al.*, 2002).Iron (Fe) uptake by *Zea mays*, commonlyknown as maize, is a nuanced process influenced by spatial heterogeneity withinthesoilenvironment(Thompson*etal.,2012*).

The spatial distribution of iron in the rhizosphere, which is the soil regioninfluenced by root activity, plays a pivotal role in determining the availabilityandsubsequentuptakeofironbymaizeplants.Understandingthespatialhe terogeneity in iron uptake is crucial for optimizing agricultural practices andenhancingtheefficiencyofironacquisitionbythisessentialcerealcrop(Kronzuck er*etal*.,2016).

Therhizosphereisadynamicandcomplexinterfacewheresoil,plantroots, andmicroorganisms interact. In this microenvironment, the availability of iron issubjecttospatialvariationsinfluencedbyfactorssuchassoiltexture,pH,andtheprese nceoforganicmatter.Maizerootsreleasevariouscompoundsintotherhizosphere,incl udingorganicacidsandrootexudates,whichcaninfluencethesolubilityand mobilityofironinthesoil(Kronzucker*etal*.,2016).

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

tothespatialheterogeneityofironuptake.Lateralroots,forinstance,areresponsible for exploring the outer regions of the rhizosphere, encounteringdifferent iron availability zones. The spatial distribution of iron uptake zones isnot uniform across the root system, and specific root segments may exhibithigheror loweriron uptakecapacities(Kronzucker*etal*.,2016).

Microorganisms in the rhizosphere further contribute to spatial heterogeneity iniron availability.Somemicrobescanenhanceironsolubilitythroughtheproduction of siderophores, organic molecules that chelate iron, making it moreaccessible to plant roots. The spatial distribution of these microbial populationsand their activities in the rhizosphere can create hotspots of increased ironavailability, influencing the areas where maize roots are more likely to absorbiron (Kronzucker*et al.*, 2016). One of the critical processes in iron uptake bymaize is the reduction of ferric iron (Fe^3+) to ferrous iron (Fe^2+) at the root-soilinterface.Thisreductionoccursprimarilyintherhizosphereandisinfluencedbysp atialvariationsinoxygenlevels.Micrositeswithdifferentredox potentials within the rhizosphere contribute to spatial heterogeneity in theavailabilityofFeimpacting theefficiencyofironuptakebymaizeroots.

Therelationshipbetweentheheterogeneousdistributionofironinsoilandtheefficienc yofironuptakebyplants remains poorlyunderstood.

The impact of soil heterogeneity on the dynamics of iron uptake by plantsneedstobeunderstood.

Theidentificationoffactorsthatmayinfluencetheheterogeneousdistributionofironis crucial inoptimizingironavailabilitytoplants.

The lack of comprehensive studies on the effect of soil heterogeneity oniron 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 agriculturist to 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 stable crop worldwide, an iron deficiency can severely affect itsproductivity. By studying the heterogeneous distribution of iron and its impactonironuptakebymaize,researcherscandevelopstrategiestoenhancecrop productivity and mitigate iron deficiency-related issues. This knowledge can beused to improve breeding programmes, develop iron-efficient maize varieties, orimplement precision agriculture techniques to ensure optimal iron availability tothecrop.

Iron deficiency is a widespread form of micronutrient malnutrition, particularlyin developing countries wheremaizeis adietary staple. Understanding thefactorsinfluencingironuptakebymaizecancontributetoaddressingthisnutritiona l challenge (Pii*et al.,2015)* In interventions such as iron fortification,bio fortification, or soil amendment practices can be implemented to enhancesoilironcontent,thusimprovingthenutritionalqualityofthecropandreducin g irondeficiency-relatedhealthissues.

Efficient nutrient management is a key aspect of sustainable agriculture. Byinvestigating the Spartial heterogeneity of iron and its relation to iron uptake bymaize, researchers can contribute to more sustainable farming practices. Thisknowledgehelpsoptimizeresourceallocation,reducenutrientlossthroughleachi ngorrunoff,andenhanceoverallnutrientuseefficiency.

Theaim ofthisstudyistoinvestigatetheuptakeofironby*Zeamays*andits relationship withits spatialdistribution in soil.

