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Original Research Article

Effect of Iron Foliar Application on Maize Grain Yield and Iron Concentration in Maize (*Zea mays* L.) Grain on the Ferralsols of Southern Togo

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Abstract: With the aim of simultaneously improving maize grain productivity and nutritional value towards enhancing food security and fight against hidden hunger, a 2-year experiment (2020-2021) was carried out at the University of Lomé Agronomic Experiment Station. The experimental design was a split-plot with three replicates. Four maize varieties: Ikenne, Tzee, Sotubaka and Sammaz 52 and three iron application rates including a control (no iron application–Fe_0), 7.50 litters ha^{-1} (Fe_{45}) and 10 litters ha^{-1} of Feramin (Fe_{60}) were the studied factors. Maize grain yield and grain Fe concentration were determined. Results showed that, on 2-year average basis, the highest maize grain yields under Ikenne (3.32±0.08 t ha^{-1}) Tzee (2.49±0.10 t ha^{-1}), Soubaka (4.03±0.10 t ha^{-1}) and Sammaz 52 (3.85±0.19 t ha^{-1}) was obtained with Fe_{60}. Globaly, yield obtained under Fe_{60} was higher than those under Fe_0 and Fe_{45} by 26 and 4% respectively. For the two years of study, the highest Fe concentrations were obtained in Ikenne and Tzee grains while the lowest were obtained in the first year in Sotubaka grains(55.21±2.96 mg kg^{-1}) and in the second year in Sammaz 52 grains (41.66±2.19 mg kg^{-1}). On 2-year average basis, the Fe concentration in Ikenne grains was higher than those in Tzee, Sotubaka and Sammaz 52 grains by 8.91; 13.92 and 19.27%, respectively. On this same basis, the highest grain Fe concentrations were obtained under the four varieties with Fe_{60}. Globally, grain Fe concentration under Fe_{60} was higher than those under Fe_0 and Fe_{45} by 141.89 and 20.31% respectively.

Keywords: Maize, variety, Fe, yield, and concentration.

INTRODUCTION

Maize is the most cultivated cereal crop in Togo. It is the staple food of populations to such an extent that the issue of food security seems to be restricted to its spatio-temporal availability and accessibility for households. The total area devoted to maize cultivation over the past five years has increased from 675,831 in 2016 to 755,187 in 2021 ha and national production from 826,896 to 929,020 t (DSID, 2022). This maize cropping was characterized not only by low productivity with a national average yield not exceeding 1.50 tons ha^{-1} for more than ten years (FAO and IFAD, 2021), but also by poor concentrations of essential micronutrients, especially iron. However, micronutrients are major determinants of the health of pregnant women and the fetus (Sandalinas, 2005). A lack of micronutrient intake, especially iron and folic acid, during pregnancy was one of the recognized causes of intrauterine growth retardation (Allen, 2003), maternal and infant mortality (Sandalinas, 2005). According to the World Health Organization, nearly a quarter of the world's population, including 36.50% of pregnant women and 39.80% in children aged 6-59 months suffered from anaemia and in African Region, 60.20% of children under 5 years were affected by anaemia in 2019 (WHO, 2021). These problems continued to impose an economic burden on developing countries (FAO/WFP, 2002; Wessells and Brown, 2012).

One of the main causes of this nutritional problem in developing countries was the low bioavailability of dietary iron (Hurrell and Egli, 2010). Among the solutions recommended to overcome this

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problem figure prominently in the formulation of tablets and food supplements rich in micronutrients; but it was clear that the high cost of commercially formulated food supplements made them inaccessible to low-income households, especially rural ones. Faced with this new challenge, it would therefore be necessary to seek economically and socially justified solutions. One of them is the production of food meeting, at least, the daily nutritional needs (Gregorio *et al*., 1999). Iron (Fe) is an important nutrient for humans and plants. It is very important for plant growth and its deficiencies hindered plant growth and production (Kanai *et al*., 2009). Soil Fe deficiency is a global problem that not only affects crop yield reduction, but also food quality (Kanai *et al*., 2009; Manzeke *et al*., 2014). Iron fertilizers were widely used to increase yield and concentration of iron in fruits as well as crop quality. They could be applied in different ways, such as foliar application, soil application (sprayed on the soil surface or applied into the soil) and seed coating method. Foliar application was considered the most effective method for increasing both grain yield and grain micronutrient content (George and Schmitt, 2002). It is a simple and direct application on the leaves (Hosseini *et al*., 2007). Foliar fertilization with micronutrients often stimulates more nutrient uptake and efficient allocation in the edible plant parts than soil fertilization, especially with cereals and leafy vegetables (Lawson *et al*., 2015). Essential micronutrients for plant growth are required in very small amounts compared to macronutrients such as nitrogen, phosphorus and potassium (White and Brown, 2010).

However, mineral micronutrient fertilizer use is currently limited in African countries due to general issues of cost and supply, the lack of information on micronutrient problems, a reliable fertilizer recommendation system, and the poor availability of micronutrient fertilizers (de Valença *et al*., 2017). Studies aimed at the simultaneous improvement of yield and nutritional value in the foods most consumed by populations, such as maize in sub-Saharan Africa were poorly developed in this area (Macauley and Ramadjita, 2013). Due to socio-economic importance of maize and that of micronutrients for the proper functioning of the body, it is therefore urgent to find production techniques that could simultaneously improve the yield and the concentration of essential micronutrients in maize grains. The objectives of the study were t (i) to assess the effect of foliar iron fertilizer application on maize grain yield; (ii) to determine the most iron-accumulating variety in maize grains and (iii) to determine the iron application rates that the nutritional value of maize grain.