2. METHODS

Maize (*Zea maize*) was selected for pot trials based on the fact that it iscommonly consumed. Maize (*Zea mays*) is one of the most widely cultivatedcerealcropsglobally,servingasastaplefoodformillionsofpeople.Aknowledgeoftheinsituheterogeneityofleadinanearlierstudyoncontaminant heterogeneity (Anibasa and Ramsey 2020) was applied to simulatesimilar scales of heterogeneity of the iron in this study based on known scale ofheterogeneities.Maize(*Zeaymaize*)wasusedinagreenhousepottrialmodelling the simulated in situ heterogeneity. Herbage samples was processedand analyzed for the concentrations of iron in roots and shoots at the end of thegrowthperiodusing appropriateanalyticalmethodsandequipmente.g.theAtomic Absorption Spectrometer (AAS) Data collected from this study wasanalyzed using appropriate statistical tools. Growth medium samples were alsoanalyzed for the concentrations of iron. These data will provide information onthe uptake potential of the maize and availability of these nutrients to potentialconsumers of these crops.

2.1 ExperimentalDesign

Thiswasdoneasdescribedby(Solomon-Wisdom*etal.*,2015).Fourheterogeneitymodelswassimulated(usingexcelcomputer modelswithacombination of the Robust ANOVA- a visual basic programme developed basedon a FORTRAN programme and previous work, which will generate the levelsof heterogeneity similar to those that had been found in field sites and previousfield studies. The scale of heterogeneity used, the plant

species selected, and themean Fe concentrations that was chosen, was based upon conclusions of pottrialsinearlierstudies(Ogunlade-Anibasa,2023)Thesamplesizewasdetermined using power analysis to estimate the minimum number of replicatesrequiredtodetectastatisticallysignificantdifferencebetweenmeansofdifferent treatments based on the assumption that data will be normal in theirdistribution.Datafromtheseedgerminationwasusedforpoweranalysishaving confirmed they are normally distributed using the Kolmogorov Smirnovtest.It is impossible to simulate the exact in situ heterogeneity (real lifesituation). The actual spatial heterogeneity of nutrients can only be estimated bysampling at the field site, and it is practically impossible to recreate the exact insituheterogeneityinpottrials.Inviewofthispotentialcomplexity,themodelofheterogeneity was designed to simulate as closely as practicably possible the insitu heterogeneity of trace elements measured at this scale in field sites in anearlierstudy(Anibasa,2023)witharangeofintermediateHF(HFrangedfrom1to3.22(3.22atthe20mscale).Theproposedsimulationofheterogeneity factors (HF) was 1.00, 1.25, 2.00 and 3.19 while an overall mean concentrationof approximately 1000 mg/kg in all treatments was maintained The simulationwas based on the log-normal distribution observed in those field sites, withincreasingvaluesofgeometricstandarddeviation(GSD)andhencethevaluesof 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 theearlyestablishmentof theseedling.

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

Thiswasdone asdescribedby (Anibasa,2016).Prior toseedgerminationexperiment, one seed tray was washed and sterilized with household bleach (onepart to nine parts of water), thoroughly rinsed with tap water and finally withreverse 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 afterseeds had been sown. A light density fine grade, Sinclair vermiculite of (grainsize 2.0-5.0 mm) with neutral pH 7 (which is lighter and easier for seeds tobreakthrough it) was used for sowing seeds. It was watered with tap water untilevenly moist

before sowing seeds and then placed in the seed trays about 1cmbelow the rim. The seeds was sprinkled thinly on the vermiculite or according tosupplier'sinstructionifpresentandcoveredthinlywithvermiculite. Aftersowing, the large tray with drain holes was used to cover tray to let in light andair,preventmediumfromdryingoutandbecomingdampaswell.Theywereleft to germinate in a greenhouse under a photoperiod of 16 hours' natural lightand maintained at a temperature of 30 C ± 5°C.The Tray was removed oncegermination occurred. Watering was done carefully when the top of the seedtraysappeareddryusingafinespraywateringcan,andwatersprinkledgentlyto avoid resetting or disturbing the seeds.The surface was kept evenly moistand never dried out. *Zeamays* considered for initial transplanting into unspikedgrowthmediumafter7daysofgerminationtoensurepropergrowthand establishment before the actual transplant into the trace metal spiked growthmedium.Aftergerminationandthedevelopmentofthefirsttrueleaves,plantso f approximately equal size was selected and transplanted into the Centre ofseparate circular 1- litre pots (15 cm deep and 12 cm wide) pots for each speciescontaining unspiked growth medium (washedsilver sand, John InnescompostII, 7 parts sand to 3-part compost). Thirty seedling of *zea mays* was transplantedinto pots (making a total of 30 seedlings) of unspiked growth medium first fortwo weeks and was watered daily using a fine rose watering can. This wasmaintained under 16 hours of natural light at 30 ± 5 o C in the greenhouse.

Attwoweeksafterthefirsttransplanting,tenseedlingsofeachspecieswastransplanted

into the 15 potscontaining growth medium spikedwithFe atconcentrations of 1000 mg/kgFe added (homogenous)and0 mg/kg Fe addedtreatment(control)andheterogeneoustreatmentwhichsimulatedrealisticheterogenity. A total of 30 pots was maintained (1000 mg/kg (homogenous) and0 mg/kg added treatment (control and heterogeneous treatments) for 6 weeksunder a photoperiod of 16hours natural sunlight at 30 ± 5°C in the greenhouse.These were maintained in 3.5-litre square pots (dimensions 17 cm x 24 cm) in asimple randomized block design both in 1000 mg/kg Fe added and 0 mg/kgadded Fe as control and heterogeneous treatment were rotated clockwise by 90oweekly toreducetheeffectof uneven environmentalconditionswithinthegreenhouse.Randomizedblockswerebetweentreatments,becauseofthenumberoftheavailablespace/m2 of greenhousebenches.

2.3 GreenHousePotExperiments

This was done as described by (Anibasa, 2016) and (Ogunlade and Ramsey2023).Fifteen(15)rigidsquarepots(14X14cmand17cmdeep)werethoroughly washed with detergents and labeled with namesof plant speciesthree treatments e.g. Homogeneous, heterogeneous and control. A customizedcell divider made from a 1 mm clear polyethylene terephthalate glycol (PTEG)sheet was inserted into the pots to produce a 5 by 5, 2-dimensional grid witheach cell measuring 25 mm square and 170 mm deep. This was used to createthe designed heterogeneity models. The relatively thin PETG helped to maintaintheheterogeneity designby reducingthecollapseofeachcolumnafteritsremoval.Labeledpaperlinerswereinserte

dintoeachcellwhilefillingcellswithgrowthmedia.Itprovidedafillingtemplate,tohel ptomaintainthestructural integrity of the divider and minimize spillage from adjacent cells. Thegap between the paper liners and the outer edge of the pot were packed with aninert Sinclair Perlite (grain size 2.0-5.0 mm) because of the non-vertical sides ofpots.Cellswerefilledaccordingtotheparticulardesignedmodelofheterogeneity. Filling of the pots was done in two stages to ensure that equalvolume of growth medium goes into the cells and that the growth medium isevenly distributed throughout the pot. The gently compacted growth mediumwasmeasuredwith a 100 ml customizedcontainer into each cell according tothe design. The growth medium will be tapped down before an additional 50 mlwill beaddedandtappeddown again. Completed potswere placedondriptrays and arranged on benches in the randomized block design with blocks of 3 rowsand 3columnsasshownintable1

Thegrowthmedium wasmoistenedfrom belowby capillaryactionbeforetransplanting seedlings already established in an unspiked growth media for twoweeks. Tap water was applied using a fine rose watering can. This ensured thatthe heterogeneity is disturbed to a minimal extent. The percentage moisturecontent 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 theCentreofeachtreatmentaftertwoweeksgrowingintheunspikedgrowthmedia.Ten

replicates of each treatment was maintained in the greenhouse forsix weeks under simulated sunlight using light-emitting diodes (LED) lights(undera photoperiodof 12 hours) at30±5C.

2.4 Harvesting

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

theimpactofheterogeneityontheplantspecies.Shootsofalltreatmentswasharvested.