MATERIAL AND METHODS

Experimental Site

The study was carried out at the Lomé Agronomic Experiment Station (SEAL), located at the University of Lomé -Togo (6°22' N, 1°13'E; altitude of 50 m, slope less than 1 %). The soil type was a rhodic Ferralsol locally called "Terres de barre", developped from the continental deposit (Saragoni *et al*., 1992). This type of soil represents 47% of the soils of the maritime region (Worou, 2000) and covers part of the arable land in Ivory Coast, Ghana, Togo, Benin and Nigeria (Raunet, 1973 and Louette, 1988). The climate of the experimental site is the guinean type, bimodal and allows for two maize cropping seasons, one from April to July and another from September to December (Sogbedji *et al*., 2017). Annual rainfall at the site is between 800 and 1100 mm. The annual average temperature is between 24 and 27°C (Worou, 2000; Somana *et al*., 2001).

The experimental plot was under fallow for three years. Before the maize sowing in April 2020, initial soil properties and soil texture were determined on the first 20 cm soil layer (0-20 cm depth) on the experimental site from twenty-four (24) composite soil samples using the standard methods of the International Institute for Tropical Agriculture (IITA, 2014). These composite soil samples were analysed at the Laboratory of Soil Water Plant Fertilizer of the Togolese Institute for Agronomic Research (LSEVE-ITRA). Total C and total N levels, exchangeable base concentrations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}), pH, cation exchange capacity (CEC) were determined. The soil of the experimental site is slightly acidic (pH=6.12) and has low total C (0.59%) and total N (0.05%) levels. It is sandy and contains 81.05% sand, indicating that this soil is well drained with low contents of P (7.29 mg kg^{-1}); K (22.44 mg kg^{-1}) and Fe (42.84 mg kg^{-1}) contents. Its CEC is very low 2.82 mmol kg^{-1}, as are the exchangeable bases Ca^{++}, Mg^{++}, Na^{+} and K^{+}, with respective values of 41.42; 5.98; 1.17 and 0.57 mmol kg^{-1} (Table 1).

Table 1: Soil properties at the onset of the experiment

Parameters	Values
pH (H_2O)	6.12
MO (%)	1.02
C total (%)	0.59
N total (%)	0.05
NO_3-N (mg kg^{-1})	1.92
P available (mg kg^{-1})	7.29
K available (mg kg^{-1})	22.44
Fe total (mg kg^{-1})	42.84
Exchangeable bases (mmol kg^{-1})	
Ca^{2+}	41.42
Mg^{2+}	5.98
Na^{+}	1.17
K^{+}	0.57
Total CEC (mmol kg^{-1})	2.82
Sable content (%)	81.05
Silt content (%)	6.62
Clay content (%)	12.33

MATERIAL

Biological material

Four varieties of maize were used as biological material: Ikenne 9449 SR (Ikenne), TZEE W pop STR QPM (Tzee), Sotubaka and Sammaz 52. Table 2 presents the characteristics of the four varieties.

Table 2: Varieties characteristics

Varieties	Genetic nature	Breeder	Maintainer	Height (cm)	Grain colour	Production cycle (days)	Potential yield ($t.ha^{-1}$)
Ikenne 9449 SR (Ikenne),	Composite	CIMMYT/ IITA	ITRA	190-210	White	90-100	5
TZEE W pop STR QPM (Tzee)	Composite	IITA	ITRA	170-185	White	80-85	3.50
Sotubaka	Composite	IER	ITRA	210-230	Yellow	100-110	6
Sammaz 52	Improved population	MENKIR ABEBE	IAR, Zaria	190-195	Orange	95 (medium)	6

Source: CORAF (2019); CORAF (2017); Laba and Sogbedji (2015)

Fertilizers

Three types of fertilizers such as NPK: 15-15-15; Urea 46% N and Feramin 6% of Fe were used.

METHODS

Experimental Design

The experiment took place during the first growing seasons (April to August) of two consecutive years (2020 and 2021). The trial was set up using a split-plot design with three replications. The main plots included the iron fertilizer treatment: control (Fe_0); 7.50 litters ha^{-1} of feramin 6% of Fe (Fe_{45}); 10 litters ha^{-1} of feramin 6% of Fe (Fe_{60}); and the sub-plots, the varieties: Ikenne, Tzee, Sotubaka and Sammaz 52. Nine (09) main plots (15 m x 3.20 m) and thirty-six (36) sub-plots (3.20 m x 3 m) were laid out. The distance between the blocks is equivalent to that between the plots and is 1m. Each experimental unit contains four lines of maize separated from each other by 0.80 m.