Plant stems were cut 0.01 mm above the soil surface for shoot harvest and soilremoved from the roots using a sieve. Soil was removed from harvested plantmaterialsbyrepeatedwashingusingtapwateranddriedat60oCfor48hours.

This was milled (using an herbage mill) for acid digestion using nitric andperchloricacidsand analyzedforFeusingtheAAS.

2.5 ChemicalAnalysis

ShortenedRootswerecarefully washed toremovesoilparticlesthatcouldintroduce potential bias in measurements of Fe concentration. Harvested rootsand shoots were dried at 60ºC for 48 hours in a fan oven, weighed for DryWeight,andanalyzedforFeconcentrationusinganAtomicAbsorptionSpectrome ter(AAS)afteraciddigestionusingnitricacid(ThompsonandWalsh, 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 ofsmaller masses,

with suitable checks on data quality. The growth media wasanalyzedfor their actual Fe concentration. Regressionanalysiswas usedtoshowtherelationshipbetweentheactualconcentrationsandthenominalconcentrations.

2.6 AcidDigestion

Thiswasdoneasdescribeby(AOAC, 1990)withlittleamendments

Samples of maize shoot and root was washed thoroughly after harvesting toremoveany externalcontaminants. The maizeshootandrootwasdriedtoremoveexcessmoisture.Themaizerootandshootwas grindedintofineparticles to increasethe surfaceareaavailable fordigestion.

The respectiveprepared samples of maizewas weighed 0.3g using a weighbalance and it was poured into a beaker 70% of concentrated nitric acid wasadded.Thebeakercontainingthesampleandnitricacidwasplacedinamicrowave digesting system at a temperature of 100-200 degree delicious forfiveto ten minutesintheprocessoftheheatingdistilledwaterwas added.

The digestion process was completed when the maize shoot and root of therespectivesampleswerediss olvedcompletelyandnosolidresidueorundigestedparticlesremain

Thedigestedsampleswereallowedtocooltoroomtemperatureanddilutedwith deionized water to reduce the acidity and concentrate the analytes in thesolutionforsubsequentanalysis.Filterpepperwasusedtofilteranyundissolvedparticlesorinsolubleimpuritiestoobtainaclearsolutionforfurtheranalysis

2.7 DataAnalysis

Datawereanalyzedusing statisticalsoftwareMinitab 18andSPSS 25forWindows. Statistical tools such as analysis of variance (ANOVA), RANOVA(robust analysis of variance) as shown in Appendix iii was be used to test forsignificanceofmeasuredvariableswhilstKolmogorov-Smirnovtestwasusedto test for normal distribution of data as shown in Appendix ii Other relevantstatistical toolsand software packageswereused toanalyzeandmodeldatafromthisstudy.

2.8 QualityControl

Appropriatesafetymeasuresandprocedurewerefollowedtoensurethereliability of the test results. Chemicals and reagents used were of analyticalgrade, utensilswere thoroughly and properly cleaned during the research.Samples were cautiously handled to minimize cross-contaminations and reagentblanks, duplicate samples, and certified Reference material(CRM)IAEA-V8wereincorporatedintosamplebatchtocheckforcontamination,analyticalprecision and estimation ofbiasrespectively.

3. RESULTS

ThemeanshootFeconcentrationforthecontrol,homogeneousandheterogeneoustreatmentswere1121mg/kg,1405mg/kgand831mg/kgrespectively (Figure 1) while the mean root Fe concentration for the control,homogeneous and heterogeneous were 5965mg/kg, 7111mg/kg and 5389mg/kgrespectivelyasshownin(Figure2).Therewasnosignificantdifference(P> 0.05) in the root and shootFeconcentration between treatments (Appendixv).ThecontrolhasthehighestshootFeconcentrationof1121mg/kgfollowedby the homogeneous treatments 1405mg/kg and the heterogeneous treatmentswith the lowest mean shoot concentration of 831mg/kg (as shown in Figure 3).This indicates that the normal soil is rich in Fe. The highest mean root Feconcentrationof7111mg/kgwasrecordedinthehomogeneoustreatmentsfollowed by the control 5965mg/kg and the heterogeneous treatment had thelowest mean root Fe concentration of 5389mg/kg (as shown in figure 3). Thisshowed that *Zea Mays* will accumulate Fe easily in a homogeneous distributedFe medium. The root and shoot concentration were over 100 times higher thantheWHOrecommended valueof45mg/kginplants (Table1).

The concentration factors for control, homogeneous and heterogeneous were0.3656, 0.4394 and 0.3209 respectively. The concentration factor (C.F) washighest in the homogenous treatment with about 0.1% higher than the controlandheterogeneous.Thisshowedthat*Zeamays*accumulateFefromthesoiland

translocatedabout10%oftheaccumulatedFetotheshootinrespectiveofthespatialdistr

ibution.

Table1:Meanconcentrationin(mg/kg)ofmaizerootsandshootsbetweendifferenttreatments.

Soil Treatments	Meanconcentration(mg/kg)
Root	
Control	5965±674
Homogeneous	7111±2492
Heterogeneous	5389±1374
Shoot	
Control	1121±511
Homogeneous	1405±123
Heterogeneous	831±114
Recommendedvalue	45mg/kg(WHO2002)

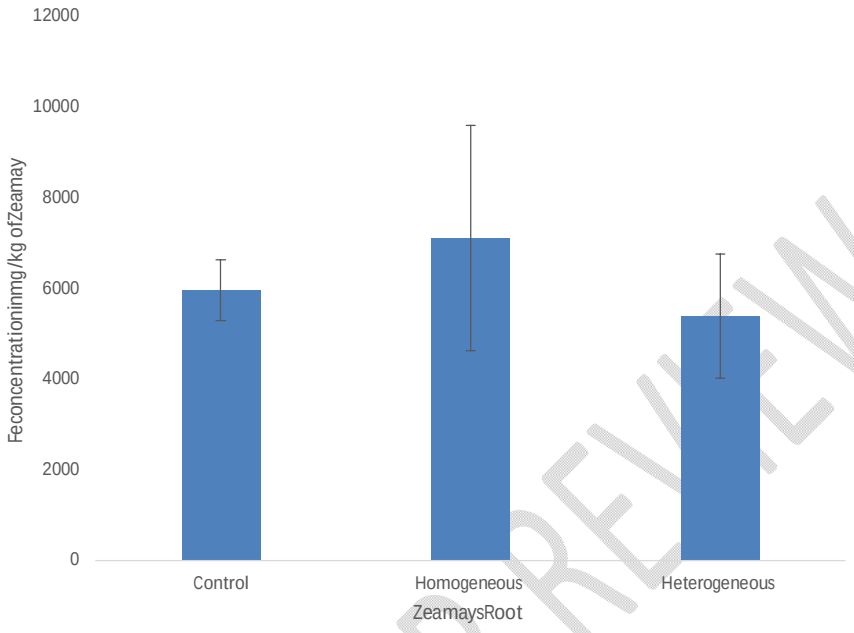

Figure1:Ironconcentrationofmg/kgof*Zeamays* rootbetweentreatments

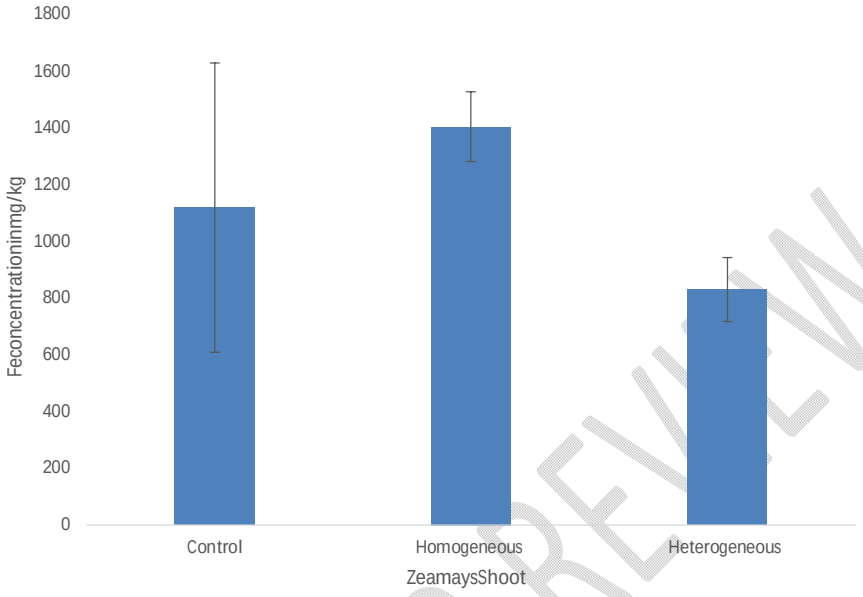

Figure 2: Iron concentration in mg/kg of *Zea mays* shoot betweentreatments

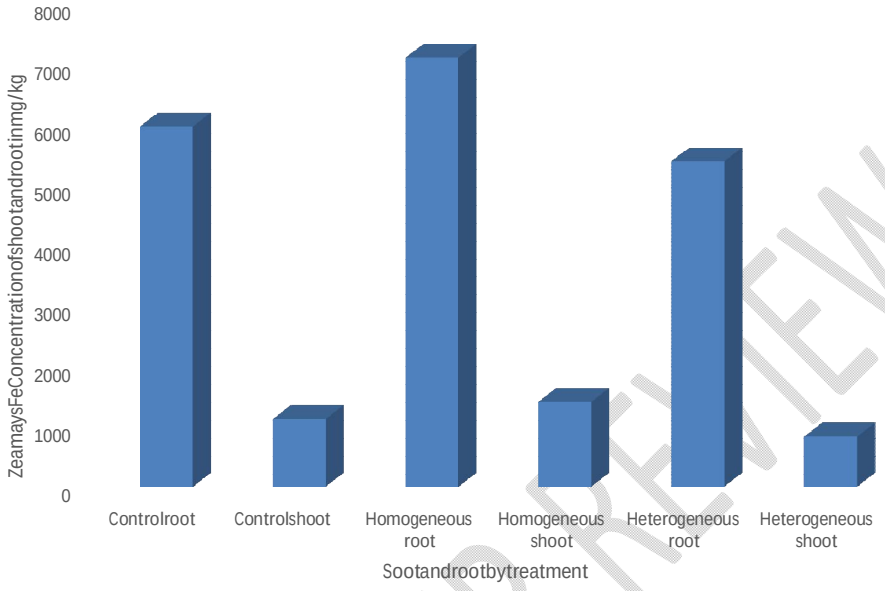

Figure 3: Comparison of Shoot and Root concentration of betweentreatments

4. DISCUSSION

The results of this study indicate that the spatial distribution of Fe in the soil hassignificant impact on the Fe uptake by maize plants. Iron was found to haveaccumulated to a greater extent in the root in all treatments. This suggests thatplant thrived well in normal Fe rich soil and on enhanced or Fe fortified soils.The higher shoot Fe concentration in the homogeneous treatment compared totheheterogeneoustreatmentindicatesthattheplanthavetendenciestoaccumulatehigherFeinahomogeneouslydistributedsoil.Comparingthemeasured