Table 3: Iron rates applied and corresponding quantities of Feramin 6% of Fe) and iron

Iron rates (%)	0 (Fe_0)	45 (Fe_{45})	60 (Fe_{60})
Feramin 6% of Fe quantity (litter ha^{-1})	0	7.50	10.00
Iron quantity (g ha^{-1})	0	450	600

Soil and crop management

At the beginning of each growing season, the experimental site was prepared through the following successive operations: clearing, deep plowing with dabas, levelling, demarcation of blocks and plots. The maize seeds were sown on April 14, 2020 and April 25, 2021 at four seeds per hill, follow-up of thinning at one plant per pocket carried out ten (10) days after sowing. The planting scheme was 80 cm x 25 cm, giving a density of 50, 000 plants ha^{-1}. 200 kg ha^{-1} of NPK: 15-15-15, were applied to the plants on the 15th day after sowing. 100 kg ha^{-1} of urea 46% N was applied at the beginning of flowering (35th day after sowing). NPK: 15-15-15 and urea 46% N were point-placed at a depth of approximately 5 cm. Iron fertilizer were brought by foliar application. Iron fertilizer (Feramin 6% of Fe) was applied in two times for each variety: at tassel appearance stage and again after 2 weeks (Hagh *et al*., 2016). The water quantity used for each Fe spray was 200 litters $ha^{-1.}$ Iron foliar application was done between 3 p.m. and 5:30 p.m. Two weeding and one hilling were carried out respectively on the 14th, 30th and 45th day after sowing. Two insecticide treatments against the caterpillars were done and the crop was harvested on August 14, 2020 and August 21, 2021.

Maize grains yield determination

Maize grain yields were determined from the three centres lines of each experimental plot. The harvested cobs were dried and then shelled. The maize grain weights were taken when the moisture content of the grains was around 12%.

Sampling

Maize cobs were harvested from nine (09) central plants of the three central rows of each experimental unit. These ears have been shelled and dried. Composite samples of the same colour of maize grain obtained after sorting were made. 50 g samples of maize grains were taken from each maize variety and from each composite sample of maize grains harvested. Similarly, composite samples of 50 g of soil were made and submitted for analysis.

Chemical Analysis

The maize grain samples taken were put in an oven at 70°C for 48 hours then finely ground and sieved. Soil samples were also ground and sieved. The soil samples taken were also finely ground and sieved. The solubilization method used for soil samples is mineralization by acid attack (mixture of hydrochloric acid and nitric acid) according to standard NF ISO 11466 or the aqua regia method (ISO, 1995) for soils. It is carried out in a closed and hot environment (110-

150°C). For 1g of finely ground sample and weighed by using a BEL L303i type electric scale (Pmax=310g, Accuracy= 0.001), a 3:1 proportion of acid mixture is required (3ml of hydrochloric acid and 1ml of 'nitric acid). For maize grain samples, the solubilization method used is mineralization by acid attack with nitric acid. It is also carried out in a closed and hot environment (150°C). For 1g of dried and finely ground maize sample and weighed by using a BEL L303i type electric scale (Pmax=310g, Accuracy= 0.001); 4ml of nitric acid is required. 10 ml of hydrogen peroxide (H2O2) at 9% was added beforehand to each sample and left to act for 24 hours before the acid attack. After acid attack and heating, the samples were filtered using filter paper (Walsh and Beaton, 1973). The filtrate obtained contained the chemical elements to be assayed. The determination of Fe was done by atomic absorption spectrophotometry (Pinta, 1973, Tee *et al*., 1989). The brand of atomic absorption spectrophotometer used is iCE 3000 SERIES THERMO FISCHER.

Data Analysis

The analysis of variance (ANOVA) of the data obtained was done by using the GenSTAT discovery edition 12 software at the 5% threshold and Duncan's test was used to discriminate the means at this threshold.

RESULTS AND DISCUSSION

Effect of iron rates on maize grain yield

The maize grain yields obtained under different rates of iron were presented in Table 4. The yields of the first year are higher than those of the second year of experiment, on average by 11.45%, Analysis of variance revealed that iron rates had a significant effect on maize grain yield. The yields obtained with the application of 7.50 litters ha^{-1} of Feramin 6% of Fe (Fe_{45}) and 10 litters ha^{-1} of Feramin 6% of Fe (Fe_{60}) were statistically identical; but for the two years of cultivation, the highest maize grain yields were obtained with the application of Fe_{60}. On 2-year average basis, the yield obtained under Fe_{60} (3.42±0.65 t ha^{-1}) was higher than those obtained under Fe_0 and Fe_{45} by 26 and 4% respectively.

The highest maize grain yields obtained in the first year under the different iron rates compared to those obtained in the second year of experiment was due to the climatic factors, especially the rain, which could lead to leaching or loss of the product after its foliar application in second year of cultivation. Indeed, the cumulative rainfall obtained over the period from April to August 2021 (540.90 mm) in the study area was higher than that recorded over the same period of 2020 (342.50 mm). It therefore appeared that rainfall could influence the effectiveness of foliar iron application on grain maize yield. In addition, the difference between the yields of the two years of experiment could be explained by the effect of previous crops and especially by the variation in the chemical composition of the soil.