Fe concentration with the World Health Organization recommendedvalue of 45mg/kg of plants; it is evident that all three treatments exceeded therecommended Fe value. The mean root Fe concentration was 119.76 to 158.02timeshigherthantheWHOlimit,whilethemeanshootFeconcentrationwas 18.47to31.22timeshigher.ThesefindingsindicatesthattheFeconcentrationin the plants are relatively high, which may have implications for health impactfor humans and animals.

Efficient iron uptake and translocation mechanism arecrucial for adequate iron accumulation in the shoots which is essential for plantgrowth and development (Romheld and Marschner, 1986). Iron concentration toshoot was greatly reduced in this study complex interaction of edaphic factorsandplantsspecificmechanismmayhavebeenresponsibleandthisstudyshowedthatspatialdistributionofFeinthesoilcanbesignificantlyinfluence uptake. Thiscan be exploredtoimprove Fe concentration ofsoils deficientinFe to improve plant

growth and consequent availability to humans and animals.The high shoot Fe concentration observed in control treatment can be attributedto the fact the inherent soil was rich in Fe. The added Fe resulted in increased Feuptake by the plants, leading to elevated Fe concentration in both the shoots androots. However, it is important to note that these high Fe concentrations may notnecessarily translate to improved plant health or nutrient availability. ExcessiveFeconcentrationcandisruptthebalanceofotheressentialnutrientsandpotentiallyhaveadverseeffects onplant growth anddevelopment.

5. CONCLUSION

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

All three treatments exceeded the recommended Fe concentrations set by theWorldHealthOrganization(WHO)forplants.ThehighFeconcentrationsobserved intheplantsmaybeattributedtotheinherentFerichcontrolsoiland thefortifiedtreatmentswhichhasimplicationsforimprovingthenutritionalqualityof maize for humanconsumption.

6. RECOMMENDATIONS

Basedontheresultsofthisstudythefollowingrecommendationcanbemade:

Soil Management: Given the trends in theiron concentrations of*Zea Mays*in the control, homogeneous, and heterogeneous treatments, it is important toconsidersoilmanagementpracticestooptimizeironavailabilityformaizeplants.Thi smayincludemeasuressuchassoilamendmentwithiron-richfertilizersororganicmattertoimproveironcontentandavailabilityinthesoil.

Translocation Enhancement: While the control treatment exhibited highershoot iron concentrations, indicating efficient translocation from roots to shoots,the homogeneous group had higher root iron concentrations but comparativelylowershootironconcentrations.Therefore,strategiestoenhancethetra nslocation of iron from roots to shoots could be explored, such as the use offoliarsprays containing chelated ironorbio fortificationtechniques.

Site-Specific Approaches: The lower iron concentrations observed in bothshootsand roots of theheterogeneoustreatment suggest limitationsin ironavailability and uptake. It is important to identify the factors contributing to thislimitation, 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 ironavailabilityinheterogeneoussoils.

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

45mg/kg. While this may be beneficial in terms of addressing iron deficiency inhumans consuming maize, it is important to consider the overall nutritionalbalanceandpotentialhealthimplicationsofexcessiveironintake.Furtherre search is needed to assess the bioavailability and bio accessibility of iron inmaize plants with high iron concentrations to ensure optimal nutritional benefitswithoutpotentialadverseeffects.

Long-TermMonitoring:Tofullyunderstandtheeffectivenessofrecommended interventions and the stability of iron concentrations in maizeplants, long-term monitoring studies should be conducted. This would helpassessthesustainabilityofsoilmanagementpractices,thepersistenceofenhanced iron uptake and translocation mechanisms, and any potential changesinplanthealthorproductivityovertime.

CropDiversificationandRotation:Additionally,consideringcropdiversificationa ndrotationstrategiesmaybebeneficial.Introducingleguminous crops or cover crops known for their ability to fix atmosphericnitrogen and improve soil health can contribute to better iron availability forplants.

Collaboration and Knowledge Sharing: Collaboration among researchers,agronomists, and farmers is crucial for sharing knowledge and best practicesregardingironuptakeoptimizationinplants.Thiscanfacilitatethedevelopm ent and adoption of effective strategies tailored to specific regions and productionsystems.

By implementing these recommendations, it is possible to improve iron

uptakeand accumulation in maize, thereby enhancing the nutritional quality of the cropand addressing iron deficiency concerns in populations relying on maize as astaplefood.

REFERENCES

Anibasa, G. O. (2016). *In situ metal heterogeneneity-its implication for plantuptake.*Micheal.H.RamseyandElizabeth.A.John(eds).LambertAcademicpublishingcompany,GermanyISBN978-3330-00833-5

Anibasa,G.O.,andRamsey,M.H.(2020).*Heterogeneityfactor-anovelprogram and approach to soil trace metal contamination. Zumajournalofpureandandappliedscience*.11(1):32-56ISSN11196548.

Anibasa, G. O., and Udeze, I. E. (2019). Accumulation of Potentially ToxicElementsinOccimumgratissumandVernoniaamygdalinasoldinGwagwaladaMarket,FederalCapitalTerritory-Abuja,Nigeria.*ZumaJournalofpureandAppliedSoilogy*,10(1).

Fageria,N.K.(2001).Nutrientinteractionsincropplants.*JournalofPlantNutrition,24 (8),1269-1290*.