The highest maize grain yields obtained with the application of Fe_{60} could be explained by the high quantity of iron contained in this fertilization formula, which would have allowed the maize plants to absorb enough iron and further increase their photosynthetic activity, which resulted in increased yield. Iron is a necessary element for enzyme system, which brings about oxidation-reduction reactions and electron transport chain in the plant, synthesizes chlorophyll, maintains the structure of chloroplasts, and enzyme activity, also it regulates respiration, photosynthesis, reduction of nitrates (Eskandari, 2011). Some authors (Rawashdeh and Sala, 2015) showed that foliar application of Fe and soil application of Fe alone or in association with other micronutrients to wheat grown on Fe deficient soils enhance plant growth, yield quantity and quality

Influence of variety and iron rate interactions on maize grain yield

Table 4 presents the maize grain yields obtained under the different interactions. These yields varied from 1.88±0.16 to 4.21±0.07 t ha^{-1} and from 1.86±0.06 to 3.85±0.13 t ha^{-1} respectively in the first and second year of experiment. On 2-year average basis, maize grain yields under the different interactions varied from 1.87±0.11 to 4.03±0.10 t ha^{-1}.

Variety and iron rate interactions had also a significant effect on grain maize yields. In the first year of cultivation, the highest grain maize yield under Ikenne (3.40±0.13 t ha^{-1}) was obtained with the application of 7.50 litters ha^{-1} of Feramin 6% of Fe (Fe_{45}). However, the highest yields were obtained with the application of 10 litters ha^{-1} of Feramin 6% of Fe (Fe_{60}) under Tzee (2.68±0.13 t ha^{-1}), Soubaka (4.21±0.07 t ha^{-1}) and Sammaz 52 (4.07±0.07 t ha^{-1}). In the second year of experiment, just like the 2-year average basis, the highest maize grain yields under the four varieties were obtained with the application of Fe_{60}. However, it should be noted that the foliar application of iron significantly increased maize grain yield.

The better grain maize yield obtained under Ikenne with the application of Fe_{45}, in first year could be explained by the effect of previous crops and the variability of the soil chemical composition of the experimental plot. The law of non-proportional returns or the law of diminishing returns (Antonelli, 1910; Fromont, 1928; Deleplace and Lavialle, 2008) could also explain it. The highest yields obtained under the four maize varieties with the application of Fe_{60} in the second year of cultivation and on 2-year average basis would be due to the availability in sufficient quantity and the iron absorption capacity by the maize plants. This would have increased their photosynthetic activity;

which led to increased maize grain yields under this rate. Iron is involved in plant metabolism, synthesis of chlorophyll and photosynthesis; it is a component of many enzymes and has structural role in hemetype and other proteins (Wiedenhoeft, 2006; Fageria, 2008). Hagh *et al.*, (2016) found in their study that Fe foliar application improved maize grain yield by 5.8%; with this result, they conclude that Fe foliar application had slight effects on plant yield. Other authors (Pareek and Poonia, 2011) found 14.8% and 11.2% enhancement in pod and haulm yield of groundnut as the result of foliar Fe application. However, the rates of increase in maize grain yield obtained in this study with the iron foliar application were greater than 20%. Indeed, on 2-year average basis, maize grains yields obtained with the application of Fe_{45} and Fe_{60} were higher than that obtained with the control (Fe_0) respcetively by 24.31 and 30.20% under Ikenne; 25.13 and 33.16% under Tzee; 24.84 and 26.73% under Sotubaka; 13.27 and 18.83% under Sammaz 52. It was reported that applying high concentrations of Fe to ginseng (*Panax ginseng* C.A. Mey) leaves increased root yield and quality (Zhang *et al.*, 2013). The differences in grain maize yields observed under the maize varieties would be due to their genetic characteristics and to climatic factors.

Table 4: Mean maize grain yields for each interaction, year and 2-year average

Varieties	Iron rates			Means	F. pr	CV (%)
	Fe_0	Fe_{45}	Fe_{60}			
Maize grain yields ton ha^{-1}						
Year 1						
Ikenne	2.69±0.10b	3.40±0.13a	3.30±0.11a	3.13±0.36b	0.049	9.40
Tzee	1.88±0.16b	2.50±0.08a	2.68±0.13a	2.36±0.39c	0.045	12.50
Sotubaka	3.43±0.14b	4.14±0.13a	4.21±0.07a	3.92±0.40a	0.049	10.20
Sammaz 52	3.53±0.07c	3.82±0.09b	4.07±0.07a	3.81±0.25a	<.001	10.50
Means	2.88±0.71b	3.47±0.67a	3.57±0.65a	3.31±0.72	0.027	10.10
Year 2						
Ikenne	2.40±0.14b	3.05±0.10a	3.23±0.09a	2.89±0.40b	0.047	9.30
Tzee	1.86±0.06b	2.17±0.07a	2.29±0.05a	2.11±0.21c	0.012	11.40
Sotubaka	2.93±0.13b	3.80±0.16a	3.85±0.13a	3.53±0.48a	0.047	10.10
Sammaz 52	2.95±0.23b	3.51±0.20a	3.64±0.20a	3.37±0.36a	0.005	10.90
Means	2.53±0.49b	3.13±0.67a	3.25±0.64a	2.97±0.66a	0.018	12.10
2- Year Average						
Ikenne	2.55±0.14b	3.17±0.10a	3.32±0.08a	3.01±0.38b	0.044	9.40
Tzee	1.87±0.11b	2.34±0.07a	2.49±0.10a	2.23±0.30c	0.046	10.60
Sotubaka	3.18±0.07b	3.97±0.09a	4.03±0.10a	3.72±0.43a	<.001	9.80
Sammaz 52	3.24±0.08b	3.67±0.17a	3.85±0.19a	3.59±0.31a	0.016	9.60
Means	2.71±0.60c	3.29±0.67b	3.42±0.65a	3.14±0.69	<.001	9.70

Fe_0=0 litter ha^{-1}; Fe_{45}= 7.50 litters ha^{-1} of Feramin 6% of Fe and Fe_{60}= 10 litters ha^{-1} of Feramin 6% of Fe
The data were discriminated in the horizontal direction; except the average values of the varieties, which were discriminated in the vertical direction. Values that were followed by the same letters are statistically identical.