Fimmen,R.L.(2015).Rhizosphereredoxdynamics:frommeasurementsinthelaboratorytopredictionsandmeasurementsinthefield.InS.Banerjee, M.B.H.Awad,andM.N.Al-Subai(Eds.),*SoilandWaterContamination: From molecular to catchment scale* (pp. 101-128).CRCPress.

Gupta, U. C., and Lipsett, J. (1981). Iron nutrition of field crops. *Advances inAgronomy*,34,1-88.

Johnson, L. K. (2017). Soil Microbial Communities and Their Role in MaizeGrowth and Nutrition.*Frontiersin PlantScience*,6,1465.

Kabata-Pendias, A., and Mukherjee, A. B. (2007). Trace elements from soil tohuman.Springer ScienceandBusiness Media.

Kelerpteris, K., Argyraki, A. andAlexakis, D. (2006).Multivariate statistics andspatial interpretation of geochemical data for assessing soil contaminationbypotentiallytoxicelementsintheminingareaofStratoni,North Greece.*GeochemistryEnvironmentAnalysis*6: 349-355.

Kronzucker,H.J., Coskun, D., Britto, D.T., and Huynh,W.Q.,(2016). The role ofsilicon in higher plants under salinity and drought stress. *Frontiers inplantscience*,7,210358.

Li, G., Kronzucker, H. J., and Shi, W. (2016).The response of the root apex inplantadaptationtoironheterogeneityinsoil. *FrontiersinPlantScience*,*7*,344.

Marschner,P.(2012).Rhizospherebiology. In*Marschner'smineralnutritionofhigherplants*(pp.369-388). AcademicPress.

Ogunlade-Anibasa,G.O, John E.A (2023)-*the binary simplistic Heterogeneity anunrealistic model for risk assessment and phytoremediation* J Am sci;19(10):1-15.ISSN1545-1003(Print);ISSN2375-7264.

Pii,Y.,Mimmo,T.,Tomasi,N.,Terzano,R.,Cesco,S.,andCrecchio,C.(2015).Microb ial interactions in the rhizosphere: beneficial influences of plantgrowth-promotingrhizobacteriaonnutrientacquisitionprocess.Areview.*Biologyand fertility of soils*,*51*,403-415.

Setimela, P. S., Byrnes, N., Hodson, D., andVivek, B. (2017). Genetic gains ingrainyieldthroughgenomicselectioninmaizebreedingprograms.*ThePlant Genome*,10(3),1-11.

Thompson,E.J.andWalsh,Y.R.(1983).Newapproachestothestudyofhumandystrop hicmusclecellsinculture. *JournaloftheNeurologicalSciences*,58(3),315-334.S

Thompson,S.W., Molz,F. J., Fjeld,R.A.,andKaplan, D.I. (2012).

Uptake, distribution, and velocity of organically complexed plutonium incorn (Zea mays). *Journal of environmental radioactivity*, *112*, 133-140.2012.

Vert,G.,Grotz,N.,andDedaldechamp., (2002).IRT1,anArabidopsis*TransporterEssentialforIronUptakefromtheSoilandforPlantGrowth*.ThePlantCell,14(6),1223–1233.

Vert, .J.P., Scornet, E.,Biau, G., Sahoo, S. and Coskun, D. (2015). Consistencyofrandomforests.1716-1741.

Viscarra Rossel, R. A., Behrens, T., Ben-Dor, E., Brown, D. J., Demattê, J. A.M., Shepherd, K. D., and Wetterlind, J. (2016). A globalspectral librarytocharacterizetheworld'ssoil. *Earth-ScienceReviews*,155,198-230.

White,P.J.,andBrown,P.H.(2010).Plantnutritionforsustainabledevelopmentandglobalhealth.*AnnalsofBotany*,105(7),1073-1080.

WorldHealthOrganization(WHO),(2002).Ironinguidelineforfood.2nded. Geneva:WorldHealthOrganization

Zhang,J.,Zhang,Y.,Zhang,C.,andLi,L.(2021).Effectsofironoxidenanoparticles on maize growth, nutrient uptake, and soil properties in along-term field experiment. *Journal of Soils and Sediments*, 21(12), 4600-461