Iron absorption and accumulation in maize grains

The evaluation of the level of iron absorption and accumulation in the maize grains of the varieties was made through the determination of the Fe content in the grains harvested under each variety. Fe concentrations obtained under each variety during our experiments were presented in Table 5. Grain Fe concentrations obtained under varieties in the first year of experimentation were higher than those obtained in the second year of experiment by 25.19%. For the two years of study, the highest grain Fe concentrations were obtained in Ikenne and Tzee grains, while the lowest are obtained in the first year in Sotubaka grains (55.21±2.96 mg kg^{-1}) and in the second year of experiment in Sammaz 52 grains (41.66±2.19 mg kg^{-1}). On 2-year average basis, the Fe concentration obtained in Ikenne grains were higher than those obtained in Tzee, Sotubaka and Sammaz 52 grains respectively by 8.91; 13.92 and 19.27%.

These results showed that maize varieties had a different Fe absorption capacity from one another. White grains varieties had a higher Fe absorption capacity than those of yellow and orange grains varieties. This difference in Fe accumulation in grains between the maize varieties would be linked to their genetic characteristics and to the constitution of plant tissues particularly stomata, trichomes, cuticular and epicuticular wax, cuticle and the cutin, which influenced the effectiveness of Fe foliar fertilization (Maltais, 2006). Others factors such as soil, climate, plant and their interaction affected absorption of nutrients by growing plants (Fageria et al., 2009). The crop (variety) which defined whether micronutrients were (re-) localized into his edible parts could influence iron bioavailability from crop to food (de Valença *et al.*, 2017).

The superiority of Fe concentrations obtained in the grains of the four varieties in the first year of experiment compared to those of the second year could be due to the favourable climatic conditions for the application and absorption of the fertilizer by maize plants in the first year of experiment than in the second year. Indeed, relative humidity, light intensity, rain and the wind could cause losses of the Fe fertilizer at the time or just after his application and could not allow the plants to absorb enough iron in order to transport it in large quantities in grains.

Table 5: Grain Fe concentrations for each variety, year and 2-year average

Years	Ikenne	Tzee	Sotubaka	Sammaz 52	Means	F Pr	CV (%)
	Fe concentrations (mg kg^{-1})						
Year 1	66.89±3.62a	58.85±3.46b	55.21±2,96c	57.15±3.59b	59.53±3.79	<.001	10.80
Year 2	50.95±3.36a	49.35±2.98ab	48.23±2,27b	41.66±2.19c	47.55±3.75	<.001	13.60
Means	58.92±3.00a	54.10±2.68b	51.72±1,91c	49.40±2.37d	53.54±3.61	<.001	11.40

The data are discriminated in the horizontal direction. Values that were followed by the same letters were statistically identical.

Effect of iron rate application on grain Fe concentration

Iron concentrations obtained under each iron rate after laboratory analysis of maize grains were recorded in table 6. The iron rates had a significant effect on the Fe concentration in maize grains for the two years of experiment. As with varieties, grain Fe concentrations obtained in the first year under iron rates were higher than those obtained in the second year of cultivation. This was due, not only to climatic factors and varietie performance, which would have acted on the effectiveness of the treatment and the fertilizer (Maltais, 2006); but also to iron amount variation in soil. According to Rawashdeh and Sala (2015), it is evident that foliar and soil application of Fe alone or in association with other micronutrients to wheat enhance yield components and grain Fe concentration. For the two years of experiment, the highest grain Fe concentrations were obtained with the foliar application of 10 litters ha^{-1} of Feramin 6% of Fe (Fe_{60}) i.e. 77.19±2.22 mg kg^{-1} and 65.91±3.65 mg kg^{-1} respectively for first and second year of experiment. On 2-year average basis, grain Fe concentration obtained with the foliar application of Fe_{60} was higher than those obtained under control (Fe0) and 7.50 litters ha^{-1} of Feramin 6% of Fe (Fe_{45}) respectively of 141.89 and 20.31%. The effectiveness of the Fe_{60} rate in increasing grain Fe concentration could be explained by its ability to allow maize plants to absorb enough iron in order to further intensify their photosynthetic activity (Mugenzi *et al*., 2018, Miller *et al*., 1995). However, nutrient accumulation in reserve organs would result from photosynthetic activity. The intensification of this photosynthetic activity could therefore contribute to increasing grain Fe concentration. Iron fertilization therefore increased its concentration in the grains (Majeed *et al*., 2020).

Table 6: Grain Fe concentrations for each iron rate, year and 2-year average

Years	Fe_0	Fe_{45}	Fe_{60}	Means	F Pr	CV (%)
	Fe concentrations (mg.kg^{-1})					
Year 1	35.11±3.14c	66.28±3.47b	77.19±2,22a	59.53±3.79	0.002	10.80
Year 2	24.06±2.56c	52.67±3.29b	65.91±3,65a	47.55±3.75	<.001	13.60
Means	29.58±1.81c	59.47±2.53b	71.55±3,66a	53.54±3.61	<.001	11.40

Fe_0= 0 litter ha^{-1}; Fe_{45}= 7.50 litters ha^{-1} of Feramin 6% of Fe and Fe_{60}= 10 litters ha^{-1} of Feramin 6% of Fe

The data were discriminated in the horizontal direction. Values that were followed by the same letters were statistically identical.

Effect of variety and iron rate interactions on grain Fe concentration

Table 7 presents grain Fe concentrations obtained under different variety and iron rate interactions after laboratory analysis. The analysis of variance revealed that the interactions significantly influenced Fe concentration contained in maize grains. It varied from 33.42±1.50 to 83.06±2.54 mg kg^{-1} and from 22.45±2.33 to 73.82±2.49 mg kg^{-1} respectively in the first and second year of experiment. Grain Fe concentrations recorded in the first year of cultivation under the different interactions were significantly higher than those obtained in the second year of experiment. On 2-year average basis, grain Fe concentrations obtained under the different interactions varied from 28.33±0.08 mg kg^{-1} to 78.09±2.73 mg kg$^{-1.}$

In the first year of experiment, under Ikenne variety, the highest grain Fe concentration (83.06±2.54 mg kg^{-1}) was obtained with the application of 7.50 litters ha^{-1} of Feramin 6% of Fe (Fe_{45}) which was statistically identical to that obtained with the application of 10 litters litters ha^{-1} of Feramin 6% of Fe (Fe_{60}). On the other hand, the highest grain Fe concentration were obtained with Fe_{60} under the Tzee; Sotubaka and Sammaz 52. In the second year of cultivation, the application of Fe_{60} gave the highest grain Fe concentrations under these four varieties. On

2-year average basis, the highest Fe concentrations were also obtained with Fe_{60}.

The highest grain Fe concentration obtained in the first year under Ikenne with the application of Fe_{45} could be explained by the effect of previous crops and especially by the high iron quantity contained in the soil at this moment. Because the nutrient richness of cultivated soil decreased over time if there was no compensation (Roose *et al*., 2018). The overall effectiveness of Fe_{60} under the four maize varieties, in terms of grain Fe concentration, could be explained by its ability to provide the necessary quantity iron to maize plants for grain formation. Moreover, the iron amount being high in this fertilization formula, the climatic factors could have less impact on the loss of the nutrient at the time or just after its application than a low iron rate. Plants growing in soils with limited availability of Fe were not able to accumulate sufficient amounts of Fe its edible parts (White and Broadley 2009; Rawashdeh and Sala, 2015).

Table 7: Grain Fe concentrations for each interaction, year and 2-year average

Varieties	Iron rates			F. pr	CV (%)
	Fe_0	Fe_{45}	Fe_{60}		
Fe concentration (mg kg^{-1})					
Year 1					
Ikenne	35.25±3.26b	83.06±2.54a	82.36±2.96a	0.008	6.30
Tzee	35.87±2.50c	59.30±2.71b	81.39±2.31a	0.008	6.40
Sotubaka	35.88±2.18c	61.11±1.94b	68.64±2.81a	<.001	5.40
Sammaz 52	33.42±1.50c	61.65±2.30b	76.38±2.44a	0.005	5.80
Year 2					
Ikenne	24.42±2.61c	54.60±2.69b	73.82±2.49a	0.007	7.60
Tzee	22.45±2.33c	52.13±2.14b	73.47±1.94a	<.001	5.70
Sotubaka	26.13±3.04b	58.58±1.97b	60.27±1.56a	0.002	8,00
Sammaz 52	23.24±1.34c	45.65±3.24b	56.08±3.91a	0.003	10,00
2- Year Average					
Ikenne	29.84±2.93c	68.83±2.61b	78.09±2.73a	0.004	5.10
Tzee	29.16±2.42c	55.71±2.43b	77.43±0.19a	0.002	5.70
Sotubaka	31.01±0.93c	59.70±0.02b	64.45±0.62a	0.001	6.10
Sammaz 52	28.33±0.08c	53.65±2.77b	66.23±3.17a	0.004	7.60

Fe_0= 0 litter ha^{-1}; Fe_{45}= 7.50 litters ha^{-1} of Feramin 6% of Fe and Fe_{60}= 10 litters ha^{-1} of Feramin 6% of Fe
The data were discriminated in the horizontal direction. Values that were followed by the same letters wre statistically identical.

CONCLUSION

Iron foliar application increased maize grain yield and Fe concentration in maize grains. The Sotubaka and Sammaz 52 varieties gave higher maize grain yields than Ikenne and Tzee varieties, but Ikenne and Tzee accumulated more Fe in their grains than sotubaka and Sammaz 52. The 10 litters ha^{-1} of Feramin 6% of Fe (Fe_{60}) provided the highest maize grain yield and the highest grain Fe concentration under the four varieties. Even if, this iron rate application was effective on maize grain yield and grain Fe concentration, the economic profitability of its use should be studied before its recommendation.

REFERENCES

- Allen, L. H. (2003). Interventions for Micronutrient Deficiency Control in Developing Countries: Past, Present and Future. *The Journal of Nutrition*, 133(11), 3875–3878.
- Antonelli, E. (1910). Note sur la loi du rendement non-proportionnel. *Revue d'économie Politique*, 24, 532-545.
- CORAF (Conseil Ouest et Centre Africain pour la recherche et le développement agricoles). (2019). Catalogue Régional des Espèces et Variétés Végétales CEDEAO-UEMOA-CILSS-Variétés homologuées 2016-2018. pp 4-7. Dakar, Sénégal.
- CORAF. (2017). Catalogue Régional des Espèces et Variétés Végétales CEDEAO-UEMOA-CILSS. pp 27-44. Dakar, Sénégal.
- Deleplace, G., & Lavialle, C. (2008). Histoire de la pensée économique. Paris: Dunod. 192p.
- de Valença, A. W., Bake, A., Brouwer, I. D., & Giller, K. E. (2017). Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. *Global Food Security*, 12, 8-14.
- DSID (Direction des statistiques agricoles, de l'informatique et de la documentation), 2022. Rapport bilan de la campagne agro-pastorale 2021-2022 au Togo. Lomé, Togo.
- Eskandari, H. (2011). The Importance of Iron (Fe) in Plant Products and Mechanism of Its Uptake by Plants. *J Appl Environ Biol Sci*, 1(10), 448-452,
- Fageria, N. K., Filho, M. P. B., Moreira, A., & Guimaraes, C. M., (2009). Foliar fertilization of

crop plants. *Journal of Plant Nutrition*, 32(6), 1044-1064.

- Fageria, N. K. (2008). The use of nutrients in crop plants. CRC Press, USA.
- FAO. & IFAD. (2021). Plan de développement de la filière maïs 2021-2030 au Togo. Lomé, Togo.
- FAO/WFP. (2002). Crop and food supply assessment mission to Zimbabwe. Special Report. FAO Global Information and Early Warning System on Food and Agriculture Food Programme. FAO/WFP.
- Fromont, P. (1928). La loi des rendements non proportionnels: son évolution et ses derniers perfectionnements. *Revue d'économie Politique*, 42(4), 1073–1099.
- George, R., & Schmitt, M. (2002). Zinc for crop production. Regents of the University of Minnesota.
- Gregorio, G. B., senadhira, D., Htut, T., & Graham, R. D. (1999). Amélioration de la teneur en fer et en zinc du riz pour l'alimentation humaine. Vraisemblable Agriculture et développement. n° 23, 10p.
- Hagh, D. E., Mirshekari, B., Ardakani, R. M., Farahvash, F., & Rejali, F. (2016). Maize biofortification and yield improvement through organic biochemical nutrient management. *IDESIA* (Chile), 34(5), 37-46.
- Hosseini, S., Maftoun, M., Karimian, N., Ronaghi, A., & Emam, Y. (2007). Effect of zinc× boron interaction on plant growth and tissue nutrient concentration of corn. *Journal of Plant Nutrition*, 30(5), 773-781.
- Hurrell, R., & Egli, I. (2010). Iron bioavailability and dietary reference values. *American Journal Clinical Nutrition*, 91, 1461S-1467S.
- IITA (International Institute for Tropical Agriculture). (2014). Automated and Semi-automated methods for soil and plant analysis, Manual series 7 (Ibadan, Nigeria).
- ISO. (1995). Soil quality - Extraction of trace elements soluble in aqua regia. ITeh STANDARD PREVIEW (standards.iteh.ai). ISO 11466:1995.
- Kanai, M., Hirai, M., Yoshiba, M., Tadano, T., & Higuchi, K. (2009). Iron deficiency causes zinc excess in *Zea mays. Soil science and plant nutrition*, 55(2), 271-276.
- Laba, B. S., & Sogbedji, J. M. (2015). Identification of land degradation and climate change resilient soil and crop management strategies for maize production on West African ferralsols. *International Invention Journal of Agricultural and Soil Science*, 3(2), 13-20.
- Lawson, P. G., Daum, D., Czaudema, R., Meuser, H., & Harling, J. W. (2015). Soil versus foliar iodine fertilization as a biofortification strategy for field-grown vegetables. *Frontiers in Plant Sciences*, 6, 450.
- Louette, D. (1988). Synthesis of research work on the fertility of barre lands in Benin and Togo. Montpellier, CIRAD-DSA, 34p.
- Macauley, H., & Ramadjita, T. (2013). Les cultures céréalières: riz, maïs, millet, sorgho et blé. Document de référence. Dakar, Sénégal, 38p.
- Majeed, A., Minhas, W. A., Mehboob, N., Farooq, S., Hussain, M., & Alam, S. (2020). Iron application improves yield, economic returns and grain-Fe concentration of mungbean. *PLoS ONE*, 15(3), e0230720.
- Maltais, A. M. (2006). Facteurs et conditions favorables à l'éfficacité de la fertilisation foliaire des cultures maraîchères du Quebec. Revue de littérature. Faculté des sciences de l'agriculture et de l'alimentation de l'Université de Laval, Quebec, Canada, 21p.
- Manzeke, G. M., Mtambanengwe, F., Nezomba, H., & Mapfumo, P. (2014). Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. *Field Crops Research*, 166, 128-136.
- Miller, G. W., Huang, I. J., Welkie, G. W., & Pushmik, J. C. (1995). Function of iron in plants with special emphasis on chloroplasts and photosynthetic activity. In iron nutrition in soils and plant (Ed. J. Abadia), 19-28pp. Dordecht, the Netherlands: Kluwer Academic Publishers.
- Mugenzi, I., Yongli, D., Ngnadong, A. W., Dan, H., Niyigaba, E., Twizerimana, A., & Jiangbo, H. (2018). Effect of combined zinc and iron application rates on summer maize yield, photosynthetic capacity and grain quality. *International Journal of Agronomy and Agricultural Research (IJAAR)*, 12(5), 36-46.
- Pareek, N. K., & Poonia, B. L. (2011). Effect of FYM, nitrogen and foliar spray of iron on productivity and economics of irrigated groundnut in an arid region of India. *Archives of Agronomy and Soil Science*, 57(5), 523-531.
- Pinta, M. (1973). Méthodes de référence pour la détermination des éléments minéraux dans les végétaux détermination des éléments Ca, Mg, Fe, Mn, Zn et Cu PAR absorption atomique. Oléagineux, 28è année. ORSTOM, 70-74pp, route d'Aulnay, 93140 Bondy, France.
- Raunet, M. (1973). Contribution à l'étude pédologique des terres de barre du Dahomey et du Togo. *Agronomie Tropicale*, 28(11), 1049-1069.
- Rawashdeh, H. M., & Sala, F. (2015). Foliar application with iron as a vital factor of wheat crop growth, yield quantity and quality: A Review. *International Journal of Agricultural Policy and Research*, 3(9), 368-376.
- Roose, E., Zougmore, R., Stroosnijder, L., Dugué, P., & Bouzou-Mouss, I. (2018). Restauration de la productivité des sols tropicaux et méditerranéens-Chapitre 37: Techniques traditionnelles de

restauration de la productivité des sols dégradés en régions semi-arides d'Afrique occidental. 491-517pp. Editions IRD. DOI: 10.4000/books.irdeditions.24108.

- Sandalinas, F. (2007). Les micronutriments chez la femme enceinte: un allié de poids ? Situation et stratégies de lutte contre les carences dans les pays en développement. Rapport bibliographique de recherche. UHP - Nancy 1 – Faculté de Médecine, Ingénierie de la Santé, Spécialité Nutrition et Diététique, 36p.
- Saragoni, H., Poss, R., Marquette, J., & Latrille, E. (1992). Fertilization and succession of food crops in southern Togo: summary of a long-term experiment on barren land. *Tropical Agronomy*, 46(2), 107-120.
- Sogbedji, M. J., Detchinli, S. K., Mazinagou, M.; Atchoglo, R., & Bona, A. K. (2017). Land degradation and climate change resilient soil and crop management strategies for maize production in Coastal Western Africa. IOSR *Journal of Agriculture and Veterinary Science*, 10(6), 24-30.
- Somana, K. A., Sedzro, K. M., & Akakpo, K. E. (2001). Cassava production in Togo. WASNET N^{o} 8. Accra, pp 24-28.
- Tee, E. S.; Khor S. C., Siti, M. S. (1989). Determination of iron in foods by the atomic absorption spectrophotometric and colorimetric methods. *Pertanika*, 12(3), 313-322.
- Walsh, L. M., & Beaton, J. D. (1973). Soil Testing and Plant Analysis. Soil Science Society of America, Madison, Wisconsin, 491p.
- Wessells, K. R., & Brown, H. K. (2012). Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS ONE*, 7(11), e50568.
- White, P. J., & Broadley, M. R. (2009). Biofortification of crops with seven mineral elements often lacking in human dietsiron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist*, 182(1), 49-84.
- White, P. J., & Brown, P. H. (2010). Plant nutrition for sustainable development and global health. Overview: part of a special issue on plant nutrition. *Annals of Botany*, 105(7), 1073-1080.
- WHO. (2021). WHO Global Anaemia estimates, 2021 Edition: Global anaemia estimates in women of reproductive age, by pregnancy status, and in children aged 6-59 months. https://www.who.int/data/gho/data/themes/topics/-anaemia_in_women_and_children_eng.pdf Accessed on 21 June 2022.
- Wiedenhoeft, A. C. (2006). Plant nutrition. Chelsea House Publishers, USA, 144p.
- Worou, S. K. (2000). Dominant soils of Togo: Correlation with the World Reference Base. ISSN 1014-853. Fourteenth meeting of the West and Central African Soil Correlation Sub-Committee for Land Reclamation. Abomey, Benin, October 9-13. 2000 AG/AGL. 105-120pp. Available at http://www.fao.org/3/a-y3948e.pdf. Accessed on 10 January 2022.
- Zhang, H., Yang, H., Wang, Y., Gao, Y., & Zhang, L. (2013). The response of ginseng grown on farmland to foliar applied iron, zinc, manganese and copper. *Industrial Crops Products*, 45, 388-394.

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